

Using Doppler Systems Radio Direction Finders to Locate Transmitters

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Overview

Finding transmitters, particularly transmitters that do not want to be found, can be a time-consuming process. In cases of deliberate interference, the offender typically transmits intermittently and on the same frequencies as legitimate users making it difficult to simply point a yagi at the offender and drive to his location. Since 1981 Doppler Systems has been developing radio direction finding solutions to aid communications professionals in tracking down the location of transmitters. Our current DDF7000 MultiPosition Tracker (MPT) coupled with our TargetTrack software provides the radio professional with a versatile tool to quickly find transmitters.

In particular our DF systems provide

- Automatic identification and location estimation of one or multiple targets (transmitters)
- Searchable database of all intercepts (received signals)
- Remote DF control and LOB data collection
- Map based display of LOB and estimated target (transmitter) locations
- Real time monitoring and display of estimated target (transmitter) locations
- Unattended monitoring and recording of one or more frequencies
- Delayed playback of intercepts and targets from the database

This paper provides an overview of how to use Doppler Systems' radio direction finding equipment and software to find a transmitter location.

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Nomenclature

For purposes of this paper, we will define the following terms

Bearing – The angle of the direction of the target transmission relative to the direction finder or vehicle the direction finder is mounted in.

Line-of-Bearing (LOB) – The angle of the target transmission relative to true north

Saved LOB – This is a line-of-bearing that is inserted automatically or manually onto a map. Saved LOB is sometimes referred to as a “Cut”.

Target – A transmitter or transmission source that we are trying to find

95% Elliptical Error Probability - Elliptical region representing a 95% probability that the target is within a given region

Circular Error Probability (CEP) – Radius of a circle surrounding a target representing a 95% probability that the target is within the circle.

Intercept – The receipt of a transmission resulting in a bearing measurement

Introduction

Locating a transmitter requires multiple line-of-bearing (LOB) measurements. Multiple LOB measurements can be obtained using a single Doppler direction finder by placing the direction finder at different locations and receiving multiple transmissions or from multiple direction finders located within a geographical area. Therefore, two different scenarios will be discussed. In scenario one a single mobile direction finder is deployed to locate a transmitter or transmitters. In scenario two multiple radio direction finders are used in a network to locate the transmitters. In either case our TargetTrack software provides a powerful tool enabling an operator to quickly locate the transmitter.

Target Location Basics

Estimating the location of a transmitter requires at least two line-of-bearing (LOB) measurements. Figure 1 provides an example of two LOB measurements. The estimated position of the target transmitter is at the intersection of the two LOB measurements. Because the direction finder is not perfect there are errors in the measurement of the LOBs. The TargetTrack software uses the error statistics of the direction finder to draw an ellipse around the target. The size of the ellipse then represents the quality of the estimate. Mathematically speaking there is a 95% probability that the target is within the ellipse.

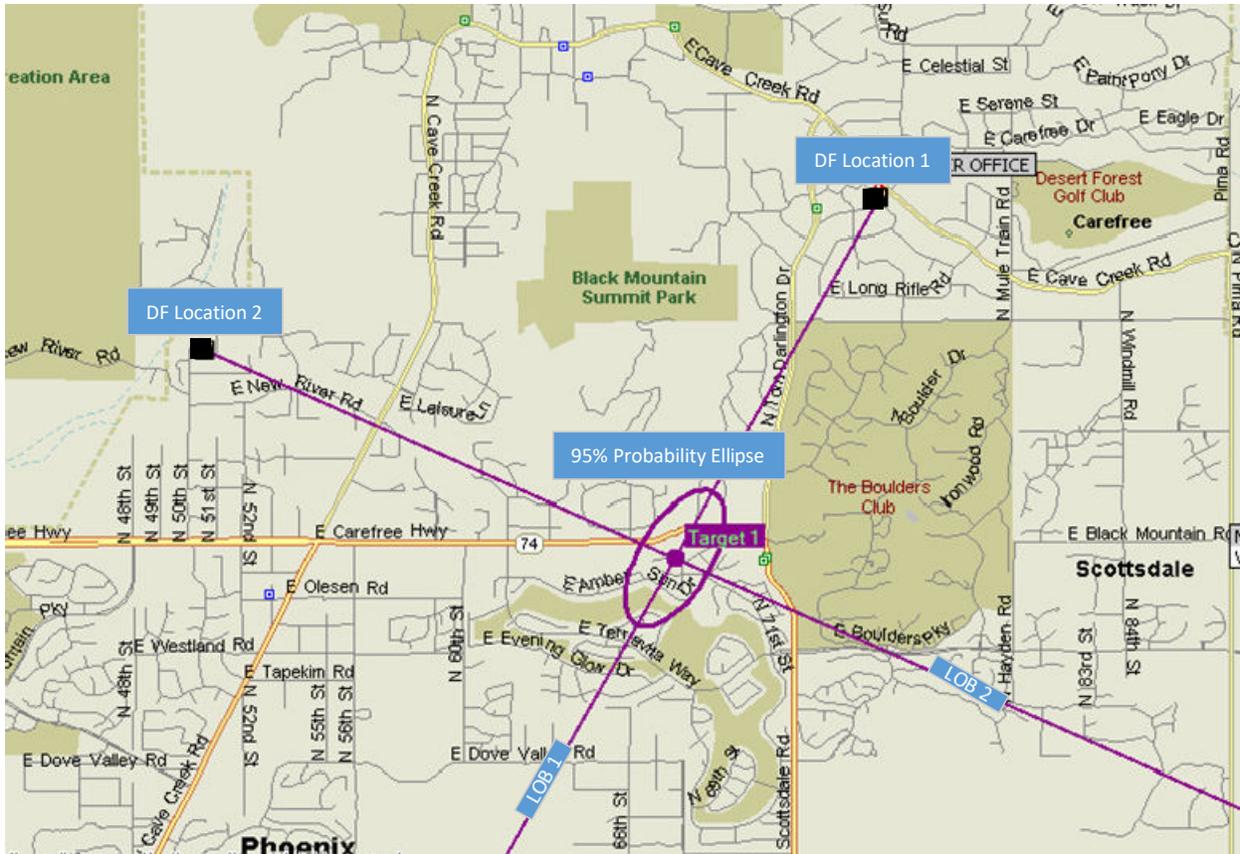


Figure 1: Two Lines-of-Bearing (LOBs) Determine the Location of a Target Transmitter

Although two LOB measurements are required, the location of the direction finders relative to the target transmitter location has a big influence on the accuracy of the estimated location. Figure 2 illustrates what happens when the target transmitter approaches a location that is in line with both direction finder locations. The area of the ellipse increases significantly providing a poor indication of the actual target location. Adding a third LOB measurement improves the estimate considerably as shown in Figure 3. Therefore, reasonable coverage of a geographic area requires at least three LOB measurements¹

¹ For a more in-depth discussion of the optimal positioning of multiple direction finders see <http://www.dopsys.com/appnotes/Site%20Location%20for%20Optimal%20Triangulation.pdf>

