A Description of QUALCOMM Automatic Satellite Position Reporting (QASPR®) for Mobile Communications

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ABSTRACT

Two-Satellite position reporting for mobile communications has been introduced into the OmniTRACS mobile satellite communication system. The first engineering demonstration in the USA occurred on 7-January-1990. This system significantly improves position reporting reliability and accuracy while simplifying the terminal's hardware. The positioning technique uses the original OmniTRACS TDMA timing signal formats in the forward and return link directions plus an auxiliary, low power forward link signal through a second satellite (Ranger) to derive distance values. The distance values are then converted into the mobile terminal's latitude and longitude in real time as messages or acknowledgments are received at the Network Management Center (NMC). A minor augmentation of the spread spectrum profile of the return link allowed the resolution of periodic ambiguities. The system also locates the two satellites in real time with fixed platforms in known locations using identical mobile terminal hardware. Specialized hardware in the satellite was not required, and the reference oscillator in the mobile hardware was held to the original specifications, 10 ppm long term, 100 ppb short term. New mobile terminal software provides for pointing the directional OmniTRACS antenna on a scheduled basis plus acquiring and tracking of the Ranger's Forward Link signal. Initial accuracies on the order of 1/4 mile have been realized uniformly throughout the USA using a satellite separation of 22 degrees and there are no dead zones, skywaves, or cycle slips as found in terrestrial systems like LORAN-C. An altitude map provides distance from the center of the earth. As of 24-January-1990, OmniTRACS in Europe is hosting the first operational implementation of the positioning system where a 9 degree satellite separation is exhibiting 2/3 mile random errors as expected. These accuracies are first results and will be improved in the near term by system tuning, wider baselines in the fixed-sites, a more precise topographic model as needed and finer timing in the forward and return signals.

INTRODUCTION

QASPR is the acronym for QUALCOMM's Automatic Satellite Position Reporting service in the OmniTRACS mobile communication system. This is QUALCOMM's preferred method of position reporting over LORAN-C because of its consistency, reliability, economy and accuracy. QASPR is controlled at the Hub by the Network Management Center (NMC) computer. The system uses a small amount of transponder capacity in a second satellite, called the Ranger, in a leased agreement similar to the messaging satellite's lease arrangements. The full time lease with back-up, allows protection against satellite failures, planned outages or government policies beyond QUALCOMM's control, contrary to our experience in working with external positioning systems like LORAN-C and GPS or highly specialized satellite systems. The OmniTRACS mission is to provide a complete two-way mobile communication service under one roof, with consistent, reliable messaging and positioning 24 hours a day, 365 days a year. QASPR now provides the internal position reporting component to that mission. QASPR also performs real-time satellite location tasks, further eliminating complexity and dependence on external sources for ephemeris data. Figure 2 shows the standard system block diagram of the OmniTRACS communication system.

PERFORMANCE

Since the first engineering demonstration in early January 1990, QASPR continually demonstrated reliable and accurate performance even while vulnerabilities in the system operation were identified and protections built in. QASPR has also been a integral part live OmniTRACS operations in Europe since January 24, 1990. QASPR will be available commercially in the USA beginning in May 1990.

Table 1 summarizes QASPR's positioning performance in CONUS using 12° satellite spacing. This is expected performance from the composite total of range errors, including 'one-shot' timing errors to the mobile unit and current satellite location errors. The actual system is currently performing at one-half this error due to a satellite separation of approximately 24°. Altitude model error accounts for an additional absolute positioning bias, typically less than 1/4 mile. Additional positioning faults result from matching solved positions to dated information in the map database. This has introduced a "position war" element into the system, which is usually decided in favor of the satellite-based vehicle solution. This was confirmed with independent GPS fixes. OmniTRACS easily supports reporting of external system data such as GPS and comparisons can be made simultaneously.

