Author:
Craig McCartney, WA8DRZ

A paper submitted for the:
1996 ARRL and TAPR Digital Conference

Constructing a Worldwide HF Data Network

Problems and Solutions

Introduction

The construction of a data communications system presents a wide range of challenges to the network designer, depending upon the needs of the users. Choosing High Frequency (HF) radio as the communications medium adds significant challenges of its own – challenges that are known to radio amateurs and shortwave listeners worldwide.

This paper describes the design choices made by a commercial company, Globe Wireless, while setting up a Global Radio Network to serve the maritime industry. The technical choices were based, at least in part, on methods and practices first developed in the amateur radio community. Perhaps the explanations that follow will assist amateurs when faced with similar choices.

History

The maritime transportation community has always had a need to communicate with ships at sea for commercial reasons. In addition, sailors have felt an understandable need for reliable communications in the event of an emergency at sea. Since early in this century, HF radio signals have been used for both purposes. More recently, satellite systems have also carried this traffic, to the point that many of the installed radio systems have not been modernized.

In the past, every seagoing nation of the world established its own Public Coast Station to serve the needs of ships in its vicinity, as well as that nation's fleet while it was on the high seas. This led to the development of, and competition between, large, high powered HF radio stations that attempted to cover the globe from a single location. About fifteen years ago, the first communications satellite to serve ships at sea was launched. Since that time the use of HF radio by ships has declined in favor of satellite systems. Today, nearly half of the world's fleet is equipped with an Inmarsat system, and that percentage is increasing.

Today, public coast stations offer two basic messaging services, radiotelegraph (Morse Code) and radio telex (using SITOR protocol). Some public coast stations also offer voice services but that is an entirely different subject and beyond the scope of this paper,

Morse Code is still the primary means of communication for a surprisingly large number of ships at sea. We estimate that 10,000 ships still communicate exclusively via Morse Code. The use of Morse Code by ships at sea is declining and will cease sometime after the full implementation of the Global Maritime Distress and Safety System (GMDSS) in February 1999. This will happen because GMDSS mandates the use of modern, automatic communications systems and eliminates the requirement for an experienced radio officer (RO) aboard ship.

Radio telex is the other means of message communication with ships using HF radio. It was originally developed to link shore based Telex machines with those aboard ship. The mechanical machines of the past have given way to personal computers, but the messages are still limited to the upper case only character set of the SITOR protocol as defined in CCIR Recommendations 476-4 and 625. This mode is nearly identical to AmTOR as used by hams.

Four years ago coastal radio station KFS in California was fighting a losing battle trying to compete with the Inmarsat satellite network using CW and SITOR. A single HF station, no matter how powerful, can not offer the global coverage of the four Inmarsat geo-stationary satellites. In order to compete with the Inmarsat system it was obvious that major changes had to be made. A new service was required that had to be equivalent, and less expensive than Inmarsat. HF radio, using the ionosphere, is certainly is less expensive than satellites with their high construction and launching costs. How, then to make the new service equivalent in other respects?

Requirements

The first step was to define the next generation HF radio maritime communications service. After considerable market research, these basic requirements were identified:

1. Ease of Use The system had to easily usable by the typical bridge officer aboard a ship at sea. No technical knowledge of radio or propagation could be assumed. Shipboard software must be as easy to use as a typical office Email interface – Lotus cc:Mail and Microsoft Mail, for example. This dictated a fully automatic system in respect to the actual sending and receiving of messages and the control of the radio equipment. The program aboard ship had to maintain close contact, via HF radio, with a central computer system ashore so that messages could be exchanged in either direction in a matter of minutes.

2. **High Capacity** The system had to accommodate the complete printable ASCII character set for messages, and allow any binary data – spreadsheets, word-processing documents or pictures, for example – to be included as an attached file. Because of

the increased traffic load that this would generate, a throughput of several times the six characters per second maximum of SITOR was essential. A new, interoperable, data communications protocol and modem were needed. The system chosen should allow high speed data transmission within the bandwidth of a standard ITU Narrow Band Direct Printing (NBDP) channel. The modem must also be able to utilize the traditional SITOR protocol on these same channels.