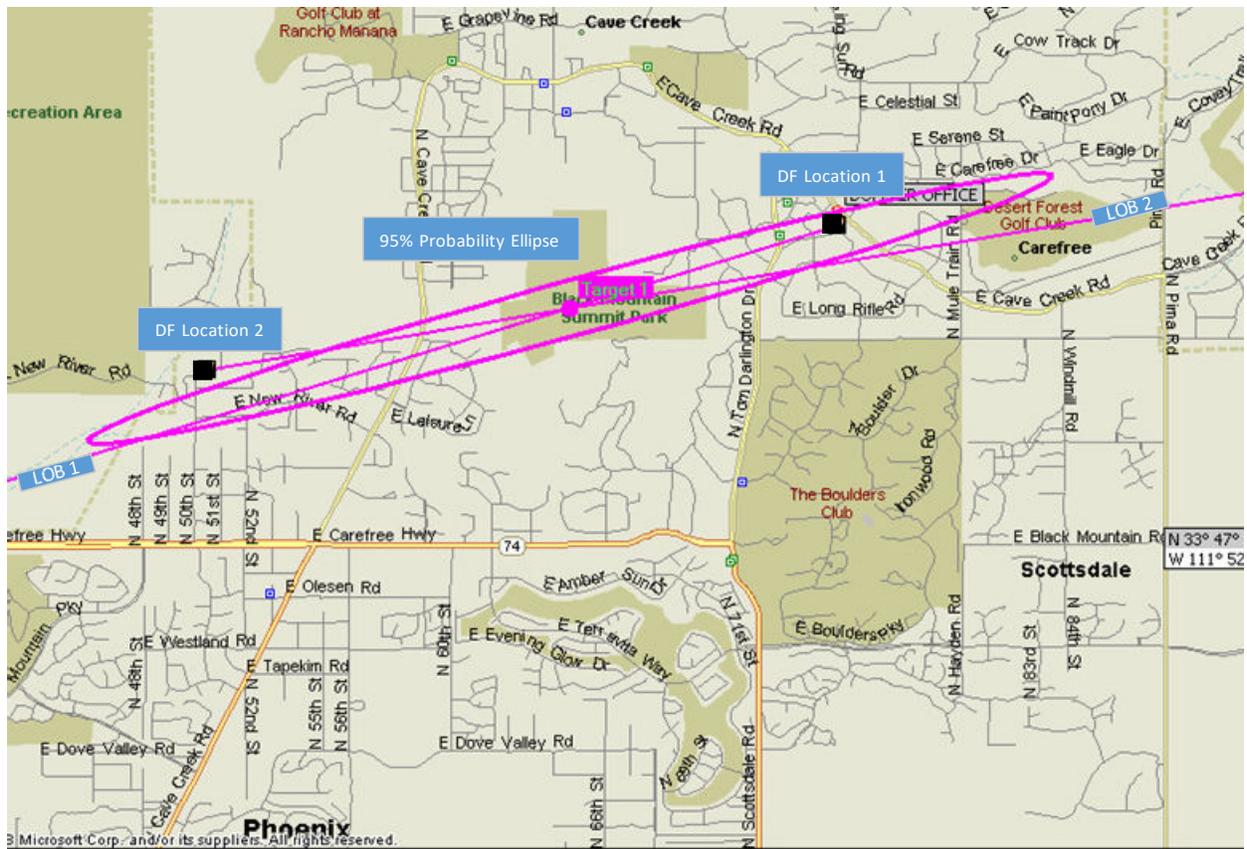


Figure 2: A Poor Estimate of Target Location Occurs if the Target Transmitter is in Line with the Two DF Locations

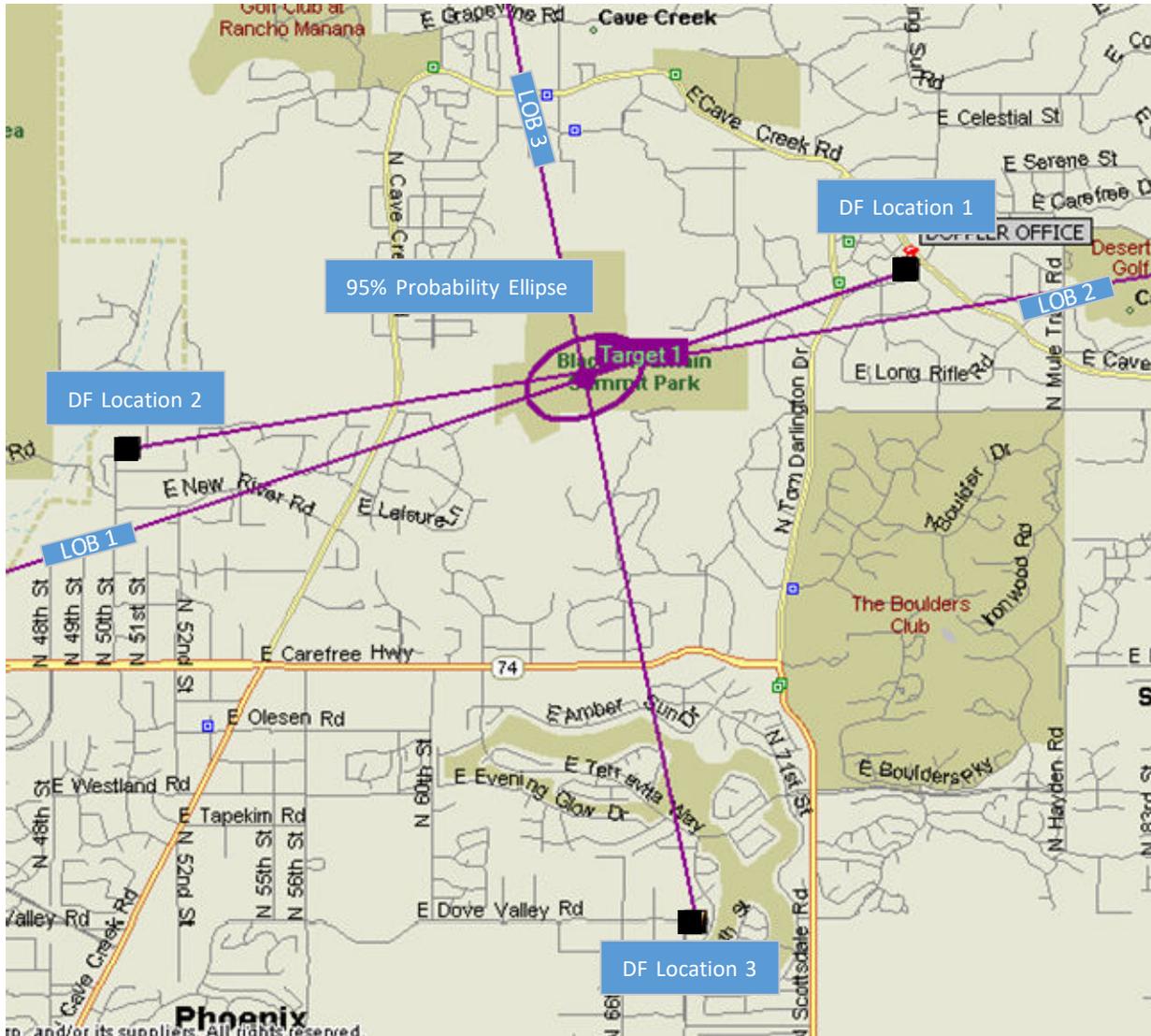


Figure 3: Adding a Third DF Location Enhances the Quality of the Estimated Location of the Target

Multiple LOB Measurements Using a Single Mobile Radio Direction Finder

Using a single mobile direction finder requires the target transmitter to make multiple or continuous transmissions. The reception of a transmission by the direction finder results in a measurement of the direction of the transmitter relative to the vehicle. For instance, if the vehicle is traveling east and the transmitter is north of the vehicle the direction finder would measure an angle of 270 degrees. If the transmission is occurring frequently the operator can simply use the display on the MPT User Interface software or the Doppler Android² application to monitor the direction and the strength of the transmission and direct the driver to the transmitter location. We refer to this as homing.

If the transmissions are infrequent or if it is unsafe to approach the transmitter location, then Doppler's TargetTrack software is used to provide an estimated location of the target transmitter. If possible, the direction finder is driven to a high point with a clear line-of-site to the transmitter and the frequency of

² See [Direction Finder Homing Software](#) for more information on these software applications

interest is monitored. The operator waits for a transmission. Upon receipt of a transmission the operator determines if it is a signal of interest and presses the Insert key or Insert button to save the LOB on the map. The operator then directs the driver to move to a different location and the process is repeated. Two saved LOBs from different locations allows TargetTrack to estimate the location of the target and provide the operator with an uncertainty ellipse drawn around the estimate similar to Figure 1. The uncertainty ellipse indicates that there is a 95% chance the transmitter is somewhere within the ellipse. TargetTrack also calculates and displays the circular ellipse probability (CEP) enabling the operator to make a good determination of the target's location. Although two lines-of-bearing (LOB) are sufficient to estimate the target transmitter's location, more measurements will result in a better estimate.

Multiple Simultaneous LOB Measurements

The location of a target transmitter can be estimated nearly instantaneously using multiple Doppler radio direction finders placed strategically around the area where the transmission is occurring. The direction finders can be fixed sites or mobiles connected via a TCP/IP network or radio modems. The Doppler Systems' TargetTrack software combines the measurements from the various direction finders and displays the estimated location and the 95% ellipse on a map allowing an operator to determine the precise location of the target. A minimum of two direction finders are required providing the target is never near a line between the two direction finders; therefore, to cover an area with no ambiguity a minimum of three direction finders is required. The network of direction finders can be any combination of mobile and fixed site units.

Required Equipment

The equipment required for radio direction finding is determined by the mission to be accomplished and the nature of the target transmitter. If transmissions occur on a continuous or regular basis and there is no danger in approaching the transmitter, a simple mobile homing system suffices. Examples would be a stuck transmitter, an oscillating amplifier, or an obnoxious jammer. If transmissions occur less frequently or if approaching the transmitter location is not possible or is dangerous then a mobile system together with our TargetTrack software is required. Examples would be an infrequent jammer, a transmission source in a restricted area, or a dangerous individual or group using radio communications. If it is important to provide an instantaneous estimate of the target transmitter location then the solution requires multiple direction finders networked together. Some examples would include infrequent transmissions necessitating unattended monitoring, location of a stranded individual, or location of dangerous individuals or groups. Also, a network of direction finders enables the identification of multiple transmitter locations which is useful when a number of individuals are communicating with each other.

