SIGNAL EMITTER LOCALIZATION USING TELEMETRY ASSETS

P. A. PARKER and M. LAKE
MIT Lincoln Laboratory

ABSTRACT

Telemetry ground stations spread over geographically diverse areas are well suited for use in passively locating the source of a distant transmitted signal. In a favorable positioning of receive sites, the accuracy of these passive localization techniques can compete with the accuracy of radars. In these cases, use of receive only assets is a less expensive alternative than the use of a radar's scarce resources. Until recently, the major technical challenge to implementation of the passive localization techniques of time-difference of arrival (TDOA) and frequency-difference of arrival (FDOA) has been the frequency and time stability of geographically separated receivers. Advances in GPS based timing and frequency references has made the implementation of TDOA and FDOA feasible. This paper shows how these limitations have been overcome using the current telemetry assets at the Reagan Test Site in Kwajalein Atoll.

KEY WORDS

Passive localization, time-difference of arrival, timing errors

INTRODUCTION

Telemetry receive systems are used to collect a signal at a passive receiver from an external transmitter located at some distance. The transmitted signal contains data which is extracted in processing. For example, during rocket launches, the vehicles often contain telemetry transmitters which send health, safety, and trajectory data to ground based receivers. The Reagan Test Site (RTS) located on Kwajalein Atoll of the Republic of the Marshall Islands has a suite of telemetry assets located on several islands throughout the Atoll, as shown in Figure 1. The distance between the Kwajalein site and the Roi site is approximately 80 km.

1 SIGNAL LOCALIZATION

While the primary purpose of these receivers is to receive telemetered data, there are other potential applications that would be enabled by a flexible receiver design. In the past, passive receivers have been beneficial in bistatic and multistatic radar applications, in which transmit and receive antennas are spatially separated [1].

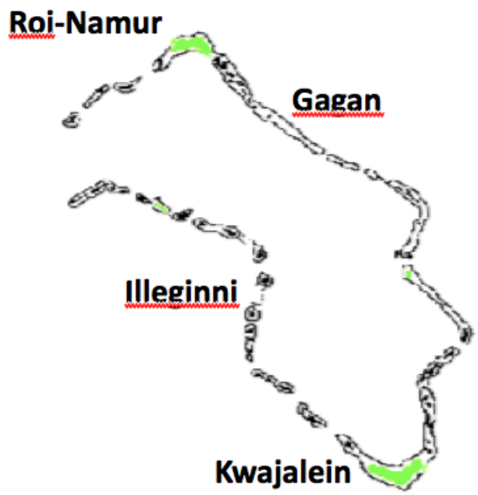

Figure 1: Map of Kwajalein Atoll showing the four islands with telemetry receivers.

The transmitting source can be a dedicated radar transmitter, a non-dedicated radar (a.k.a. transmitter of opportunity), or a non-radar transmitter of opportunity (i.e. commercial broadcasting transmitter). In all cases, the signal originates from a transmitter source on the ground, is reflected by a target, and the target return is received at the passive receiver. In multistatic localization, each transmitter/receiver pair results in an isorange contour (ellipse) defining the possible locations of the reflecting target; the contours are then combined to find the intersection where the target exists. Multistatic localization was used for the Multistatic Measurement System (MMS) from 1980 to 1993 [2], in which two receivers were located approximately 40 miles from the TRADEX radar in order to increase the accuracy of trajectory estimates for incoming reentry vehicles. The MMS operations were stopped after the metric accuracy of monostatic radars was improved, and the multistatic data no longer provided additional precision.

In addition to multistatic radar applications, these receivers could also be used in a passive localization application (see Section 2. Prior work in this area has included research on using satellites [3] and unmanned aerial vehicles (UAV) [4, 5] for passive localization. This paper discusses an application where ground based assets are used for localization.

One of the limitations of these localization techniques has been the necessity for very precise and stable clocks in order to determine the range or angle of the target. The received signals must be referenced to a synchronized time because the location error is proportional to the timing error. Currently, RTS telemetry receivers use free running clocks, which lead to large time errors and challenges when attempting to time synchronize data from different receivers. However, during standard operations when telemetered signals are being received, the recorders concurrently log an IRIG time code signal which is used as a stable GPS-based time reference. Time synchronization is achieved through post-processing of the IRIG signal with a precision dependent on the type of the recorded IRIG time-code. By using a GPS based reference for timing across all receive sites, it is possible to achieve timing accuracies on the order of 10s of nanoseconds [6].