3. **Global Coverage & Twenty-Four Hour Availability** A ship had to be able to send and receive messages no matter where it was located and at any time of day or night. It was determined that a Global Radio Network of HF stations could meet this goal. The stations in this network should be located so as to provide twenty-four hour coverage to any point on the oceans of the world. Locations were chosen using a "Cellular" model so that the resultant overlapping coverage would provide a level of redundancy to the network. Every location has transmitters and receivers on several frequency bands to overcome changes in coverage due to daily and seasonal shifts in ionospheric propagation.

Design Challenges

This design goal – round-the-clock, automated, electronic mail connectivity with ships sailing on any ocean of the world – required using modern technical solutions to replace the traditional methods of the maritime radio industry. Significant technical problems were identified:

- **Radio Path Selection** The choice of which one of several available shore stations to call, and on what frequency to make the call, was a significant technical problem to solve. This choice would need to be made automatically by the shipboard software at any time of day or night, from any position on the world's oceans and in spite of changing propagation and interference.

- **Modulation Protocol** A modern modulation method and modem that could coexist with the current SITOR system was needed. Frequency assignments in the Narrow Band Direct Printing (NBDP) portions of the maritime bands are on 500 Hertz channel centers, with no interference allowed to adjacent channels. So a severe limit on occupied bandwidth and a requirement for highly efficient use of the available spectrum were added to the list.

- **Network Interconnection** A reliable, yet affordable means was needed to back-haul messages and control information from the various coastal radio sites to the network control center, to be located in California.

Solutions Considered

Our procedure to finding solutions to the above problems was straightforward. Using brainstorming techniques, we identified any and all possible solutions that we could think of. Then each technique was examined for practicality given our needs. A small number from the original list of ideas were selected for further detailed evaluation. Described below are the results of those evaluations.

Radio Path Selection

To provide automatic radio path selection four methods, taken from military, commercial and amateur practice, were evaluated.

Automatic Link Establishment (ALE), as defined in MIL STD-188-141A, was considered in detail. Unfortunately this system suffers from high equipment costs and wasted spectrum capacity when pinging the various channels available.

Theoretical Prediction software programs from the simple MINIMUF algorithm to the complex IONCAP system were evaluated. Even given that solar data could be provided to every ship at sea in a timely manner, the accuracy of these prediction systems was just not up to our needs. Knowing that a particular ship would have an 80% chance of a useable path to a particular coast station during a 2 hour period was not nearly good enough. We needed the system to know how to move a message NOW.

The **Chirpsounder** system, developed many years ago for the US military by BR Communications was investigated. Chirp transmitters were installed at several public coast stations and the information from associated receivers evaluated. This system is very good at measuring the ionosphere in great detail, but provided much more information than we needed. It would often tell us that the FOT for a particular path was between 9 and 10 Megahertz. That information is not too useful to a maritime service provider whose nearest allocations were at either 8 or 12 Megahertz. In addition, we were concerned about interference to the safety of life at sea (SOLAS) channels in the maritime bands potentially caused by the use of a large number of chirp transmitters.

So we went back to the basics. A system that eventually was called **Channel Sounding** had been in practical use since the early days of maritime communications. It relied on the tradition that all CW coast stations, when not occupied with traffic, broadcast a “CQ wheel” on every available channel. This allowed the shipboard RO to simply tune his receiver until he found a coast station on a frequency that he could hear clearly before calling and sending his message. This seemed like a clean and simple solution to the problem, but we had to make it automatic.

Choosing a modulation protocol

High speed, single tone modems using phase modulation were available from several manufacturers. They had originally been developed for military applications (MIL STD-188-l 1 OA for instance) so size and cost were not considered important design requirements. When evaluated, these systems performed fairly well, but we needed a modem that could be had for hundreds, not thousands, of dollars.

Amateurs had developed several new systems over the years, and all available were evaluated in our search. We considered using another case shift character to add lower letters case to SITOR, as both G3PLX and AEA had done with **AmTOR**, but that still did not solve the binary file problem. **AX.25** Packet protocol was considered because it can transfer eight bit data. This protocol, which performs very well on stable VHF circuits, falls apart very quickly on any but the very best HF path due to a high symbol rate. **PacTOR** showed initial promise but had two flaws. It can only transmit 7 bit data, and in the 200 baud mode it occupies considerably more than the 500 Hertz NBDP channel bandwidth. Both **PacTOR II,** an extension of PacTOR, and **G-TOR,** which uses Golay encoding, were still in development and not ready for inclusion in our testing. In retrospect it appears that both of these modes also suffer the problem of excessive occupied bandwidth.