This section provides a description of the equipment required for

- A basic mobile homing radio direction finder
- A mobile direction finder using our TargetTrack software
- A networked direction finder system

Homing Direction Finder

A basic mobile homing direction finder, illustrated in Figure 4, consists of a direction finding processor, a summing unit, four vertical antennas, a narrowband FM receiver, and a laptop. The narrowband FM receiver can be of any manufacture. The antennae are mounted in a square pattern on top of the vehicle spaced between $1/8$ and $1/4$ wavelength apart. A laptop computer running the MPT User Interface software provides a display of the bearing relative to the vehicle.

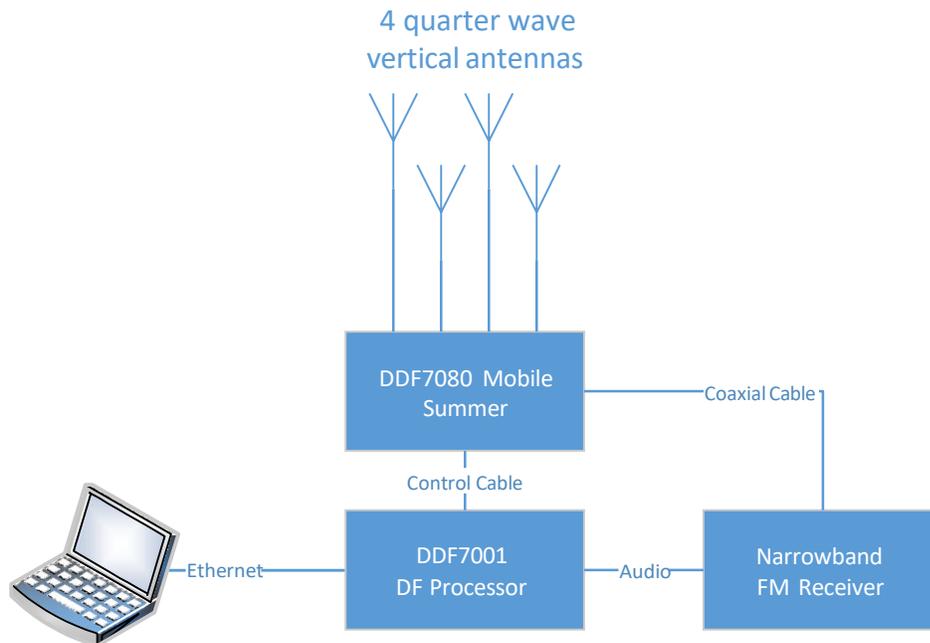


Figure 4: Basic Mobile Homing System

Mobile Direction Finder Using TargetTrack

As depicted in Figure 5, adding a GPS receiver and using a narrowband FM receiver that is supported by the MPT firmware allows the direction finder to use the TargetTrack software. Receivers supported by the firmware currently include³:

- AOR SR2200
- AOR AR8600
- AOR AR5001D
- AOR DV1
- ICOM R1500
- ICOM R2500
- ICOM R8500
- ICOM R8600
- ICOM R9500

³ If the receiver you want to use is not listed, please contact the Doppler Systems and we can discuss adding your receiver to our firmware.

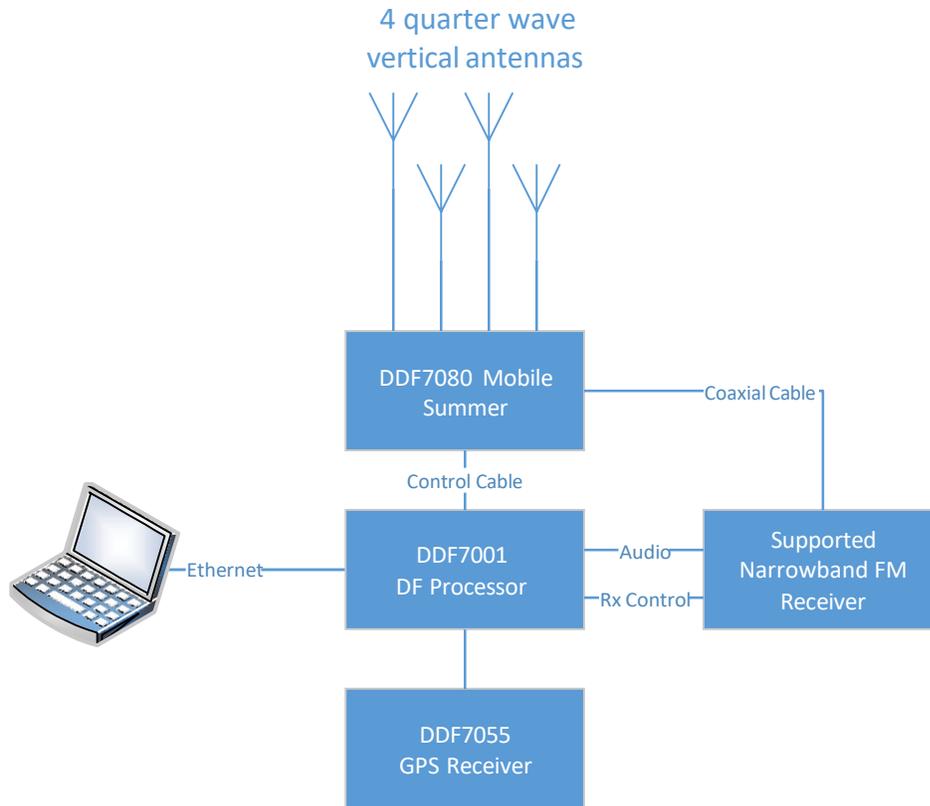


Figure 5: Adding a GPS Receiver Enables the use of the TargetTrack Software

Networked Direction Finders

Any number of mobile and/or fixed site radio direction finders can be networked to provide an instantaneous estimate of a target transmitter's location. Figure 6 provides an example of a networked system. The network can be a local area network (LAN), a wide area network (WAN), the Internet, or a private network. The only requirement is that the network interface supports Internet protocol (IP). The bandwidth requirements are minimal with bearing data transmitted every 0.5 seconds. At least one network connection to the computer must support 16 kbs for audio streaming. Typical equipment complements for a mobile direction finder and fixed site direction finder are shown in Figure 7 and Figure 8. Each DF processor supports up to 10 TCP/IP connections so multiple users can monitor and/or control the network.

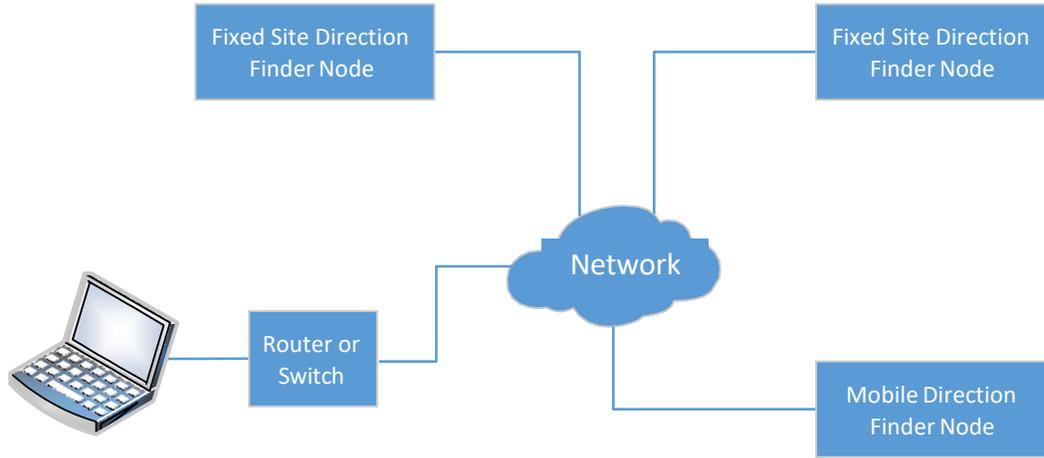


Figure 6: Example Network of Two Fixed Site Direction Finders and One Mobile Direction Finder

