"THE GLOBAL RESCUE ALARM NET (GRAN): CONCEPT AND APPROACHES"

Clara L. Calise and CDR William R. Crawford,
Naval Air Test Center

ABSTRACT

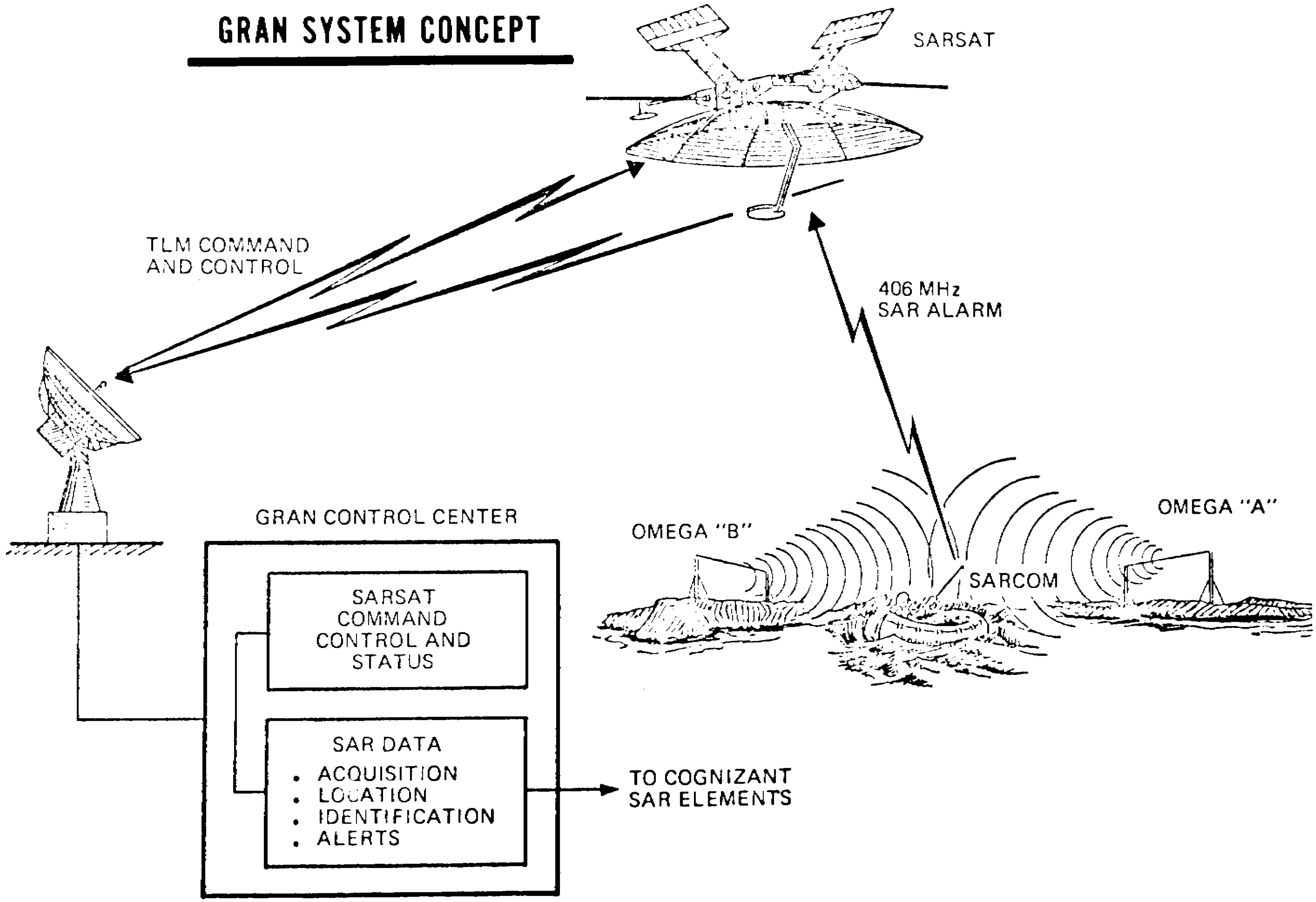
The GRAN Experiment is designed to prove a world-wide search and rescue (SAR) system utilizing Omega navigation system signals and geo-synchronous satellites. In order to develop a SAR system, the original NASA Omega Position Locating Equipment (OPLE) experiments have been expanded by the Naval Air Test Center, Patuxent River. Specifically, a fourth frequency (10.880 KHz) has been added experimentally to two Omega transmitters. This will increase line of position (LOP) ambiguities from 72 nautical miles to 360 nmi apart. Algorithms have been developed to resolve the 360 nmi ambiguities. During September and October 1974, two series of tests were conducted with Lincoln Experimental Satellite 6 (LES-6) to demonstrate the position locating potential of the four-frequency Omega concept. This paper presents the experiment design, results, and conclusions as they apply to the GRAN system.