Table 1. Expected Vehicle Position Performance (position error in miles)

User Location	Vehicle Positioning Error at Earth Surface
San Diego	0.36
Pacific Northwest	0.35
North Midwest	0.32
New England	0.36
South Florida	0.37
South Texas	0.31
Satellite Separation = 12° (103°W and 91°W	

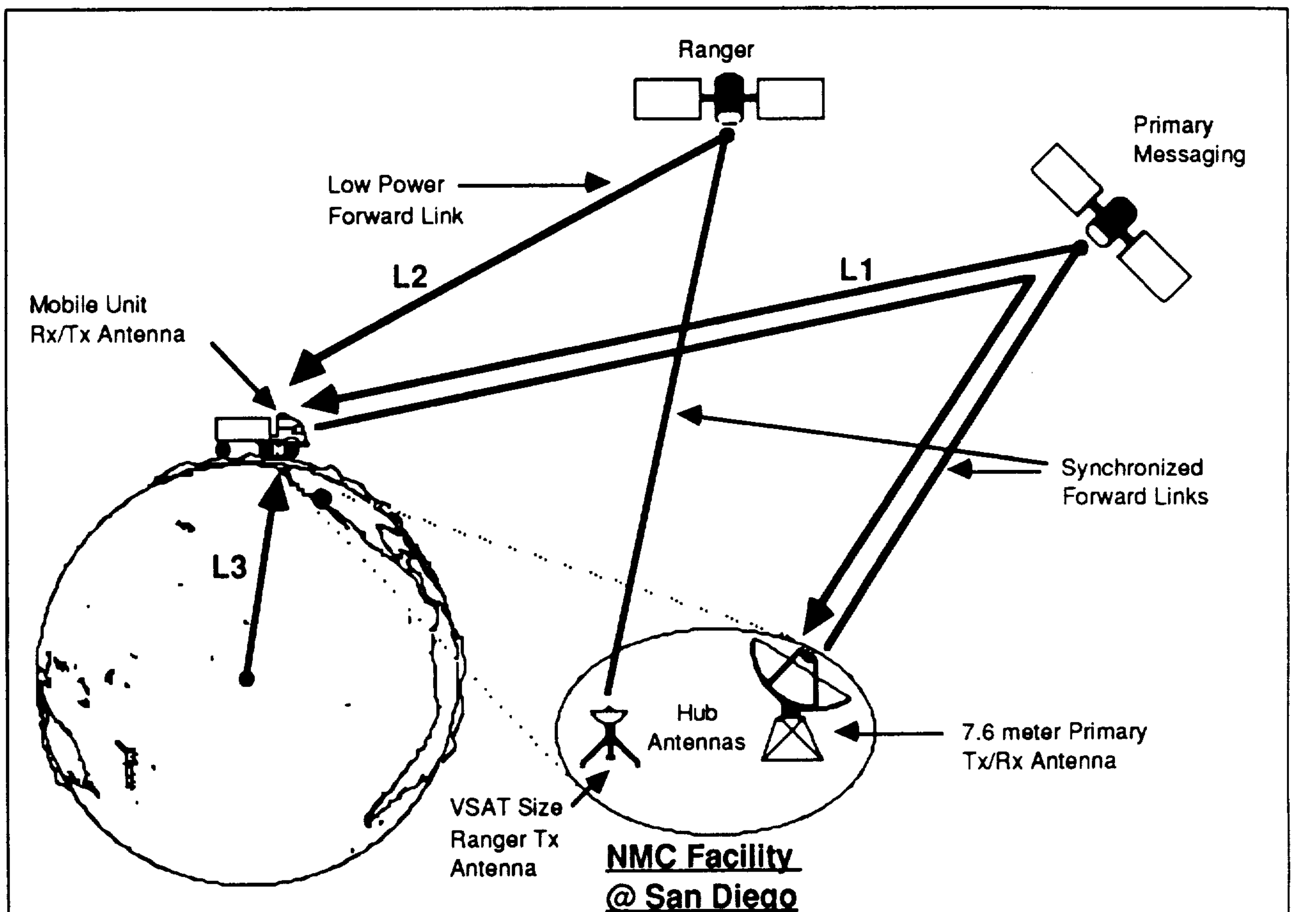

Figure 1. QASPR System Components

SYSTEM MECHANICS AND VEHICLE POSITIONING

The QASPR method uses two satellites, separated by 12° in orbital arc, to obtain positioning accuracy of 1/2 mile or better on the earth surface. Submicrosecond timing in the round-trip-delay, and a delta-time measured at the MCT (mobile communications terminal) provide all the inputs to compute the MCT position. The OmniTRACS Return Link Receivers (RLR) measure round trip delay during receipt of any return packet or acknowledgement. Delta-time is a derived value from the MCT comparing the reception of two synchronized Forward-Links. Vehicle position is achieved by multilateration from three known points in space.