CLOVER-IT, invented by Ray Petit, a ham, came very near to what we were looking for. It can transmit binary files – and at high speeds compared to SITOR. It performs well under poor HF conditions- A modem that included SITOR (actually AmTOR) on the same board, the HAL Communications PCI-4000, was available at a very reasonable cost. There was just one problem – the occupied bandwidth of CLOVER-II is exactly 500 Hertz, albeit with very clean skirts. Trying to stuff that signal into a 500 Hertz channel with no room for a little radio drift or calibration error seemed too much to risk. "Close, *but no cigar,"* we thought

An affordable back-haul method

We actually considered using HF radio to connect our network sites with the central computer system, but rejected the idea fairly quickly. We needed to use the available spectrum efficiently and using radio for the back-haul wasted it on a two-to-one ratio. Also, the number of transmitters, receivers and antennas would increase by as much as two-to-one.

An obvious solution was to use dedicated landline circuits, rented from the local telephone company. In the US this actually method works fairly well due to the competitive telecommunications environment. However it seemed that every time another international border was crossed the price went up, and up, and up.

We investigated setting up our own satellite (VSAT) network. The costs of this approach exceeded those of dedicated landline circuits. Besides, we were trying to compete with satellite on the ship-to-shore side.

Current amateur Packet radio BBS forwarding practice included using both dial-up landline and Internet Mail systems as an alternative to on-the-air exchange of messages. Could one of these ideas be used?

Solutions Adopted

For radio path selection, we built upon tradition. We had already planned to use ITU NBDP channels where, the 'CQ wheels' of Morse had given birth to the transmission of a digital 'free signal' on channels not in use. We decided to use this signal as a beacon. A scanning technique, then in use by APLink and WinLink sysops on the ham bands, was adopted. We programmed the shipboard software to scan the ship's receiver through all the available network channels, evaluating any 'free signal' it found. This information was saved in a data base. The result was that the optimum path to the shore was always immediately available. This system came to be called **Automatic Channel Sounding.**

We were wrong about not finding the ideal modulation protocol for our needs. After just a few days of sitting in the lush corn fields of Southern Illinois and thinking about it, the engineers at HAL Communications called us back. They had found a way to scale the original CLOVER protocol down just a bit and had invented a mode they called **CLOVER-400** just for us. The throughput remained almost the same and the reduced occupied bandwidth of 400 Hertz left a comfortable guard band of 50 Hertz on each side. This meant that it could meet ITU requirements for use on maritime Narrow Band Direct Printing (NBDP) channels.

Within the US we found that we could indeed afford dedicated landlines to connect our network for station control and message exchange. For overseas locations our own software team came up with a proprietary packet protocol scheme that is used over the Internet backbone. We have implemented this now on several stations where a dedicated line to the local Internet provider is affordable and reliable. Back-up systems for these locations include either dial-up modems or X.25 packet switch connections as available. Again, an idea from amateur radio was adopted for our needs.

Summary

Twelve HF stations, located in eight countries will comprise the Global Radio Network by the end of this year. A map that gives an idea of the coverage is included in Figure 2. Six coastal radio stations – KEJ in Hawaii, KFS in California, SAB in Sweden, VCT in Newfoundland, WNU in Louisiana and ZLA in New Zealand – are now on the air and operating as part of the network. Four network nodes are under construction – A9M in Bahrain, 8P0 in Barbados, VIP in Perth, ZSC in South Africa. Both A9M and VIP will be on the air very shortly with 8P0 and ZSC soon following. Two more stations, KPH in San Francisco & WCC in Massachusetts are awaiting FCC approval of the license transfer from MCI before being added to the network. Discussions for additional nodes are underway in Asia, Europe and South America.

All of the stations in the network are capable of both SITOR and **CLOVER-400** operation on the NBDP channels in use. Ships from several worldwide fleets are using our system, called GlobeEmail daily. They send and receive electronic mail messages and attached files using shore systems such as MCI Mail, cc:Mail, Microsoft Mail and the Internet.

The Global Radio Network is currently connected to the central computers in California using a combination of dedicated leased lines, shared leased lines, Internet packets and X.25 packets. Plans call for phasing out many of the dedicated lines in favor of Internet where available, and ATM or X.25 otherwise.