INTRODUCTION

The Global Rescue Alarm Net (GRAN) was conceived as a worldwide search and rescue (SAR) system designed to provide real time distress alerting, identification and position location. The Omega Navigation System, presently under construction, will provide the information from which the distress site will be computed. The GRAN concept basically consists of portable battery powered search and rescue communicators (SARCOMs), appropriate frequency translators aboard earth synchronous satellites (SARSATs) , and a network of three or more ground receiving stations (SARCENs) (figure 1). The GRAN concept has been under development for five years. It evolved as an application of the OMEGA Position Location Experiment (OPLE) performed in 1967 by the NASA Goddard Space Flight Center. In this experiment, raw OMEGA navigation signals were received at a remote test site, upconverted in frequency to VHF, and retransmitted to a synchronous satellite (ATS-1 and 3) for relay to a ground processing center where a geographic position was computed. This experiment demonstrated that OMEGA data could be relayed without distortion. (reference 1).

In 1969, the U. S. Naval Air Test Center at Patuxent River, Maryland, performed an OPLE test using a low power (less than 5W EIRP) UHF uplink. This series of experiments demonstrated

GRAN SYSTEM CONCEPT



the feasibility of low power SARCOMs for retransmission of raw OMEGA data to earth-synchronous satellites (reference 8).

The OPLE experiments required a foreknowledge of the retransmission site to within 72 miles which is the ambiguous "lane" structure of the basic three frequency OMEGA system. For the GRAN application to search and rescue such foreknowledge cannot be assumed. Thus, it became necessary to devise a method for obtaining unambiguous position location from Omega in the absence of any foreknowledge of position.

Originally, OMEGA was proposed as a five frequency system with ambiguities arising approximately every 3600 miles. However, the U. S. Navy found little demand for the five frequency format. Instead, maritime users seemed willing to accept a three frequency system with its 72 mile ambiguities. This appeared to pose no special problems for ships which could "initialize" their Omega receivers at known geographic positions upon embarkation, and keep count of lanes as they slowly traversed the seas to their destinations. The U. S. Navy was satisfied to construct the less costly three frequency Omega system with its concommitant savings in individual receiver-processor units for shipboard use. It is probable that that decision underestimated the potential user population for OMEGA, particularly air traffic. As of this writing at least one U. S. carrier is testing Omega receivers as a potential replacement for some on board inertial platforms which have demonstrated very high cost of acquisition and maintenance. For instance, many Boeing 747 passenger jets carry three inertial platforms. These remarks are offered to justify the GRAN efforts to expand the present three frequency Omega system to a four frequency system. These efforts are well within the scope of the original Omega concept, and the applications for an expanded Omega satisfy an unforeseen demand for a worldwide, reliable, inexpensive area navigation system.

The GRAN concept utilizes a four frequency OMEGA format with an additional signal at 10.880 KHz. The additional frequency was selected by Dr. J. A. Pierce of Harvard University, and has been added to two Omega transmitters for test purposes. The addition of the fourth frequency increases the lane width from 72 nmi to approximately 360 nmi, and permits use of the maximum likelihood estimator technique for resolution of position within the larger lane.

The location of the SARCOM in distress is accomplished in three steps:

1. Reception from one of three geo-synchronous satellites determines which 1/3 of the earth's surface contains the distress site.