Figure 1 highlights the system components involved in QASPR. Normal messaging is performed through the Primary satellite with Forward and Return links. Measuring and tracking round-trip-delay is a necessity for receiving return messages and therefore was already in place for the QASPR system, excepting finer resolution of the measurement. The Ranger uplink antenna provides a one-way, low power, Forward-Link signal (similar to the primary with no phase modulation) through the Ranger satellite. The period of frequency modulation in this identical copy of the primary waveform is long enough in time so that positional ambiguities do not arise when MCTs across the network compare the two signals. The MCT acquires the Ranger signal as necessary (see Figure 3) and reports the derived time difference with any return message or acknowledgements of forward messages. The NMC then processes the round-trip-delay and delta-time pair immediately as the return message is compiled for delivery to the customer. The two pieces of timing information define distances to the two satellites, L1 and L2 Figure 1, while the third distance, L3, is derived from a model of the earth's shape. A topographic model improves accuracy beyond what is achievable using only a smooth earth model.

Since QASPR incorporates and supports all of the previous methods of position reporting, a brief review of the position reporting mechanism using a sensor card, such as LORAN-C, will help clarify the QASPR technique. With a sensor card, MCT position is defined by an external navigation system. The sensor card communicates the position information directly to the main processor card in the MCT's Indoor Unit. Acknowledgements, position polls or mobile initiated messages use reserved packets to report the position information. The OmniTRACS system delivers the position and messages to the customer following their arrival through the satellite link. A single satellite transponder mix (two transponders) is used for communication to and from the MCT, even though there may be several transponders/satellites supporting a large community of users (10,000 or more). There is only one Forward-Link to the MCT and a Return-Link through the same satellite. Hence, in the original position reporting mode, the mobile's antenna seeks to stay focused toward one direction in the sky.

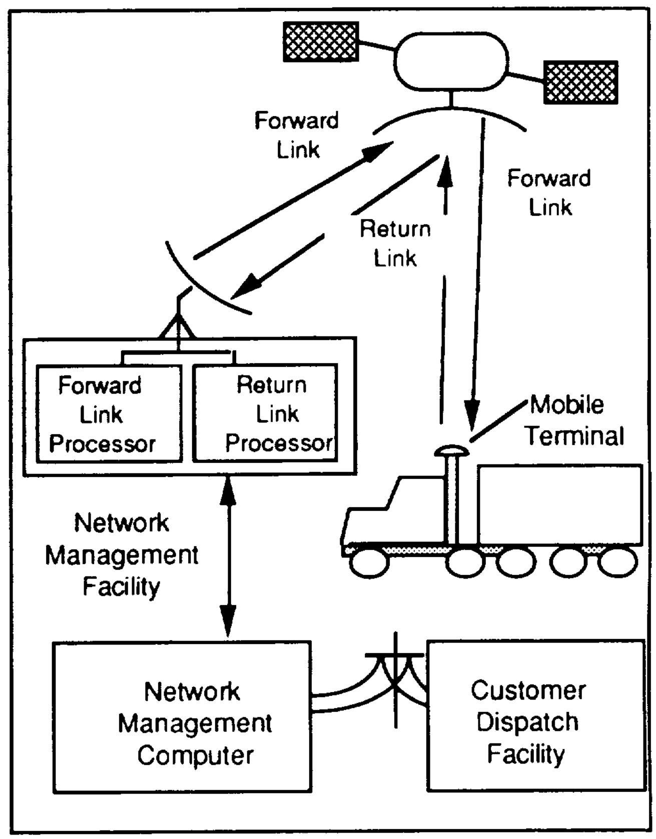

Figure 2. OmniTRACS Block Diagram

In the new QASPR technique, the same MCT antenna acquires and tracks two separate Forward Link signals from two different antenna pointing directions. Figure 3 shows the sequence of events. The additional Forward Link arrives from the Ranger satellite, 12° to 24° away from the primary messaging satellite depending on vehicle location in CONUS. Hence, the MCT must locate the Ranger at start up to expedite Ranger acquisitions when it's time to perform positioning tasks. Typically, the MCT performs Ranger acquisitions only infrequently as commanded by NMC control messages, or as required for scheduled position reporting intervals. Unsolicited position reports (mobile initiated) or specific events at the MCT, other than messaging, may trigger position reports, e.g., trailer disconnects or vehicle sensor data exceeds tolerance values. The position report packet now contains only delta-time information rather than a true position as in the previous case.

