Improving Triangulation Accuracy in High-Velocity Systems

Michael Harney
mharney@lokatur.com

I. Introduction

Wireless tracking and triangulation approaches have existed for many decades, but the last decade has seen much more focus on efficiency and accuracy of triangulation which has translated into the use of fewer sensors and more efficient algorithms. In the case of tracking high-velocity objects, there is a necessity for accuracy as the error in a tracking system can accumulate quickly and a lock on the object can be lost and never recovered. In the following paper, we will discuss a method of tracking that uses the motion of an object as an advantage in tracking it, with a higher-velocity object providing more data points to allow for more accurate tracking.

II. New Methods of Wireless Triangulation

Wireless triangulation has generally used either phased-arrays or received signal strength (RSSI) to provide the location of a source signal. The goal of providing a three-dimensional triangulation solution with x, y and z coordinates has been achieved with sensors placed on all three axes and with a coordination of either timing for phased arrays or measured distance for signal-strength approaches in order to calculate the coordinates of the source. Within the last decade, a mathematical method of triangulation has been developed for providing the three-dimensional coordinates (x, y and z) of a source by placing four sensors all in one plane to improve the RSSI approach so that the volume of space required for the sensors is optimized to just a plane and therefore exhibits an economy of scale [1]. This method also allows for automatic calibration of unknowns sources, with the fourth sensor acting as a reference for the unknown signal strength of the source. One approach to implementing this four sensor array in one plane is shown in Figure 1.

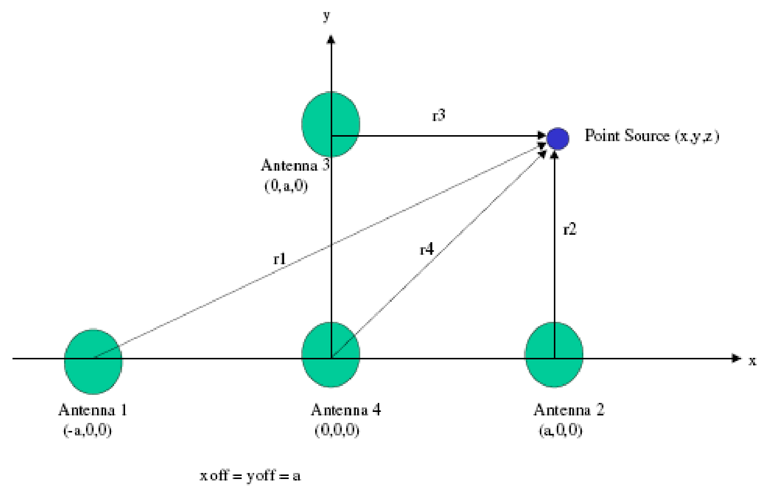

Figure 1 Antenna Placement In The Array

The tracking of a single point source with the four omnidirectional antennas in Figure 1 is accomplished by utilizing a general equation of radiative transfer for point sources as follows:

$$\mathrm{RSSI} = \frac{kI}{r^2} \qquad (1)$$

Where ***I*** is the intensity or power of the source, ***k*** is the proportionality constant for transfer of the signal through the medium, and ***r*** is the distance between the source and the receiver. Based on a distance r_n between the point source and n receivers, the equation (1) can be combined with the known coordinates of the receivers in Figure 1 to create equations which has a solution for the point source. As there are four sensors in the array, there are four independent variables that combined through analytic geometry of the array will yield the solutions for ***x, y, z*** and ***I*** (the intensity of the source which eliminates the need for calibration) [1].

III. Wireless Sensor Arrays in Motion

Although the array pattern in this setup is static, it can easily be visualized that moving sensors or antennas could constitute an array that, based on the particular geometry with Figure 1 as one example, would yield equations which result in a three-dimensional solution of the source coordinates. As an example, the static array in Figure 1 could be placed on a flying drone helicopter that tracks a stationary beacon on the doorstep of a house, with the array on the drone finding the location of the beacon to high precision so it can deliver a package precisely on the doorstep.

Another example is a moving source which is being tracked by another source with a linear profile (such as a rocket) that has a spacing of sensors along the linear profile, we can see that the movement of the source relative to the moving array provides a variation in received signal strength on each sensor on the linear array as shown in Figure 2.