2 TDOA

Angle estimation via time difference of arrival (TDOA) has been widely used in passive source localization algorithms [7, 8, 9]. When using two geographically separated receive sites, the constant TDOA locus is defined by a hyperbola where each site sits at the focal points of the hyperbola (when the source is at far distances, this is equivalent to an angle estimate with respect to the two sites). Due to estimation errors, the location of the source is not exactly on this hyperbola. Typically, the TDOA is estimated by correlating the signal received at one site with the signal received by the other site. The accuracy of the TDOA estimator is proportional to the signal-to-noise ratio (SNR), signal bandwidth, length of correlation time, and accuracy of the timing between the two sites.

To generate a localization estimate of the transmitting source via TDOA, at least four receive sites are required. This will give three independent (fuzzy) hyperbolas and some sore of non-linear estimation algorithm is used to find the most likely location of the source. In addition to the accuracy of the TDOA estimation algorithms, the accuracy of localization is dependent on the geometry of the receive locations. This accuracy is often described by the dimensionless Geometric Dilution of Position (GDOP) parameter. If the time offset error is not considered, then the effect of only the receiver position is known as the Position Dilution of Precision (PDOP). In general, the Dilution of Precision (DOP) parameter is defined such that lower values correspond to less error in positioning. DOP analyses have shown that the positional error reduces as the number of receiver stations increase [10]. The DOP is also affected by the volume of the polyhedron defined by the emitter and receiver locations [11]; as the volume increases, the location errors decrease. Therefore, greater localization accuracies can be achieved by increasing the distance between the receivers, also known as the receiver baseline.

To supplement TDOA estimation in determining the source location, the frequency difference of arrival is also sometimes used (FDOA) [3, 4, 12]. By using FDOA the requirement of having four sites for source localization can be relaxed. In addition, motion of the source, or motion of the receivers can be used to decrease the DOP and thus increase the resolution of localization.

3 TIMING ERRORS

The primary challenge for implementing localization techniques using the telemetry assets at RTS is the timing errors between the sites. The receivers and recorders themselves are not locked to a stable GPS based time/frequency reference which leads to large errors in the estimate of TDOA. However, the multi-channel recorders can record an IRIG time signal in an adjacent channel. An experiment was performed to show the timing error between channels of the recorder and the results are shown in Figure 2. Over a 10 second interval, the timing errors did not exceed 0.5 nanoseconds, which is well below the errors of multi-site GPS-based timing (10s of nanoseconds). Through post-processing the recorded signal referenced to the recorded IRIG signal, accurate TDOA measurements can be made using the assets currently located at RTS.

4 DATA COLLECTION

To prove out the utility of using telemetry assets for TDOA, a 2 MHz bandwidth signal visible to the telemetry sites on Kwajalein and Roi (80 km apart) was recorded for 10 seconds. The IRIG-B time code signal was recorded in the second channel of the recorders at each site. The SNR of the signal was greater than 15 dB. Over this 10 second interval, the TDOA error was bounded by 50 ns. It is expected that by

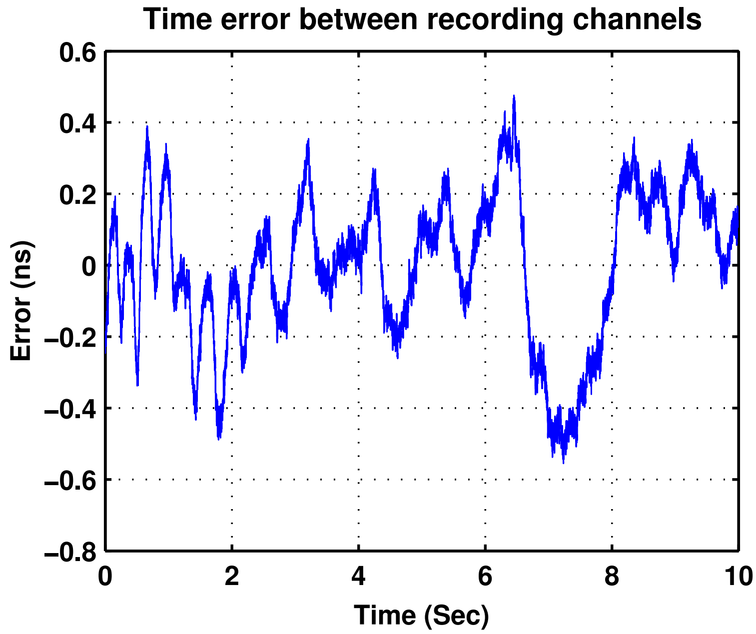

Figure 2: Timing error in nanoseconds between recording channels.

using the IRIG-G time-code, the accuracy of the timing bias will be able to be lowered. There are currently more experiments planned to analyze this error more in depth. These experiments include using the USAV Worthy (ship based telemetry asset) to explore different geometries (and thus differing DOP values). These experiments will be used to prove out the models for land-based localization and to accurately characterize the timing errors for ground sites that are typically used as telemetry receive sites.

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