2. A coarse lane estimate is then determined by one of two methods:

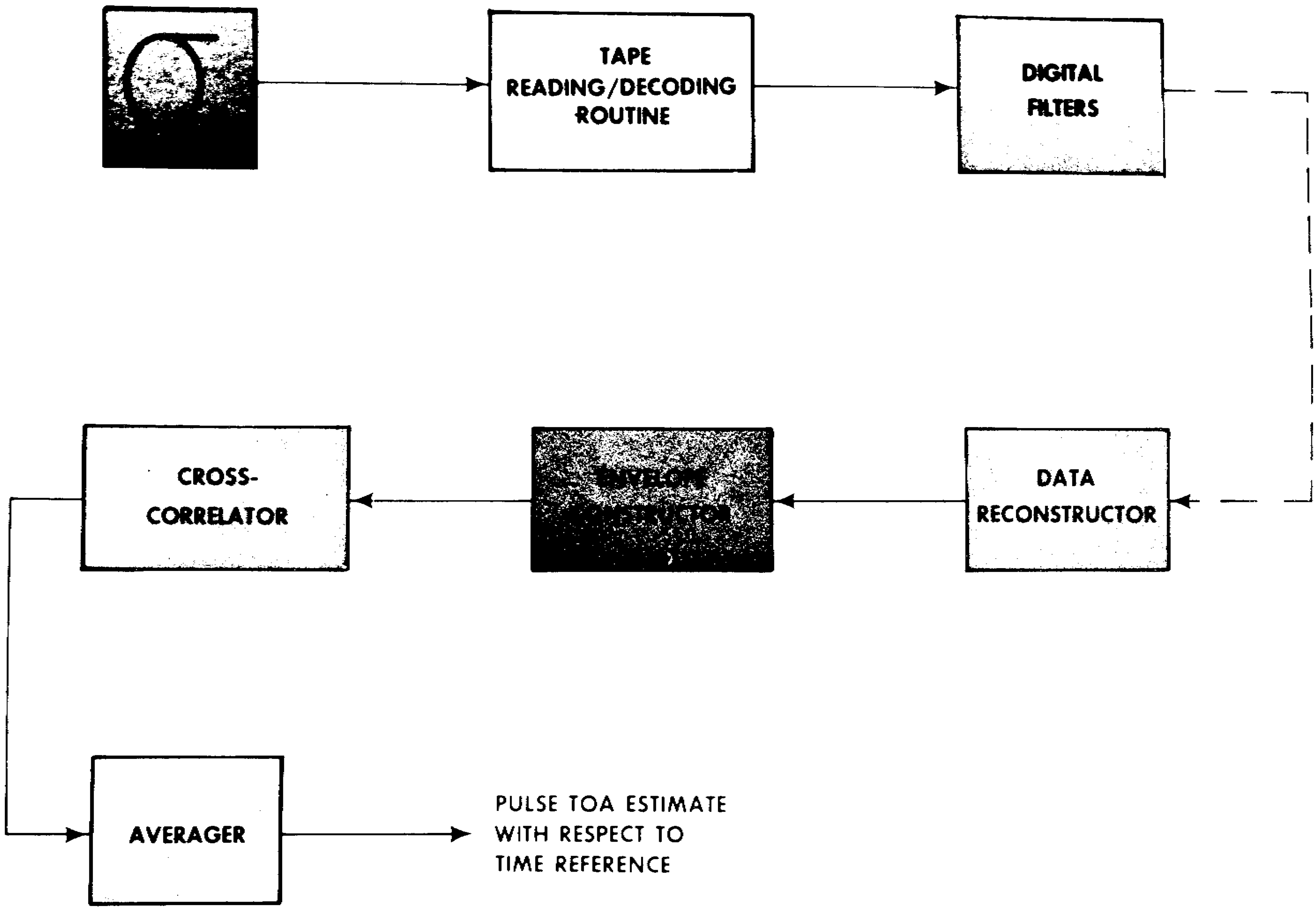
a. Signal-to-signal comparison of the relayed Omega can be used to reduce the area of interest to approximately 1000-2000 nmi.

b. Difference in time of arrival (TOA) of the Omega pulse envelope to determine a 360 nmi lane.

3. A maximum likelihood estimator, or walkup algorithm, refines this estimate to a correct 8 nmi lane and then further to a 1-2 nmi area.

The signal-to-signal comparison is based on the fact that the amplitude of very low frequency (VLF) signals decrease in strength approximately inversely with distance from the transmitter. A comparison of signals from Omega receivers potentially could be used as a coarse ranging function. Preliminary computations indicated an accuracy of $\pm$ 500 nmi at the baseline (between two Omega stations) and $\pm$ 750 nmi at the farthest location away from the baseline. Initial experiments to prove this concept were conducted by the Naval Air Test Center and Texas Instruments, Dallas, Texas, and are reported in reference (2). These experiments indicate that when the Omega transmitters are at full power (10 KW at 10.2 KHz) the signal-to-signal ratios may provide a coarse ranging function, but this function will not satisfy the GRAN requirements for a $\pm$ 180 nmi estimate to the increased lane width from the additional Omega frequency. The method of time of arrival (TOA) is more applicable to the GRAN needs than the signal-to-signal comparison.