Future Enhancements

Engineers at Globe Wireless and HAL Communications have developed an extension of the CLOVER protocol. Called CLOVER-2000 because it occupies 2,000 hertz of bandwidth, it offers a five-fold increase in throughput over the CLOVER-400 mode now in use on NBDP channels, On-air tests have confirmed this level of performance.

Globe Wireless plans to implement CLOVER-2000 in very spectrum efficient manner. The details are still under development, but consider that CLOVER-2000 alone is not able to fully utilize the spectrum of a 2.8 kilohertz maritime facsimile or voice channel.

Beyond everything above, HAL’s DSP engineers have identified changes to both types of CLOVER modulation that have the potential of doubling the throughput again, without increasing the occupied bandwidth. Those guys in Urbana sure don’t stand still!

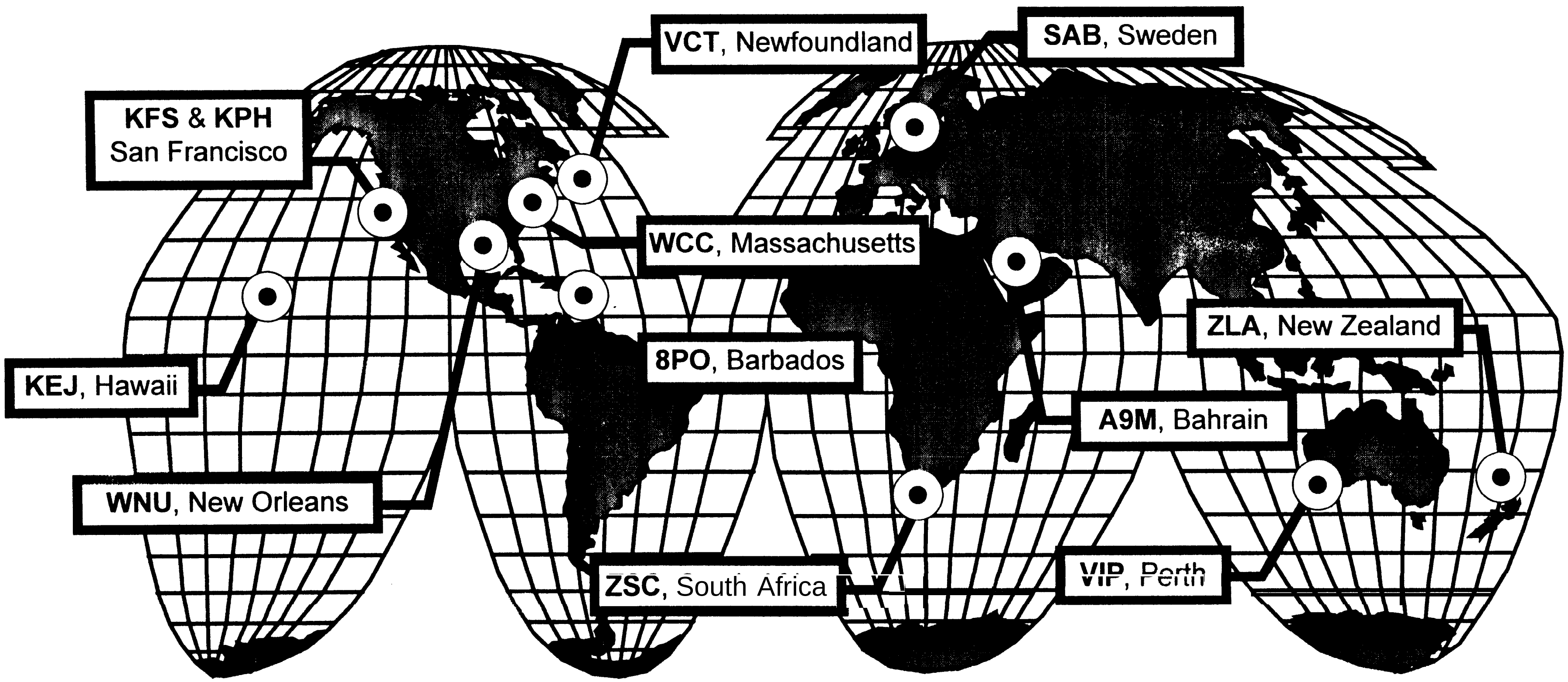

Figure 1 The Global Radio Network