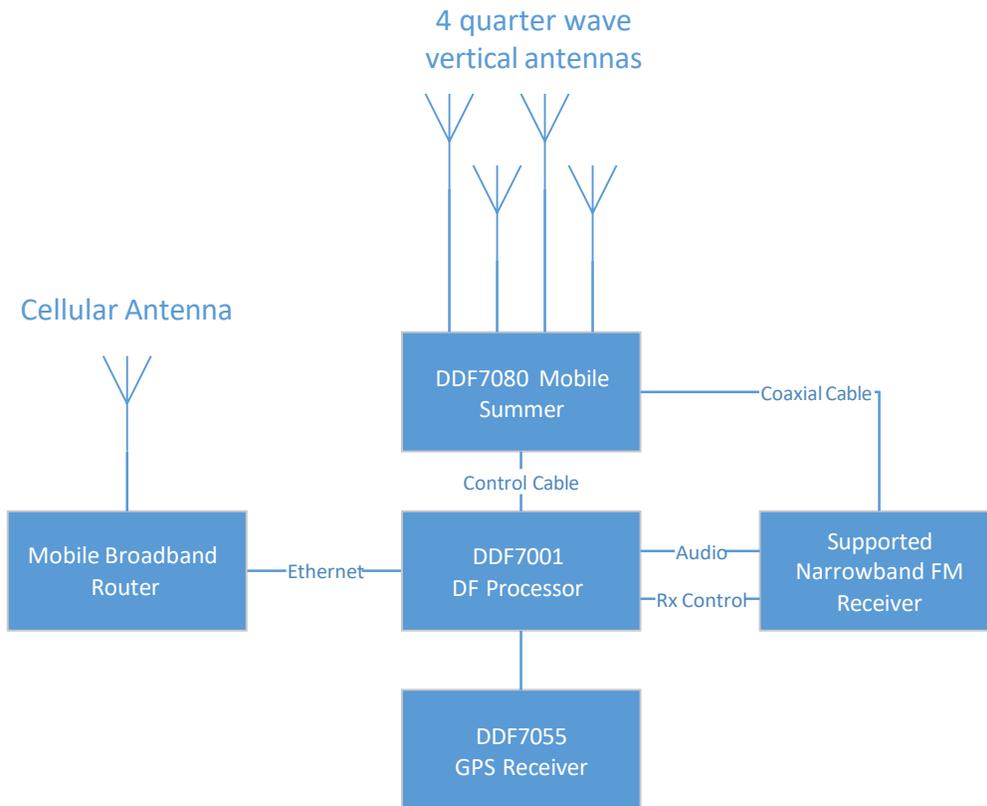


Figure 7: Equipment Complement for Networked Mobile Direction Finder Node

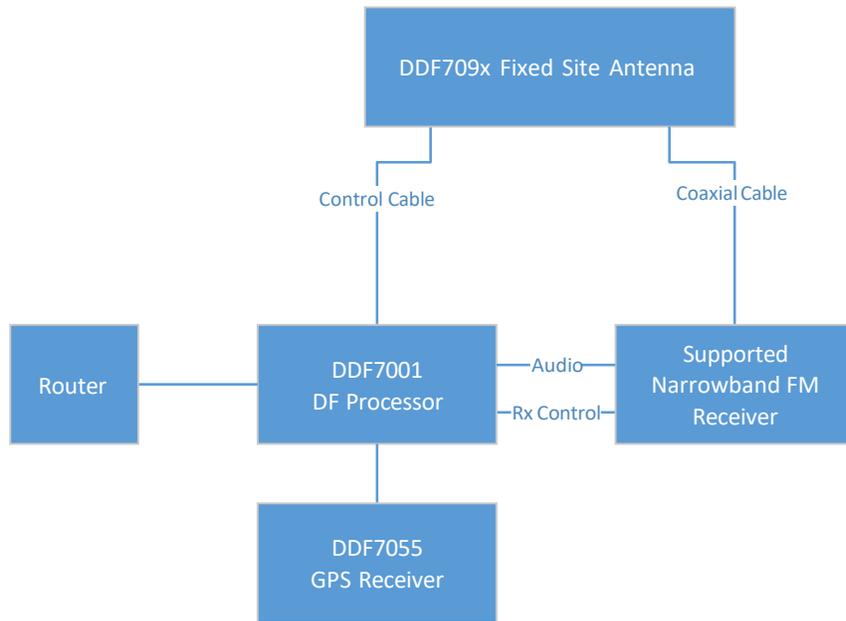


Figure 8: Equipment Complement for Networked Fixed Site Direction Finder Node

Using TargetTrack

The TargetTrack software application provides a powerful user interface for locating one or more target transmitters on a given frequency. It can be used in a single mobile system or in a network of radio direction finders. In this section we will discuss the basics of setting up the software and the various settings related to targeting.

Setting Up TargetTrack

The first order of business upon launching TargetTrack is to select a map to use. Three mapping options are supplied with TargetTrack. You can make your own maps using the MapFix software supplied with TargetTrack. You can use on-line mapping databases, such as OpenStreet, Google Maps, or BingMaps, using the Great Maps interface or you can use the ESRI ArcGIS mapping engine⁴.

Once you have a map displayed you must establish connections with the direction finders on your network. If the direction finder is directly connected to your computer or on a LAN, the available direction finders will be displayed in the lower right side of the screen. Right click on the display and choose to connect as a mobile or fixed site. Enter the name of the site in the displayed dialog and press OK. TargetTrack will connect to the site.

⁴ The ESRI ArcGIS mapping engine requires a separate license. Contact ESRI or Doppler for further details.

If the direction finder you want to connect to is not displayed in the lower right hand corner of screen right click on the map and select **Add New->Fixed Site** or **Add New->Mobile Site** from the pop up menu. A dialog will be displayed asking for information concerning the direction finder and the connection. Fill in these fields and press OK. TargetTrack will establish connection with the direction finder. A solidly colored icon at the location of the direction finder indicates a successful connection. An unsuccessful connection is indicated by an X through the icon. If the connection fails check the data you entered and if that is correct make sure your router has the proper port forwarding settings to allow the connection⁵.

If you are connecting to multiple direction finders then one of the DF sites must be designated as the primary site. Audio from the primary site is used to activate data collection, recording, and display. Typically, the first site entered will be the primary but the user can change the primary site by right clicking on the site and selecting **Set As Primary**.

Locating a Transmitter Using One Mobile Direction Finder

Upon receipt of a transmission TargetTrack displays a LOB as depicted in Figure 9. The mobile's location is displayed on the map with its heading indicated by the direction of the arrow shaped icon. The LOB is calculated every 0.5 seconds and unless the vehicle is already near the transmitter the signal may be weak and the LOB erratic. Nevertheless, the operator can use this LOB to instruct the driver to head in the direction of the signal. Once the operator is satisfied that the LOB is a good one, he presses the Insert key or hits the Insert button on the mobile display to save the LOB on the map as shown in Figure 10. The driver then moves the vehicle to another location and another LOB is saved. Figure 11 shows two saved LOBs and the resulting location estimate. The operator and driver repeat this process until they are satisfied that the transmitter is accurately located. Figure 12 shows the results of five saved LOBs.

⁵ See [Streaming Audio To TargetTrack over an Internet Connection.docx](#) for information on port forwarding for Doppler direction finders