Fine time determination in round trip delay required a minor adjustment of the return link waveform to increase the code length in the spread spectrum component of the wave form. Round trip delay prediction is already necessary for return link messaging otherwise detection and demodulation of the message will not happen reliably. For QASPR, forcing exact alignment of the TDM frame boundaries with a longer spread spectrum code provided the precision required. It was also necessary to make the long code work with the original shorter codes received in the same radio hardware. Hence this avoids a major retrofit of software in the field.

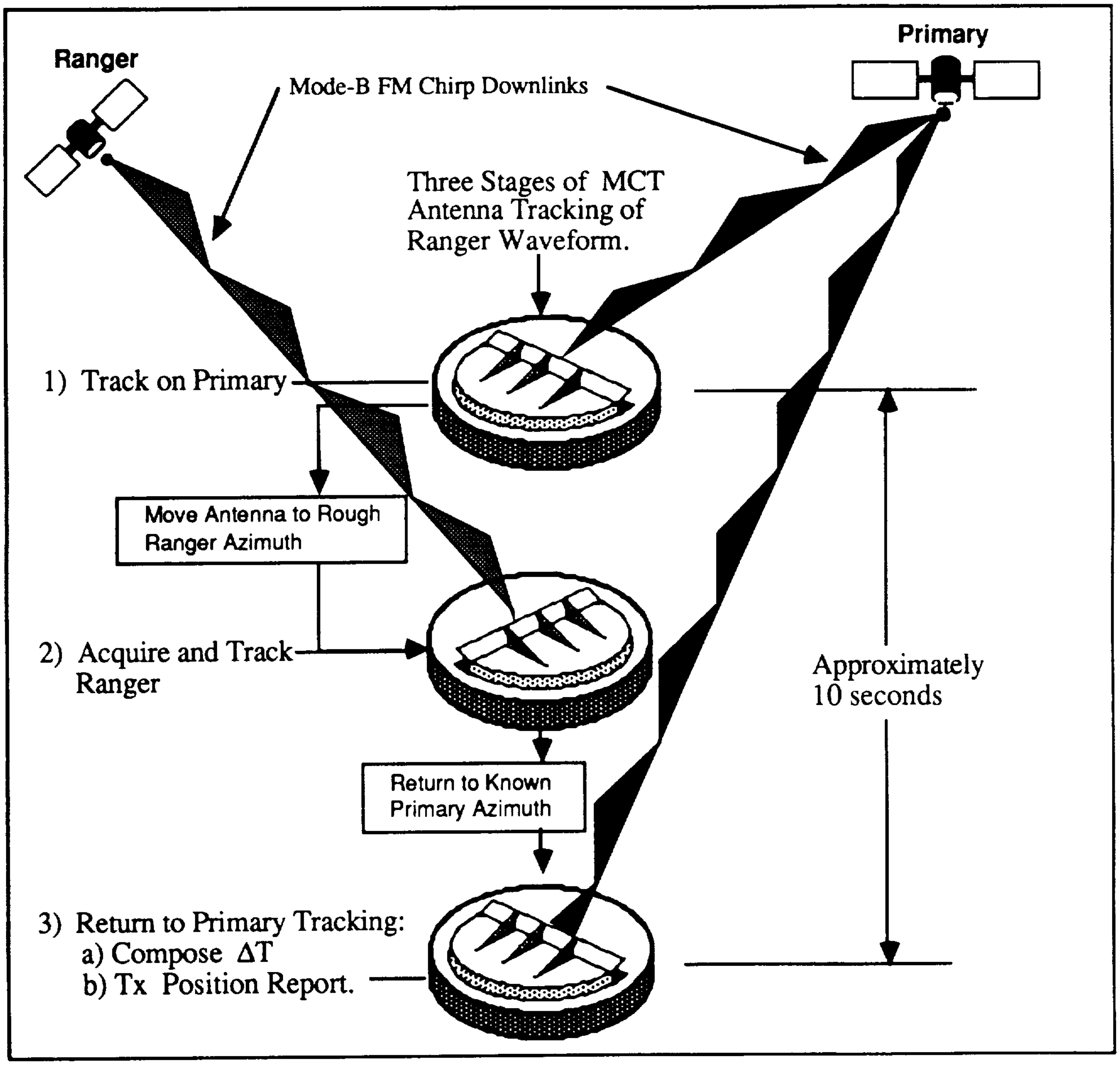

Figure 3. MCT Antenna and Signal Tracking Functions

RANGER SATELLITE FUNCTIONS

The major new MCT function is the determination of the delta-time (hop time offset) between two arriving waveforms: one from the Primary satellite and one from the Ranger satellite. The current MCT hardware cannot track these two signals in parallel because the MCT antenna must point at each satellite individually to provide sufficient signal gain. Therefore, the MCT timeshares receiving the waveform from both satellites to obtain the hop time offset.