The solution to determine the TOA of the pulse envelope can be approached in a number of ways. One approach that has been considered is outlined in figure 2. Four frequency Omega data from a recent test period has been stored on magnetic tape. This data would be digitally filtered to obtain the four individual Omega frequencies from each station. Reconstruction of the signal would then be accomplished using a third order hold technique. The reconstructed signal would then be sampled in quadrature and a technique developed by Mr. Eric Swanson of the Naval Electronics Laboratory Center (NELC), San Diego, (reference 3) would be used to construct a pulse envelope. The envelope for each frequency would then be cross correlated with a model of pulse rise and pulse decay to establish a relative time of arrival. The resulting pulse time of arrival estimate would then be averaged. The final result would be a TOA estimate with respect to the time reference, recorded on the data tapes, for each Omega station frequency. This approach will work only if amplitude information is available to determine the start of the signal. Since this amplitude



TIME OF ARRIVAL TECHNIQUE

information is not available in our present system configuration, another approach also is being considered.

Instead of detecting pulse TOA via amplitude, a means for frequency detection is being explored. This can be accomplished by:

1. Fast Fourier Transform

The application of this technique depends on the rise time of the pulse. If the signal is distorted enough in the rise time region by the automatic gain control (AGC) in the ground station, then the frequency may not be detected until the level period of the pulse, thus, diminishing the possible use of a fast fourier transform.

2. Coherent Detector

This detector provides a translation of the carrier frequency to direct current. It does not destroy phase information nor does it destroy amplitude information. The coherent detection is efficient especially when signal-to-noise ratios are low. It has the disadvantage that pulse rise times may be distorted.

3. Zero-Crossings Detector

Information contained in the zero-crossings of the waveform can be used to detect the presence of signal in noise. Of particular interest is the distance between the crossings of the waveform along the zero voltage axis. The variations in distance depend on whether signal plus noise is present, or noise alone. One possible form of this detection is a phase filter which is dependent on the frequency of the input signal and not its amplitude.

These are just a few of the possible avenues for solution of TOA estimation. Each is being evaluated to determine its adaptability to the needs of the GRAN system.

The final step in determining position location utilizes the maximum likelihood estimator derived by LCDR C. J. Waylan of the Naval Postgraduate School, Monterey, California (reference 6). His work was supported by the GRAN project and has been incorporated in the GRAN processing technique. This maximum likelihood estimator assumes that the correct major (360 nmi) lane has been identified. The estimation is then performed within this unambiguous lane by fixing the sum of the great circle distances from each of the Omega stations to the center of the lane of interest, and then varying one great circle distance over a range of values necessary to traverse all candidate lines of position (LOP) in the given lane.

This variation would be ± 180 nmi on the baseline between the two stations (figure 3). The likelihood function varies with great circle distance (figure 4), and the number of local maxima in the unambiguous lane is determined by the values of the function and the number of Omega frequencies. The cyclic nature of the function shows the necessity for lane ambiguity resolution and yields LOP estimates which fall into three categories:

