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Communications Technologies for Automated Dependent Surveillance

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1. Abstract

In this work a new concept known as Automated Dependent Surveillance or ADS is introduced. ADS is an improvement to current Vessel Traffic Service (VTS) operations. One of the enabling technologies for the ADS concept is the advent of differential GPS. The other necessary requirement is a communications link between the vessel and the Vessel Traffic Center (VTC). That is the subject of this paper. Existing communications technologies were evaluated and the three most promising selected for further testing: Advanced Mobile Phone Service (AMPS) Cellular, VHF-FM Digital Selective Calling (DSC), and Newcomb L-Band Satellite. The communications methods were evaluated according to the following criteria: coverage area, reliability, integrity, reporting interval, latency, and cost. Although all three communications methods worked, only DSC and Newcomb Satellite are well-suited for ADS implementation.

2. Introduction.

In 1991 the U.S. Coast Guard Research and Development Center (R & D Center) at Avery Point in Groton, CT was assigned the task of developing a satellite based surveillance system. This system was to enhance and improve the Vessel Traffic Service (VTS) used to monitor vessel movements within a given area. The goal was to improve oil pollution prevention and the safety of vessel movement in coastal and inland waterway regions by significantly reducing the prospect of collisions or vessel groundings. The task was developed as a provision of the "Oil Pollution Research and Technology Plan" authored in 1990 by the U.S. Interagency Coordinating Committee on oil pollution research.

The efforts by the R & D Center have focused on the use of state-of-the-art Global Positioning System satellite technology commonly referred to as GPS, particularly on the use of the R & D Center developed **differential** GPS system or DGPS. This extension to GPS uses a reference station at a known location to calculate the range error in the satellite signals for all satellites in view which are then used as correction factors. The Coast Guard is currently implementing the DGPS system along the entire U.S. coastline using existing MF radiobeacons to broadcast the correction data. This system is slated to be operational in January 1996 [1].

DGPS allows a vessel's position to be fixed to within 10 m or less and also provides a very precise course and speed determination [2]. The use of DGPS has led to the development of a VTS technology known as ADS. It is a highly capable system that is proving to be a vital supplement to the conventional radar, video and voice monitoring systems. The ADS testing described in this paper was conducted primarily in the Narragansett Bay, RI area using two vessels as test platforms: the *Vista Jubilee*, and the *USCGC Towline*.

3. ADS Description.

ADS is Automated Dependent Surveillance:

- **Automated**, because equipment aboard the vessel determines all data and transmits it digitally to the Vessel Traffic Center (VTC) without human involvement.
- **Dependent**, because the system requires that each participating vessel purchase and install equipment capable of transmitting quality data to the VTC.
- **Surveillance**, because the data provided by all participating vessels will be used to monitor the course, speed, and position of each vessel relative to each other, the shore, obstructions, shallow waters and navigational aids.

ADS is a new concept leading towards a "Voiceless VTS", where information is transferred in a digital format between the maritime community and the VTS. This digital information flow reduces reliance on traditional voice and radar reports and improves the gathering, processing and distribution of time critical information.

As part of the testing, a standard ADS data record was developed. This included vessel information of interest to the VTC such as position, time of position, course, and speed.

4. Communications Methods Tested.

The R & D Center has been studying the communications technologies necessary and commercially available to enable the flow of digital information from vessels underway to the shoreside VTC. Candidate technologies were evaluated and assessed as to their ability to satisfy ADS requirements. As a result, three communication systems: AMPS Cellular, Digital Selective Calling (DSC), and Newcomb L-band satellite, were selected for further test and evaluation.

In order to compare and contrast the different communications systems, each with their own formats and protocols, a "VTS Gateway" was developed to integrate them. The VTS Gateway consisted of Link Control computers to control each communications system and a data multiplexor. This gateway concept is described in more detail in Section 5.

The opinions or assertions contained herein are the private ones of the author and are not to be construed as official or reflecting the views of the Commandant or the Coast Guard at large.

4.1 AMPS Cellular.

AMPS Cellular is the standard analog cellular system. Cellular coverage in Rhode Island is provided by Nynex Mobile (B-side carrier) and Bell Atlantic Mobile (A-side). Commercially available coverage diagrams indicate that the state has good cellular coverage throughout the Narragansett Bay area [3].

4.1.1 Cellular System Operation.

The shipboard communications equipment consisted of a combined cellular phone/modem connected to a standard marine cellular antenna (3 dB gain omnidirectional whip). Calls were handled by the closest cellular site where they were then connected through the Mobile Telephone Switching Office (MTSO) to the Public Switched Telephone Network (PSTN). It was desired to keep the shipboard installation as simple as possible (no computer controller). In order to do this, the connection was initiated from the VTS Gateway. This enabled the shipboard equipment to function as a remote sensor and provide ADS data to the VTS Gateway only during test periods. Once the connection was established, all information flowed from the vessel through the PSTN to the VTS Gateway.