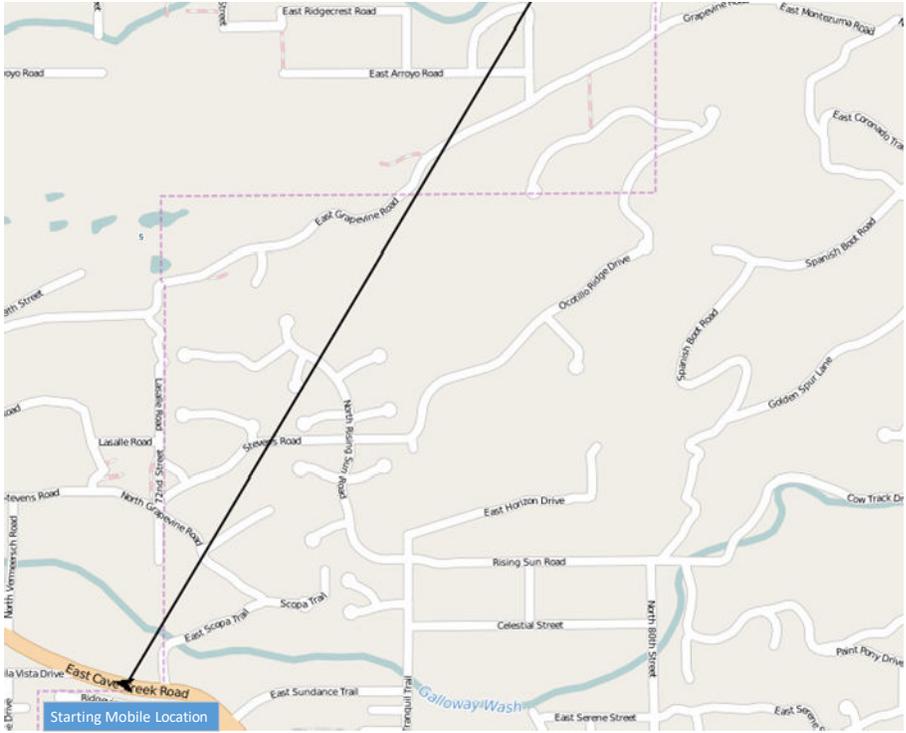


Figure 9: TargetTrack Displays LOB from Location of the Vehicle

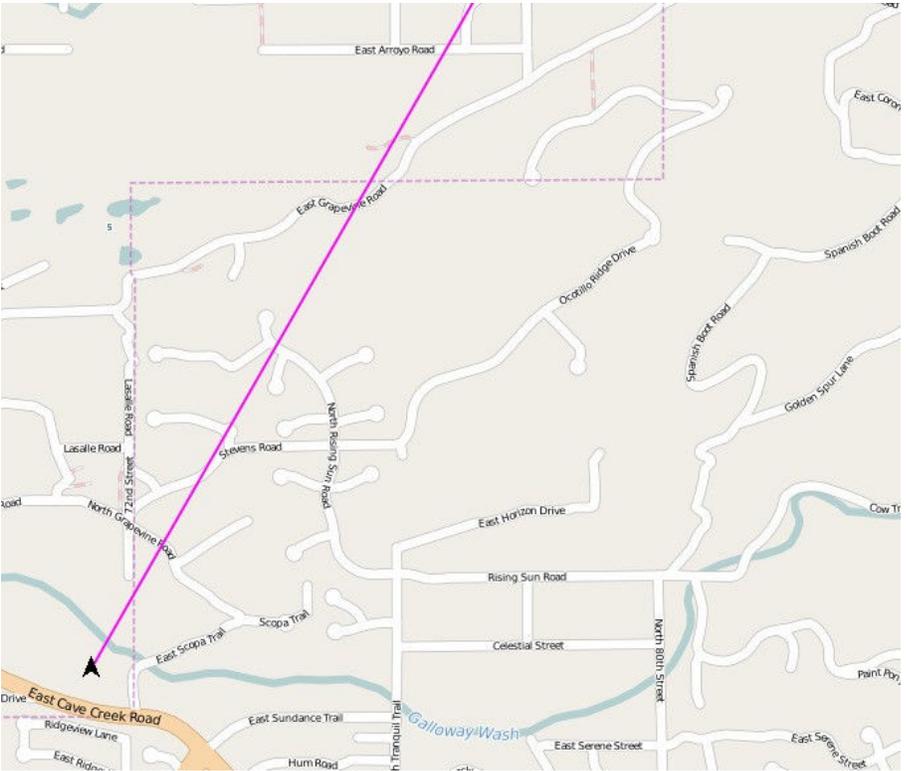


Figure 10: Operator Saves LOB on Map

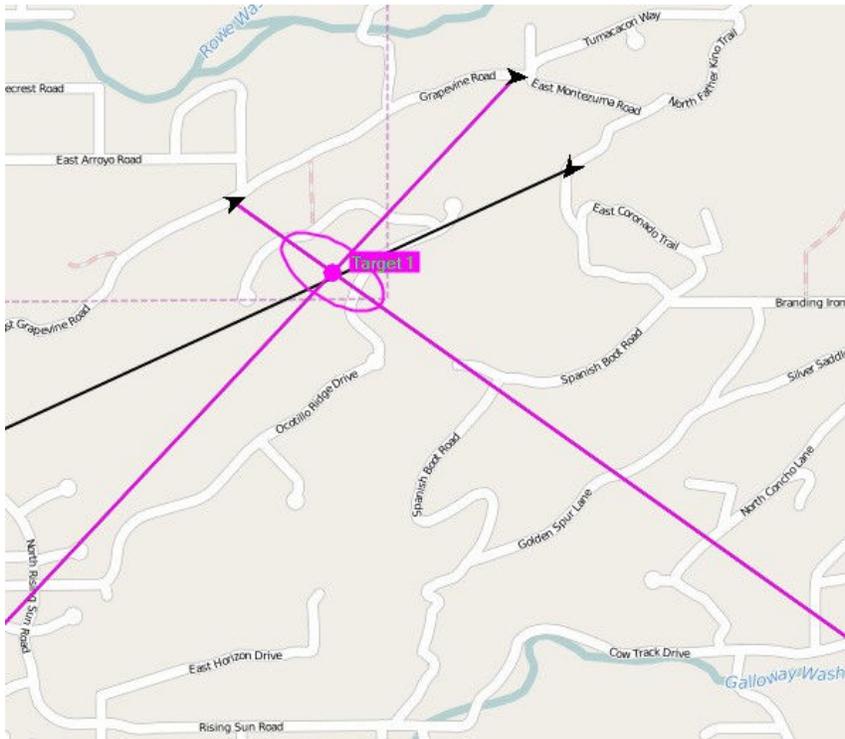


Figure 11: Two Saved LOBs Are Used To Calculate the Estimated Location of the Target Transmitter

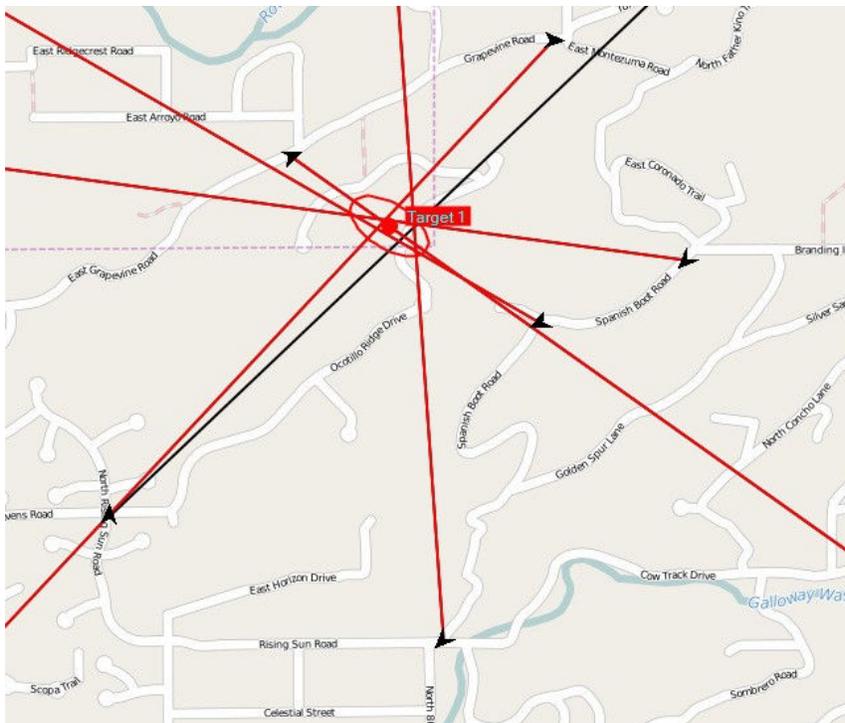


Figure 12: Five Saved Bearings Are Used to Calculate the Target Transmitter Location

Locating a Transmitter Using Networked Direction Finders

As mentioned above any number of radio direction finders can be connected via a network to provide a nearly instantaneous estimate of the target location. Each direction finder on the network receives a transmission and measures the bearing. The bearing measurement is time tagged and sent to a computer running TargetTrack. TargetTrack displays the LOBs and estimates the target location. Figure 3 illustrates the results of a three fixed site system.

It's also possible to network fixed site and mobile direction finders. In Figure 13 the fixed sites provide an initial estimate of the target location. Once the initial estimate is established the mobile can be deployed to further refine the estimated location. The mobile makes multiple LOB readings resulting in the target location estimate shown in Figure 14. Notice that the uncertainty ellipse is considerably smaller.