1. Estimates within 1-2 nmi or less of the correct LOP.

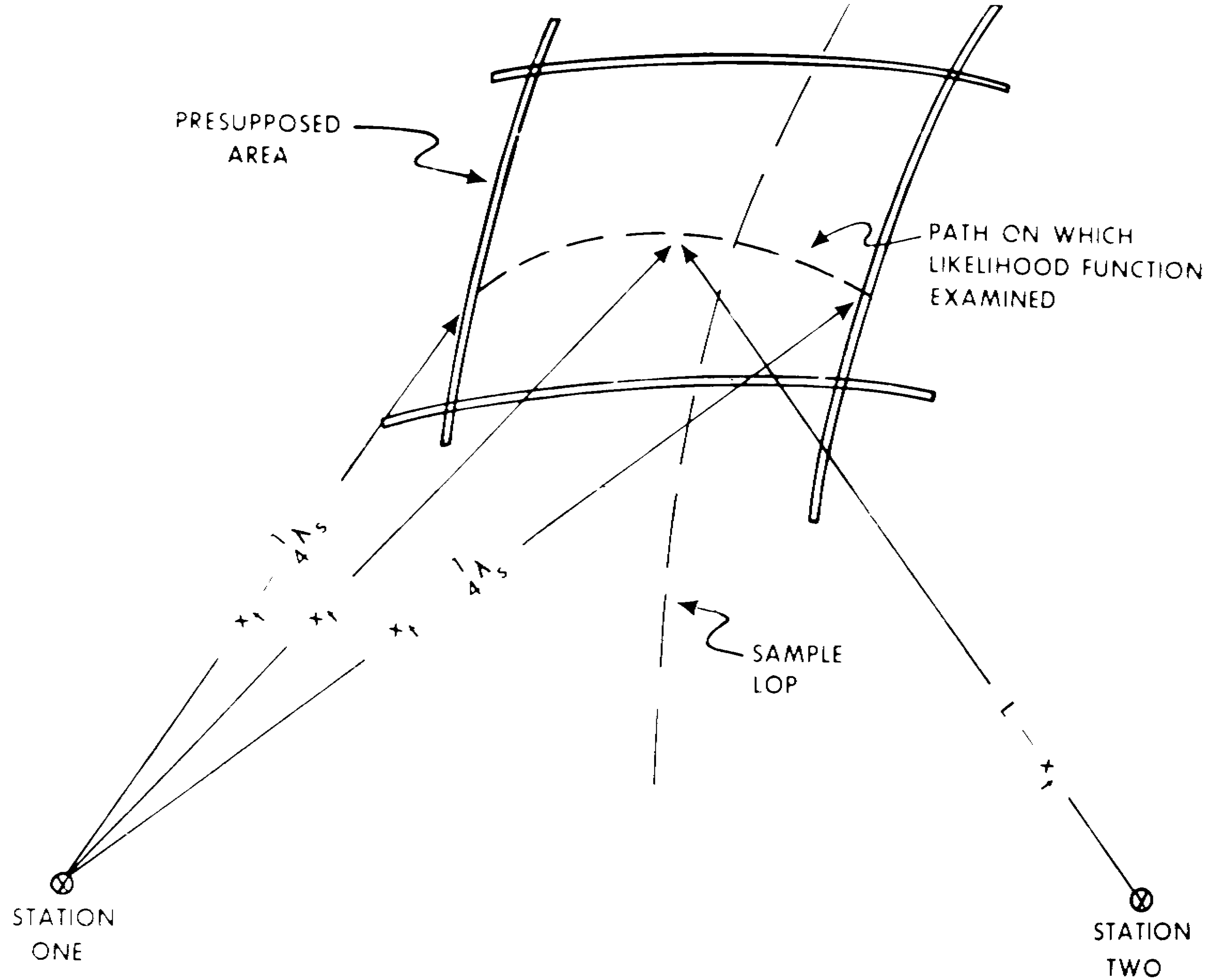
2. Estimates one half wavelength of the four Omega frequencies form the correct LOP (minor lane error).