The ADS data was provided by the differential GPS receiver in NMEA 183 version 2 format. It was transferred from the DGPS receiver to the cellular phone/modem via an RS-232 line at 4800 bps. From the cellular phone/modem the data was transmitted over a cellular channel using the MNP-10 protocol to the cell site and from there over landlines (PSTN) to the VTS Gateway. This information flow is illustrated in Figure 4-1 below.

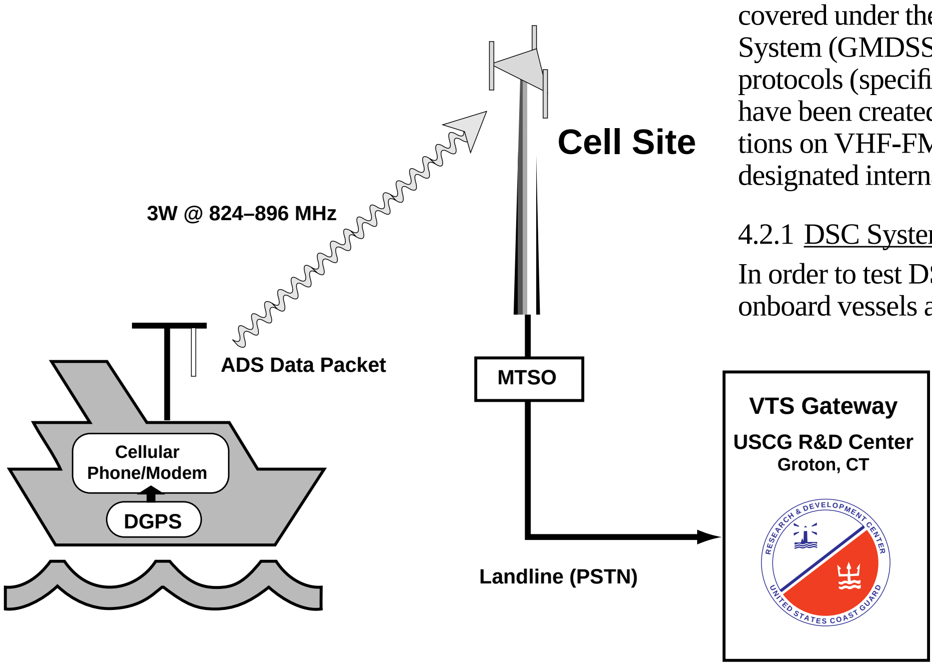

Figure 4-1 Cellular System Diagram. Flow of ADS data from ship to shore via the cellular data link.

4.1.2 Cellular Testing Results.

The *Vista Jubilee* was tracked for over 100 hours which provided a considerable amount of data. Since the cellular phone\modem established a dedicated circuit between the DGPS receiver and the VTS Gateway, data arrived at the VTS Gateway as it was output from the DGPS receiver—typically every second. The Link Control computer sampled the data, providing only every fifth data packet to the multiplexor. Even so, with 100+ hours of tracking, that added up to over 60,000 data packets recorded. The data collected verifies that there is good cellular coverage throughout the region. However, the system did not function very reliably, as there were numerous missed reports due to fluctuations in the quality of the cellular channel.

4.1.3 Cellular System Conclusions.

Despite several advantages, the AMPS Cellular system is not well suited for VTS ADS applications. These advantages include: equipment that is inexpensive, readily available, and easily installed, no requirement for a USCG owned and maintained infrastructure, no time delay in transmitting the ADS data from the vessel to the VTS Gateway, and large bandwidth per channel (compared to the other systems). However, high service costs, low capacity (competing with numerous other cellular users for a limited number of channels), as well as high cost and complexity at the VTS Gateway (one phone line and modem required per tracked vessel), outweigh any such advantages.

4.2 Digital Selective Calling.

Digital Selective Calling (DSC) is an international standard originally designed for distress and hailing on VHF, MF, and HF frequencies. Use of DSC for distress and hailing is covered under the Global Maritime Distress and Safety System (GMDSS) requirements [4]. Extensions to the DSC protocols (specifically CCIR Recommendations 821 and 825) have been created to enable DSC to be used for VTS applications on VHF-FM channel 70 (156.525 MHz), the channel designated internationally for DSC use.

4.2.1 DSC System Operation.

In order to test DSC, equipment needed to be installed both onboard vessels and at a shore location in the Narragansett Bay area. The shore installation consisted of a computer with DSC card to control operations, a VHF-FM radio, an RF power amplifier, and a Yagi antenna mounted on an existing tower. The shipboard equipment consisted of a DSC radio connected to a standard marine VHF-FM whip antenna (3 dB gain, omnidirectional). The same differential GPS system described above was used to provide ADS data to this communications system as well.

ADS information was provided to the DSC radio by the DGPS receiver as NMEA 183 sentences over an RS-232 line. The DSC radio used this data to formulate the DSC protocol messages that it transmitted. The DSC messages received at the shore site were reformatted by the Link Control computer and then sent to the VTS Gateway over the PSTN using modems. This system is illustrated in Figure 4-2.