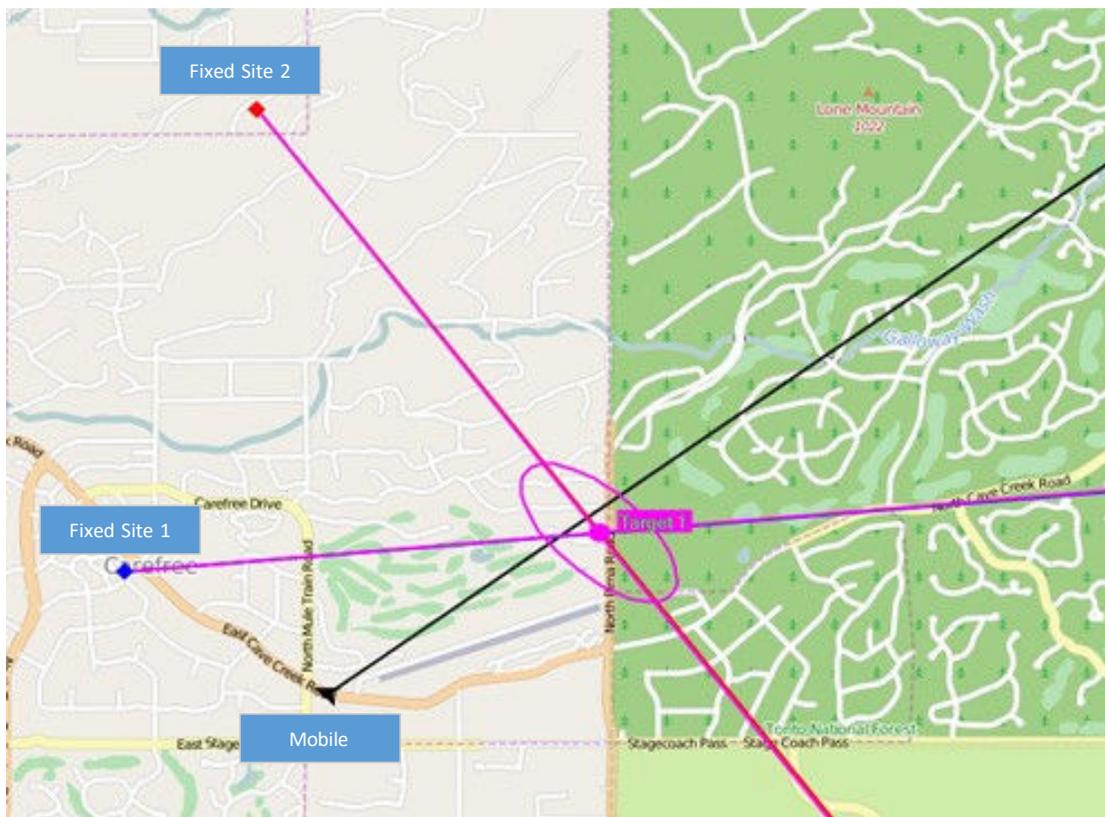


Figure 13: Initial Estimate Using Two Fixed Sites and a Mobile

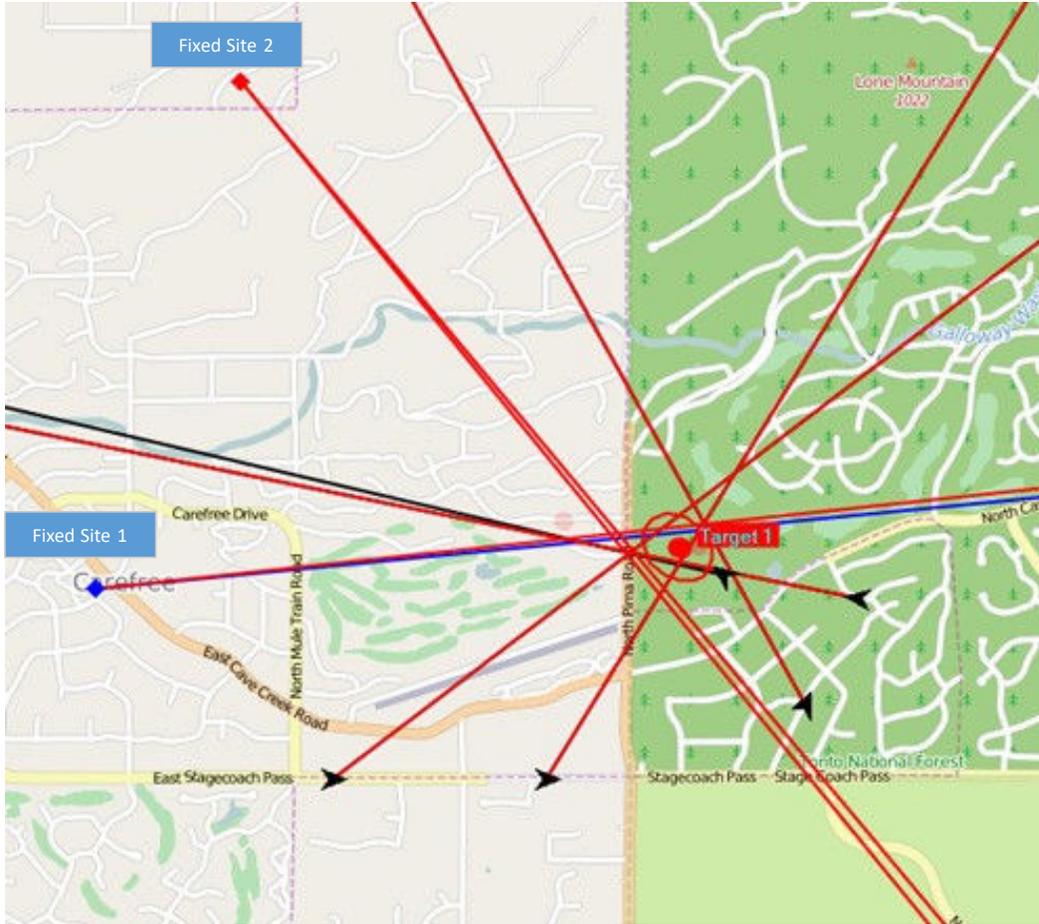


Figure 14: A Mobile is used to reduce the Uncertainty of the Transmitter Location

Locating Multiple Transmitters on the Same Frequency

TargetTrack has the ability to discriminate between multiple targets and provide an estimate of each transmitter's location. This gives the operator the ability to identify the location of multiple speakers in a back-and-forth conversation. TargetTrack will automatically identify a new target if the target estimate lies outside of an existing estimated ellipse. In Figure 15 two individuals are having a conversation and TargetTrack estimates the location of each transmitter.

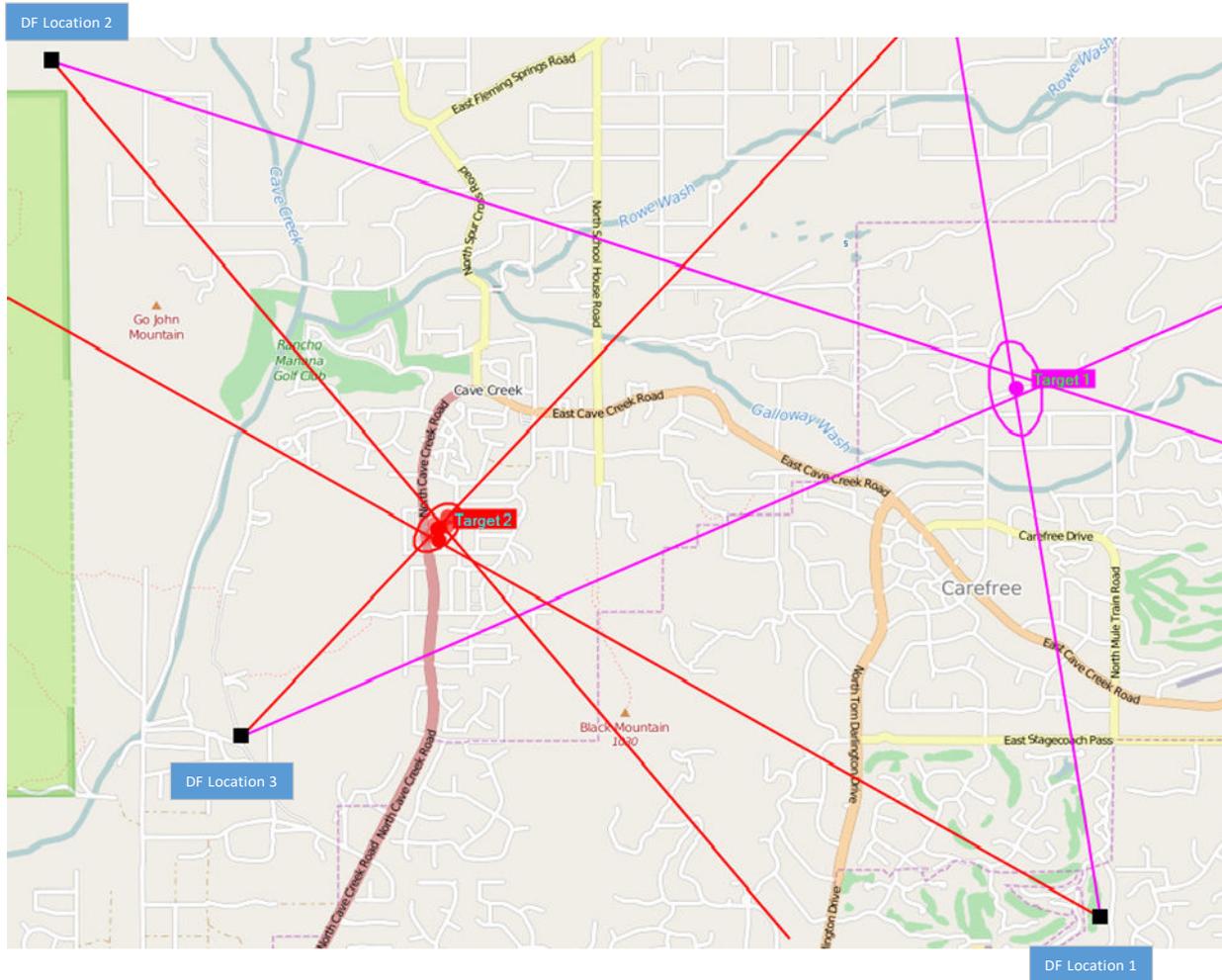


Figure 15: Multiple Transmitters are Automatically Located Using TargetTrack

TargetTrack Settings for Estimating Transmitter Location

There are a number of settings in the TargetTrack software that enable to operator to achieve the best possible target estimates and visually display the results. In this section we will define these settings and discuss how to use them.