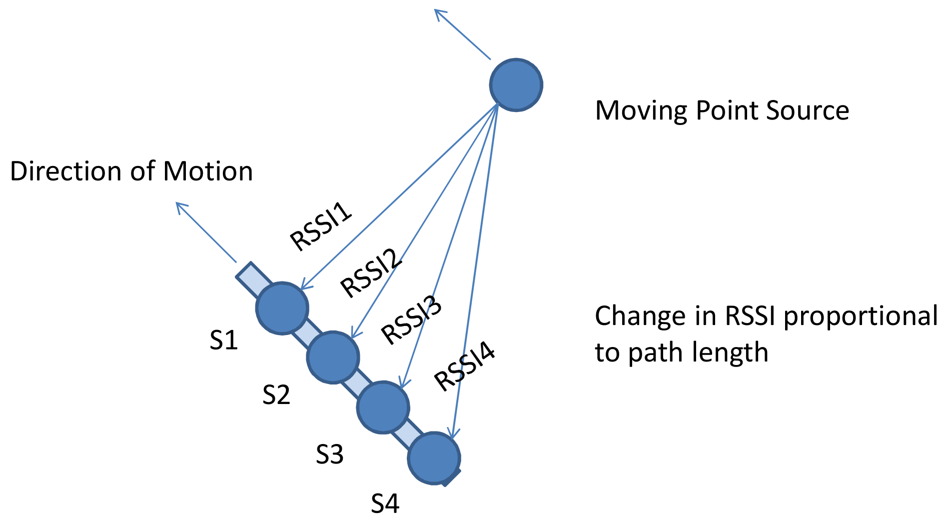

Figure 2. Changes in RSSI Between A Moving Sensor Array and Signal Source

This variation along with known geometry of the sensors on the linear array and previously calculated coordinates of the source allows for a new determination of the bearing of the source along with updated coordinates. As the array moves closer to the source, the signal strength increases (with the signal-to-noise ratio also improving) allowing for a more accurate determination of the coordinates. Of course, there are limitations in change of direction of moving objects due to inertia and control stability, but the ability to triangulate a source more accurately on a moving platform provides for advanced information on the bearing changes of the source.

As shown in Figure 3, as the linear array moves relative to the point source being tracked, the variation in RSSI at each sensor and the last previously calculated coordinates of the source relative to the array allows for computation of the new coordinates of the source. The accuracy of this method improves as the array gets closer to the point source because the received signal strength (RSSI) is inversely proportional to the square of the distance from the source, so the error in estimated coordinate values decrease at an exponential rate (and the accuracy correspondingly increases exponentially). Also, there are additional data points accumulated that are used for determining the coordinates through the methods in equation (1). This allows for an integration of data over time to estimate the correct coordinates of the source.

Although it would seem intuitive that the fastest and most accurate approach to intersecting the point source would be a direct line of sight to it, the moving array benefits by meandering towards the source as each lateral transition in Figure 3 allows for new calculation of coordinates of the source at each lateral movement that is closer than the last and these values are integrated to obtain a more accurate location as the array gets closer to the source.

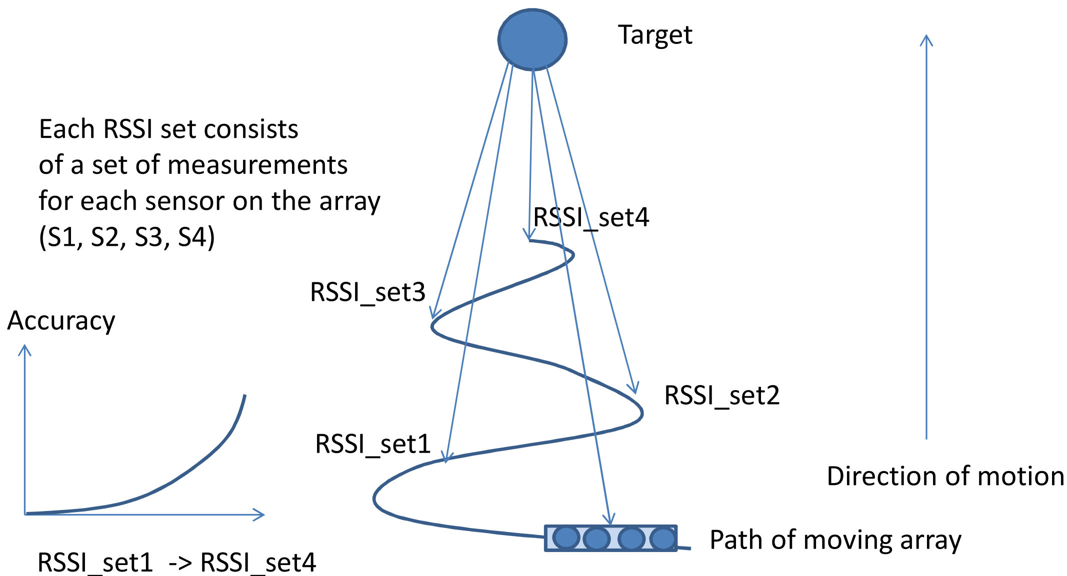

Figure 3. Variation in RSSI Due to Path of Moving Array

IV. Conclusions

The concept of tracking a source in three dimensions by taking signal strength measurements while moving and using the known coordinates of the array and calculated coordinates of the source is described in US Patent 10,123,297 which has also been used to locate the coordinates, room and floor of a wireless devices in a multi-level building by moving in a pattern such as a square on one floor with a mobile phone [2]. There are likely many other applications for tracking objects in motion that could be considered.

The predictive advantage of tracking a high-velocity object with the method described in this paper and visually diagrammed in Figure 3 is apparent. The ability to calculate the bearing angle of the object in advance while moving at high-speed effectively provides an integrating estimator of the high-speed object within close range allows for a quicker closed loop response in tracking and intercepting the moving object.

References

1. Harney," A Method Of Triangulating Point Sources Using Omnidirectional Sensors", https://www.researchgate.net/publication/228418966_A_Method_Of_Triangulating_Point_Sources_Using_Omnidirectional_Sensors , Apeiron, Vol. 13, No. 4, October 2006

2. US Patent Office #10,123,297 "System, method and devices for performing wireless tracking", http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=10123297.PN.&OS=PN/10123297&RS=PN/10123297