As shown in Figure 3, the MCT antenna stops tracking the Primary's downlink, acquires and tracks Ranger hop timing, then returns to the Primary. Because of the importance of a precisely controlled time synch for Return Link message transmissions, the delta-time is measured in the last stage of the operations when the MCT antenna returns to the Primary. This allows the most precise determination of the delta-time because returning to Primary tracking from Ranger tracking is much shorter than the initial changeover to the Ranger signal acquisition and tracking. This includes time for antenna azimuth rotations for a total of about 10 seconds. So, upon return to the Primary, the delta-time is measured then prepared for the return message.

The mobile unit does not require new performance levels in mobile terminal clock accuracy. The mobile terminal clock has life time stability of better than 10 ppm however a short term stability of better than 100 ppb is the necessary specification for the QASPR technique to perform to the positioning accuracies mentioned earlier. This requirement again allowed the introduction of the QASPR into the OmniTRACS system without major hardware redesign. In total, the QASPR method has allowed for the elimination of the LORAN sensor card and its associated antenna hardware plus cabling and installation, and the addition of a small chip to implement a specialized long spread spectrum code for the return link.

SATELLITE POSITIONING TECHNIQUE

Although the primary function of QASPR is locating the MCTs, a reliable means of supporting that function with current and accurate satellite positions is necessary. Rather than obtain ephemerides from satellite controllers, satellite position is obtained through the reverse process of multilaterating the satellite from Fixed MCTs.