Site Quality

Site quality is used as an indicator of quality of the LOB measured by the site. A fixed site antenna mounted in a clear area has a 1 degree RMS error. This corresponds to a site quality of 4 in TargetTrack. If the site is in a less than ideal location the bearings may exceed the 1 degree RMS value. Decreased accuracy can be caused by close in conductive structures or geological features such as large rocks, hills, or mountains. If this occurs TargetTrack will draw an uncertainty ellipse that is too small. To counteract this the operator can set the site quality lower resulting in a more realistic uncertainty ellipse. Figure 16 illustrates the effect of decreasing the site quality. The site quality of each direction finder can be set individually. The default setting for a fixed site is 4 and for a mobile site it is 3.

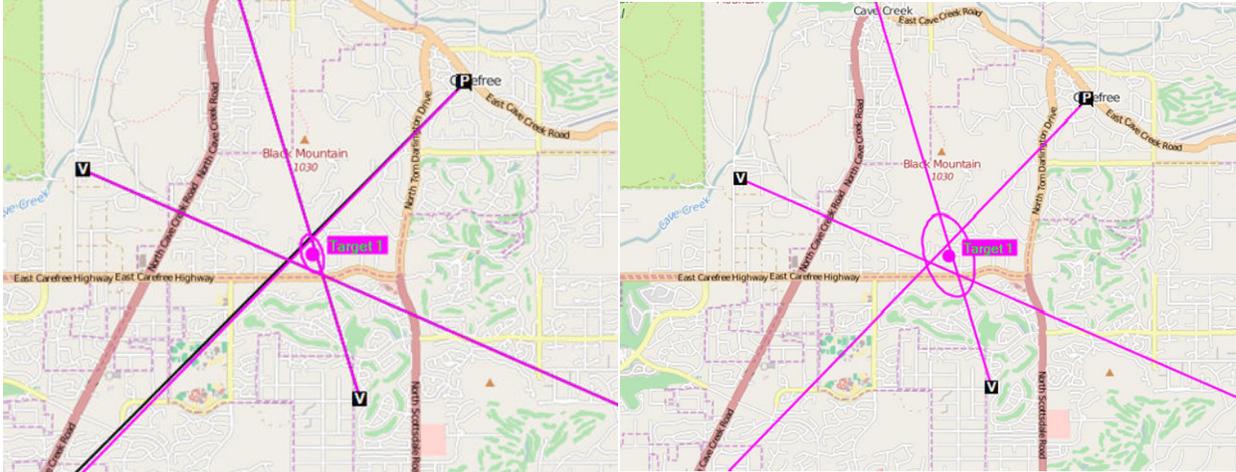


Figure 16: Uncertainty Ellipse is Larger when the Site Quality is decreased from 4 to 2

Instantaneous and Average Estimates

When a signal is being received, TargetTrack computes an estimate of the target location every 0.5 seconds. These instantaneous estimates are averaged to provide an estimated location of the target and to draw the uncertainty ellipse. At least two bearings from each site are required to compute the average. The average is a running average and the number of averages is user settable. The default is 10 which works well for stationary transmitters or moving transmitters in a car, truck, or boat. For faster moving vehicles, such as aircraft the number of averages should be reduced.

Several settings affect how the estimates are displayed. These settings are contained in the **View** and **Target** menus.

View Menu

Figure 17 shows the contents of the **View** menu. When the **Show Bearings** item is checked every LOB from every site is displayed when they occur. Most operators prefer to see the bearing lines. Checking the **Show Estimated Target Locations** results in the display of all the instantaneous estimates used to calculate the average location of the target with the estimates fading as they become older.

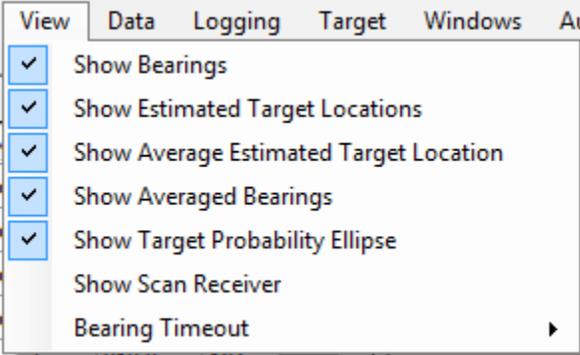


Figure 17: The View Menu Control the Display of the Bearings and Targets

Typically these estimates clutter up the display; however, if the transmissions are very short (< 2 seconds) the instantaneous estimates may be useful. Selecting show **Average Estimated Target Location** displays the average location of the target as a colored dot on the map. **Show Averaged**

Bearings prompts TargetTrack to display the average bearings used to calculate the average location. The **Show Target Probability Ellipse** causes TargetTrack to display or hide the calculated uncertainty ellipse. Figure 18 shows an example display with all the View menu items checked.

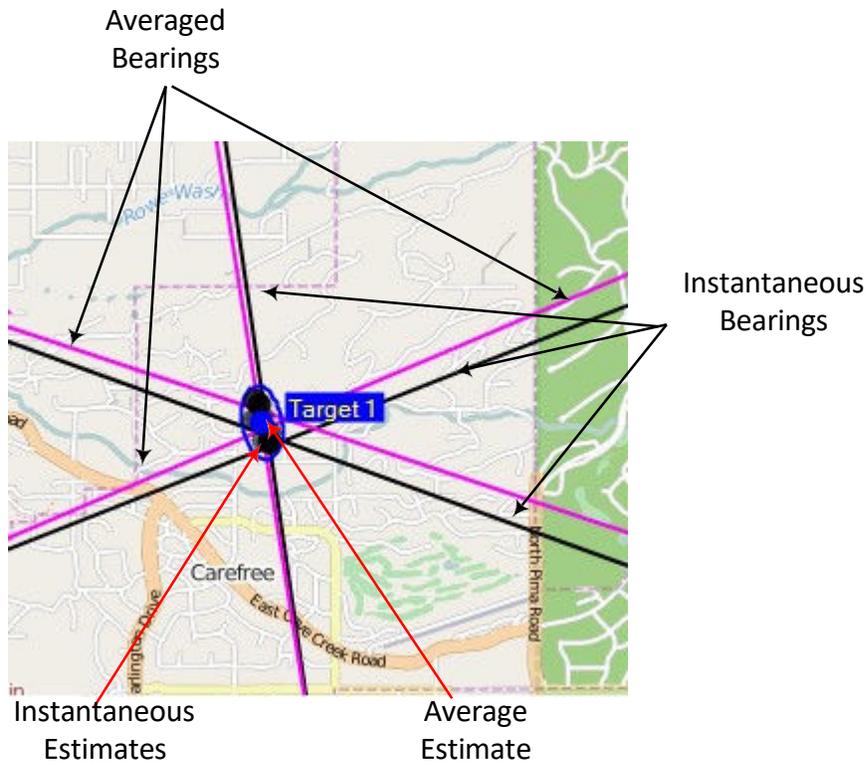


Figure 18: Definitions for the View Settings for Targeting

The Bearing Timeout defines the time that the last bearing is displayed after the transmission stops. In mobile systems it is best to set this time to 1 second. For fixed site systems a value of 30 seconds works well but operators may want to adjust this to suit their own tastes.

Target Menu

The **Target** menu allows the user to fine-tune the target display to fit the user's preferences and to fit the particular target transmitter characteristics. **Estimate Size**, shown in Figure 19, allows the user to select four different icon sizes for displaying the instantaneous and average target locations.

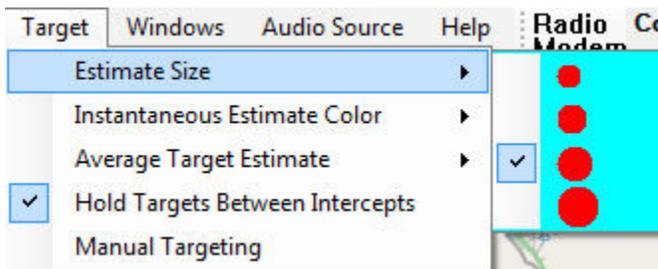


Figure 19: The Estimate Size Menu

Instantaneous Estimate Color allows the user to select the color for the instantaneous estimates. In Figure 18 above black was selected. The most recent estimate will be shown in black, older estimates will progressively fade to lighter shades of gray. The number of instantaneous estimates shown is controlled by the number of averages which is set in the **Average Target Estimate** menu.