3. Estimates farther from the correct LOP than the previous two (major lane error).

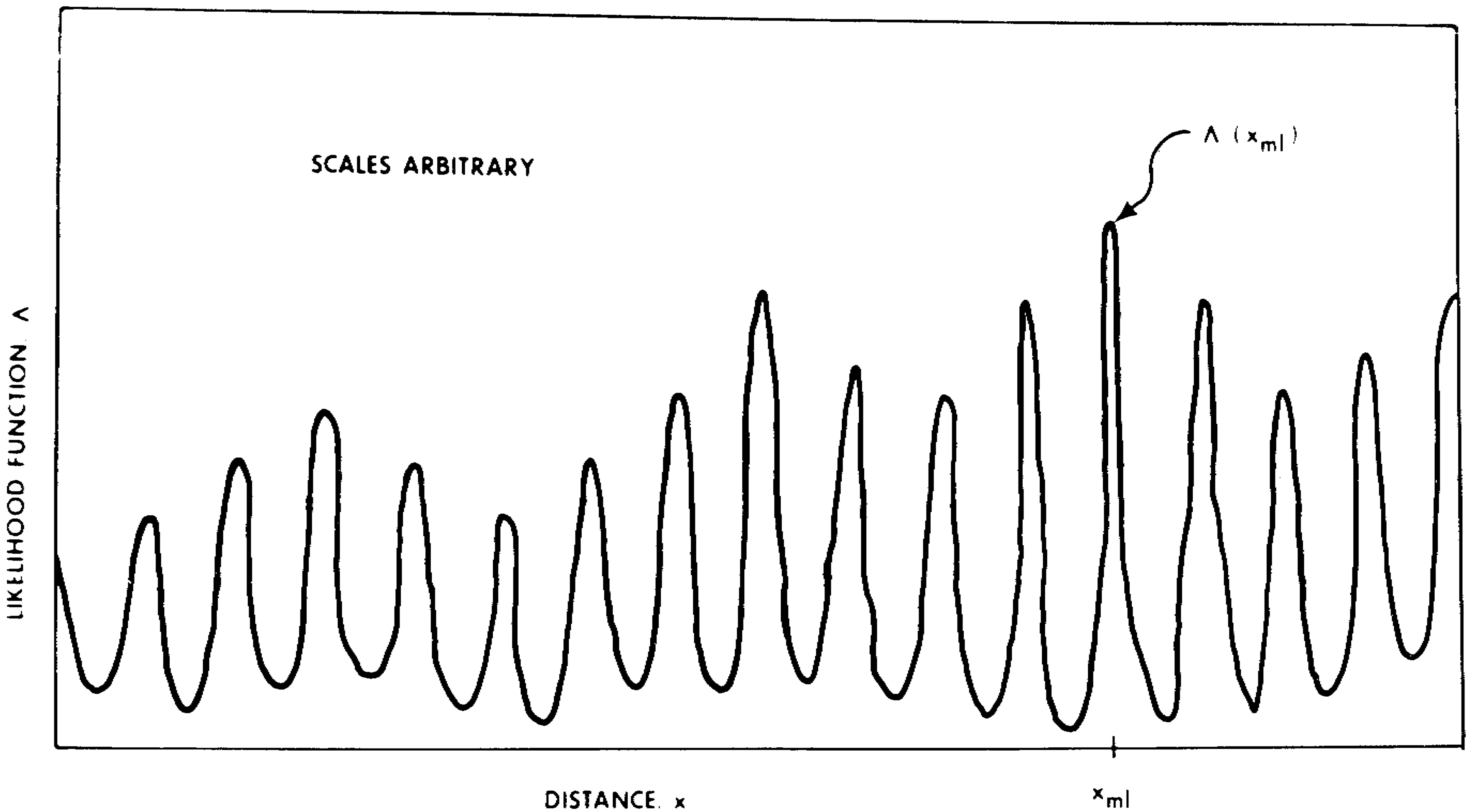
In the GRAN application at least three stations (two station pairs) would be used to obtain two LOP's. The intersection of these LOPs would yield a better position estimate of the SARCOM than the use of one LOP. The use of four stations (three station pairs) would pinpoint the 1-2 nmi distress area.

Data retransmission tests are presently being conducted at remote sites using LES-6 as the SARSAT link and two experimental four frequency Omega stations (Forestport and Trinidad). The data collected from each of the seven remote sites will be processed using both the maximum likelihood estimator and the walk-up technique developed by Professor Pierce (reference 4). Processing using the walk-up method, is being done at Texas Instruments, Inc., Dallas, Texas. These results will be compared with those of the maximum likelihood estimator as part of the analysis to help determine the adapatability of the estimator in the present configuration. Further analysis of the data will be done to determine the effect of using skywave correction factors in the calculations.

From the detailed analysis of the collected data it will be possible to determine the best position estimate, using the maximum likelihood estimator, based on a foreknowledge of the correct 360 nmi. Also, the best technique for arriving at a TOA estimate of this 360 mile lane in order to fit the GRAN system, will evolve from this collected data. Each of these pieces when added together, will equal a global search and rescue system with a position location ability of 1-2 nmi.



GEOMETRY FOR THE ESTIMATION PROBLEM



A TYPICAL LIKELIHOOD FUNCTION

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QUESTION AND ANSWER PERIOD

MR. CHI:

In the global rescue system, what is the philosophy in the first large determination of the location of the person to be rescued? How far do you have to know—distance wise? How do you locate it? Do you have several stations in the globe?

MS. CALISE:

There will be several SAR centers or, search and rescue centers, located in different parts of the world.

MR. CHI:

So what is the ambiguity resolution then you need?

MS. CALISE:

We need a 360 mile lane, which will be accomplished with the fourth frequency. The data that we've selected has shown that if we're using a 360 mile lane we can come within, say, one to two nautical miles, in determining the position—actually in this case, a line of position.