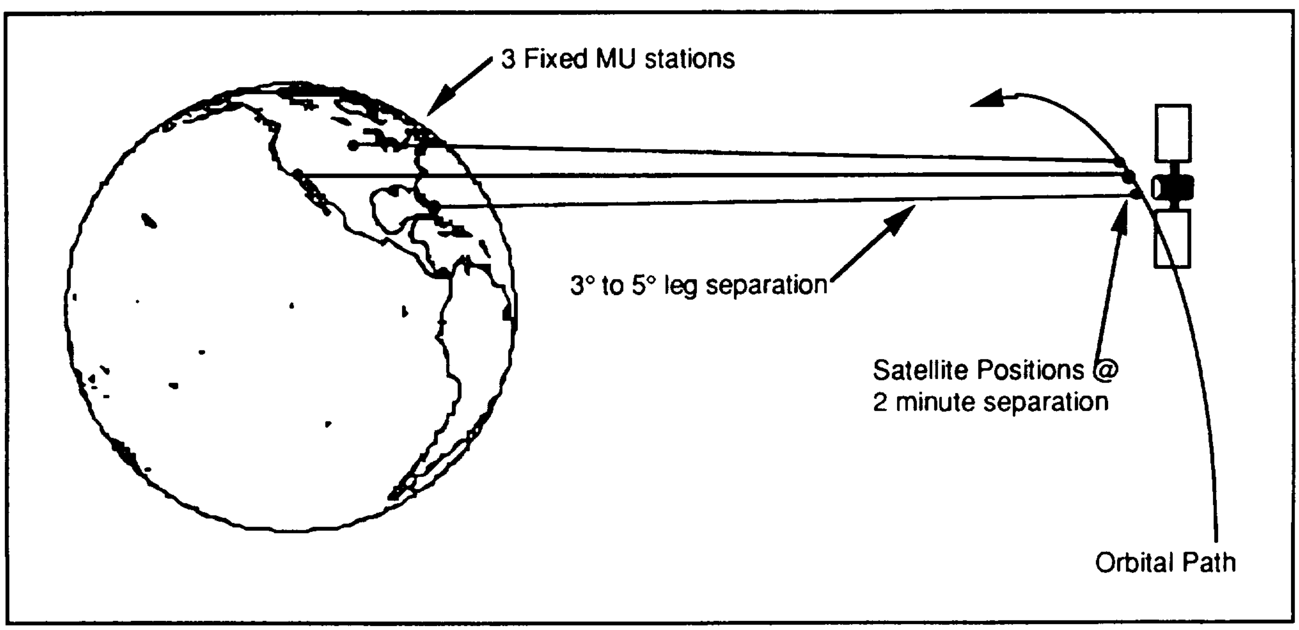

Figure 4. Satellite Positioning From Fixed Mobile Units

The alternative of obtaining a satellite ephemeris report from satellite owners implies a delayed version of what the satellite was doing perhaps weeks ago, and therefore will lack the required accuracy at current time. This approach also has the undesirable complexity of setting up and organizing an efficient interface with every possible satellite owner who could provide the transponder capacity. The ability to pinpoint the satellite in real time provides a robust positioning system which immediately follows any station keeping maneuvers and quickly adjusts to backup satellite configurations in the unlikely event of a satellite failure.

As shown in Figure 4, three or more fixed observing sites are used to determine the satellite positions in real-time. One is located with the Hub station. At least two others are placed in geometrically diverse locations to provide the most favorable conditions for the satellite position solutions. The station locations are defined from survey data and the lengths to the satellite are defined through the same process as vehicle positioning. Hence, Fixed Units are identical in form and function to the mobile equipment. The NMC makes the distinction regarding Fixed Units status.

FIXED UNIT ALLOCATION

Fixed MCTs are used to track and determine the positions of the two satellites in real time. There is complete identity in hardware and software used by the Fixed Units and the mobiles. This provides for a robust system that doesn't require two separate code versions and each group (mobiles and fixed) can act as continuous test beds for the other. The main difference within the system between them is how the NMC views them. Geographical location is important from the standpoint of positioning accuracy both for the satellites and the MCT location.

Figure 3 (near to scale for satellite distance to the earth) shows that the angular separation of directions from example Fixed Unit locations toward the satellite are very narrow even for the wide baselines provided by the CONUS geography. Therefore, Fixed Units must be spread out as far as possible, yet have antenna gains high enough to satisfy link budget requirements. For reliability, the five Fixed Unit locations shown in Figure 5 have been installed. Any three (including San Diego) of the five can provide primary location data; the spares provide backup if a primary fails or loses its link. The five fixed unit sites are currently operating near the following cities:

San Diego, CA
Minot, ND
Seattle, WA
Bangor, ME
Melbourne, FL

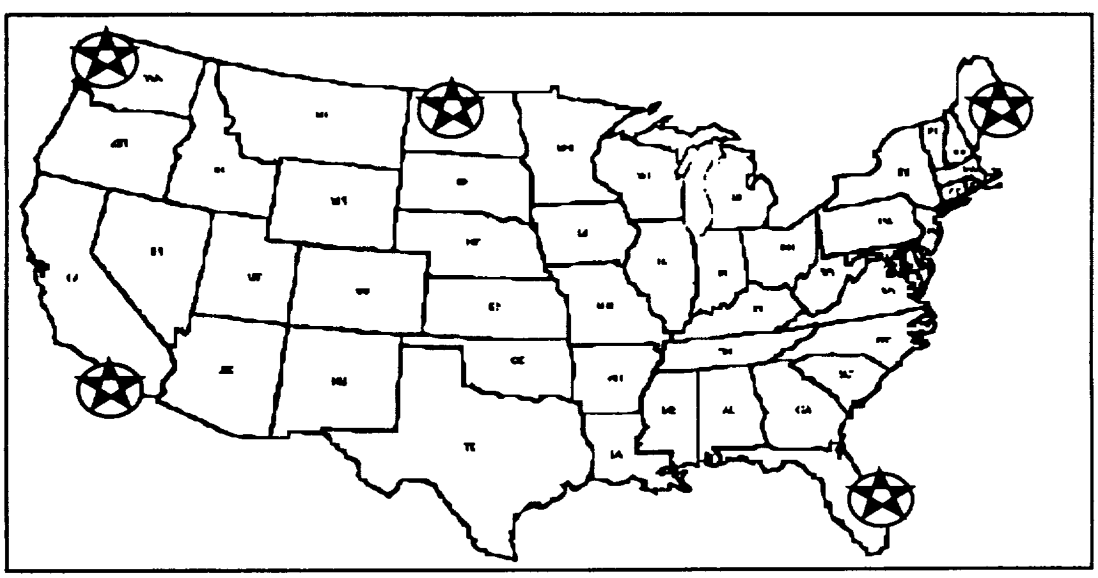

Figure 5. Fixed Unit Locations for CONUS