TargetTrack calculates a running average of each bearing measured by each site. It uses these averages to calculate the probable location of the target transmitter. It also calculates a 95% probability ellipse and a circular error probable (CEP) radius. **The Average Target Estimate** (Figure 20) settings determine how these items appear on the screen.

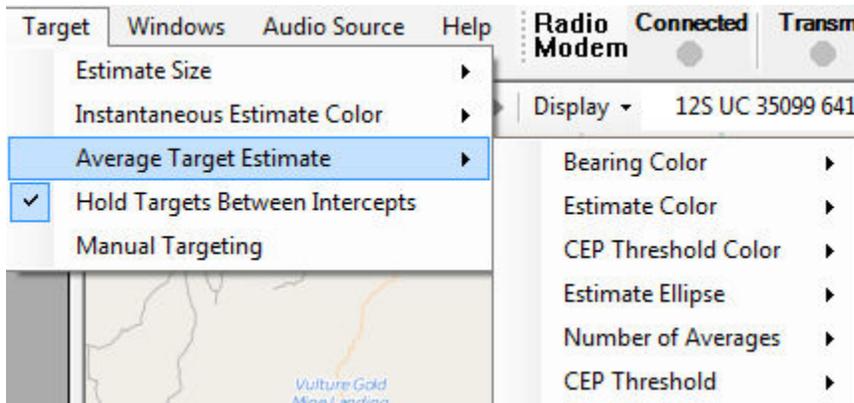


Figure 20: Average Target Estimate Menu

Bearing Color sets the color of the average bearings; **Estimate Color** sets the color of the average estimate and the ellipse; and **CEP Threshold Color** sets the color of the average estimate and the ellipse once the CEP threshold is reached. The user sets the CEP threshold. Once the CEP radius is less than the threshold, the average estimate and the ellipse changes color. The color change alerts the user that the CEP is below the specified threshold.

The **Number of Averages** allows the user to set the number of averages used in the running average. The default value is 10 which corresponds to a 5 second running average. A setting of 10 will track a fixed or slow moving transmitter. If the transmitter is moving faster a lower setting may be necessary.

The probability ellipse can be displayed as a drawn ellipse with the estimate at the center of the ellipse or as a heat map. Examples of both methods are shown in Figure 21 and Figure 22. The **Estimate Ellipse** menu item allows the user to select the method of display.

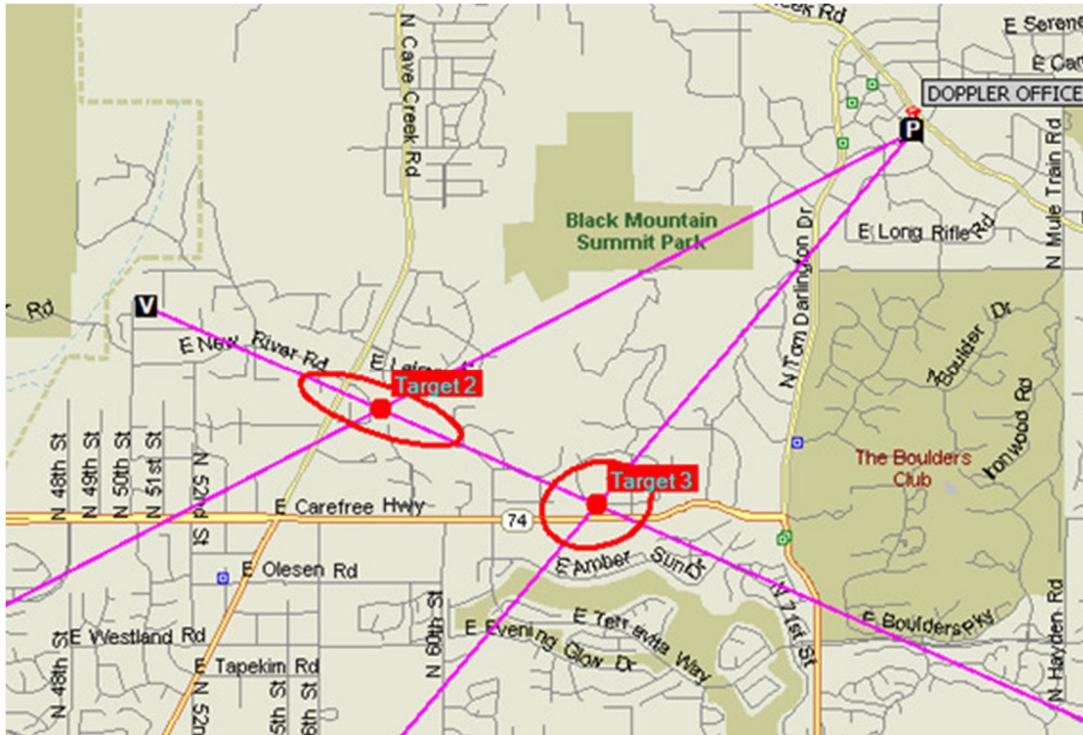


Figure 21: Display of Target as Ellipse with Estimated Location in the Center

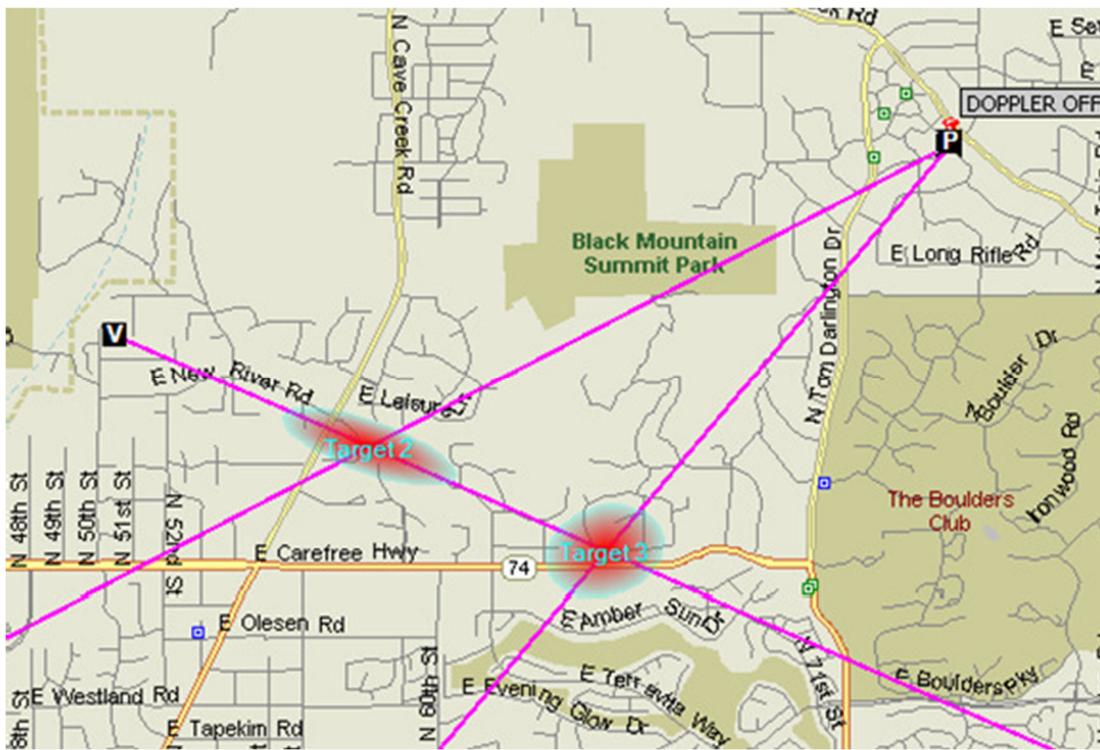


Figure 22: Display of Target as a Heat Map

Checking **Hold Targets Between Intercepts** causes TargetTrack to maintain the average bearings and estimated target locations after the transmission ceases and then use this data to restart the target

estimate when the transmission resumes. Unchecking this item causes the estimate to be reset at the beginning of each transmission.

Manual Targeting allows the user manually start and stop the target estimation. This feature could be used if there were a large number of transmitters on a given frequency and only one transmitter was of interest. In that case the user could listen for the transmitter of interest and start targeting when it began transmitting and stop targeting when the transmission ended.

Conclusion

Finding hidden or rogue transmitters can be an arduous and time-consuming task. Doppler Systems radio direction finding equipment and software simplify the task allowing an operator to quickly get a good estimate of the transmitter's location. The software provides a clear and concise display of single or multiple transmitter locations. For more information on the available equipment visit our web site at www.dopsys.com or give us a call at 480-488-9755.