MR. CHI:

If there are numerous users with this equipment, then I believe you will need perhaps a system to reduce the distance in order to make quick rescue,

MS. CALISE:

The techniques that we'd use would take the 360 mile lane. And resolve it down to a position, if I understand you right.

MR. CHI:

How do you know which 360 mile lane?

CDR. CRAWFORD:

The philosophy is, at this point, to make some kind of trade-off between not having any knowledge of where you are and zeroing in within one or two miles.

First of all, you know which satellite so that puts you in an area—we're talking about a global system and we're also talking about getting a snapshot of OMEGA data. And this is really where the trade-off comes in, how long a snapshot do you really need.

So when Clara talked about having a computation time of three minutes, we're looking at still maintaining the three minute Opal retransmission time of the data. Of course, the longer you collect OMEGA data the better you're going to get a feeling for the phase.

So this puts some demands on the amount of power that you're going to carry in the battery in the SARCOM. Some studies by Eric Swanson at NELC, and he took the worse case conditions, indicated that with three frequencies his integration time, in order to get within the 72 mile lane, or really half of 72 mile lane, was something like between 30 and 45 minutes.

If you have four frequencies you have more data but with the fourth frequency you have the wider lane. In this case, on the base line you have 360 miles. Start looking at that integration time under worse case conditions and the integration time then goes down toward between 3 and 6 minutes.

This is also almost within the present window of Opal transmission time of 3 minutes of relaying of data. So, it's a tradeoff between lane width and integration time to be able to pick the correct length.

MR. CHI:

The reason I raised the question is that I believe the system is very good if the time of arrival of rescue is short. In any event, the philosophy of reducing to the positional location of the person in need of help, is the lapse of time which really is under consideration. Whether you go from 8,000 miles to 360 miles and go down to 72, but I obviously have to go to the direct point before you can help the person.

Now, what is the overall time regardless of how you would do it, and what is the philosophy of approaching it which would, actually should, allow one to reduce time to a minimum to yet the location of the person?

I can see there are difficult tradeoffs that you can use. The question is, how long do we have?

CDR. CRAWFORD:

I'm going to take a tangent here for a minute. Let's look at the OMEGA format problem which I'm certain is behind some of your comments here. One of the things we proposed, and Miss Calise made reference to it, is that a fourth frequency, a fourth navigational frequency, be transmitted, and of course the 1088 does give you with two frequencies differences 226 hertz lanes.

Another set of frequencies, let's say some timing frequencies, spaced by 250 hertz certainly is a solution to doing the lane identification, you know, the 72 mile lane identification in this philosophy of stepping down. Although, then there is a tradeoff, there's another tradeoff that we've looked at as far as the bandwidth of the system goes.

This means that we're looking at trying to fit say, 40 channels into the 100 kilohertz bandwidth which has already been assigned as a search and rescue frequency at 406.0 to 406.1 megahertz. We're looking at a 2-1/2 kilohertz bandwidth for each one of the retransmissions so this allows us to accommodate a large number of users.

So you can use a frequency in time diversity, let's say, because you won't have somebody coming on calling for and sending in an alarm at the same frequency at the same time. Now as far as time to get to a person, this is going to be primarily determined by the distance from the accident site and the nearest search and rescue force.

Now, we're looking at the total amount of processing time, the retransmission between the three minutes, let's say for the SARCOM, and a two minute processing time, total computer time, before you get an identification of who it is and where he is. So that this should take approximately five minutes.

Then you have to relay the information to the appropriate Coast Guard site or Air Force recovery site and then it's up to them to get there.

Does that answer your question as far as time goes? What we're really looking at is—can a small snapshot of OMEGA data, say three minutes long, collected from anywhere in the world, give us a unique location or, with some confidence, let's say a number of locations, but certainly not a complete coverage area that's maybe 300 miles square?

DR. WINKLER:

You have proposed a fourth OMEGA frequency which presumably will also be time shared. Could that be accomplished with a unique frequency at each station with just one which also should give you the same lane resolution, albeit at a small penalty?

The answer's yes?

CDR. CRAWFORD:

How many unique frequencies would you have on those? Are you talking about eight?

DR. WINKLER:

Yes. But of course these would not be audible in all segments which you have serviced. It was said in one from North Dakota for instance, cannot be received anywhere in the Indian Ocean, I think. So there would be no likelihood for the frequency to appear at that time.

On the other hand when you hear a certain one loud and strong you would know you have your fellow somewhere on North America. It would make identification much simpler, I think.