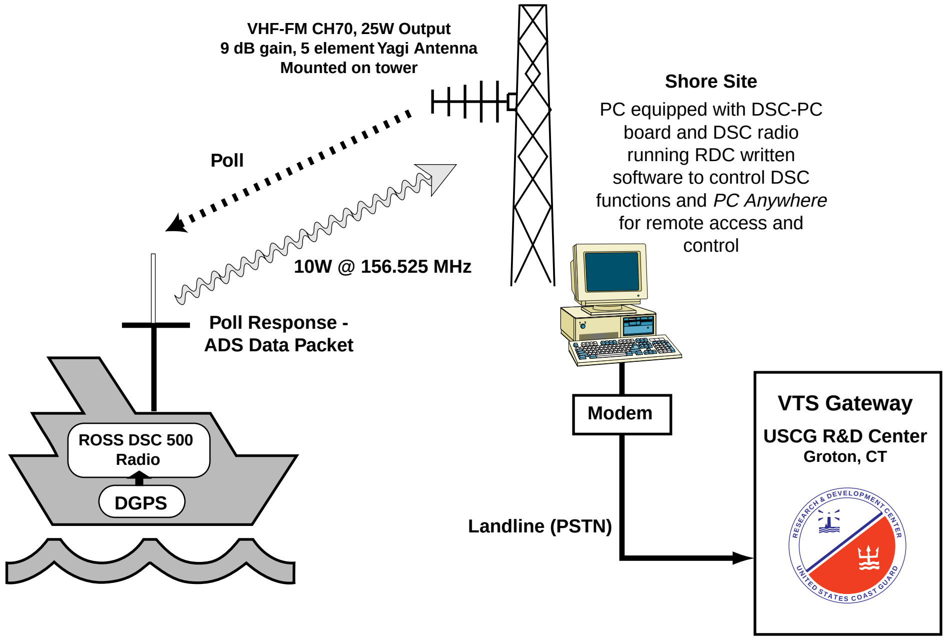

Figure 4-2 DSC System Diagram. Flow of ADS data from shipboard DSC equipment through the shore site equipment to the VTS Gateway.

4.2.2 <u>DSC Testing Results.</u>

Data was collected from multiple platforms, but less total data (~14,000 data reports) was collected from the DSC system due to the longer reporting interval. The DSC system was used in a polling mode with the base station sending out poll requests to both the *Vista Jubilee* and the *CGC Towline* every 30 seconds. The *Vista Jubilee's* ADS equipment was left on continuously and test periods were coordinated with her underway schedule. Less data was collected from the *CGC Towline* since her ADS equipment was turned on only when underway—which unfortunately did not generally coincide with the test periods.

No real surprises appeared in the collected data. As expected, the signal strength falls off with distance from the shore site. Also, the signal strength falls off towards the edges of the main beam of the directional antenna. One item that is of interest is that qualitative evidence seemed to indicate that voice reports were received at farther distances from the shore site than the DSC reports—this is contrary to what was expected. Discussions with the manufacturer indicate that the problem was probably a poorly aligned DSC board. At what level a DSC report becomes indecipherable remains to be investigated.

DSC also has a capacity problem. Due to the requirements of the DSC protocols only 15 DSC polls can be made and responded to per minute. There are some ways to increase the capacity, though an in depth discussion of this is beyond the scope of this paper. One method would be to divide the harbor up into sectors and use directional antennas from multiple sites much like the cellular system. Further capacity could also be achieved by using additional channels for DSC use—currently only channel 70 is authorized by the FCC [5]. There is no technical reason this can't be done as the radios are all frequency agile; this is a regulatory issue.

4.2.3 <u>DSC System Conclusions.</u>

The Digital Selective Calling system is a viable alternative for VTS ADS use. The system offers many advantages: there are no monthly or per minute charges for use regardless of traffic volume, there is international acceptance of the system, it is being used for VTS systems worldwide, and the shipboard equipment is small, inexpensive, and easy to install. However, there are some disadvantages which need to be weighed. The shore infrastructure must be established and maintained which can be very expensive if there are no existing facilities that can be used. Furthermore, the capacity is very limited due to spectrum limitations. In deciding whether to use DSC as the ADS communications system for a port, these advantages and disadvantages need to be weighed based upon the geographic area, the particulars of the port, and the goals of the VTS.

4.3 Newcomb Satellite.

The final communications system of the three to be discussed is the Newcomb Satellite system. This is a geostationary satellite system using the RDSS band (1608–1626 MHz) and is a successor to the defunct Geostar system.

4.3.1 <u>Newcomb System Operation.</u>

The shipboard equipment consisted of a Newcomb CP-1 direct sequence spread spectrum (DSSS) satellite transmitter with integrated GPS receiver. The same radiobeacon receiver used in the previous two systems was used here to provide differential corrections to the GPS receiver internal to the Newcomb CP-1. The CP-1 was connected to a small, flat L-band antenna and a very small, flat GPS antenna.

The ADS data was generated by the internal GPS receiver and then automatically transmitted by the CP-1 as a data packet every 10 seconds. The Newcomb CP-1 transmissions were relayed by a geostationary satellite (GTE Spacenet III) and received at the Mobile Datacomm (MDC) satellite earth

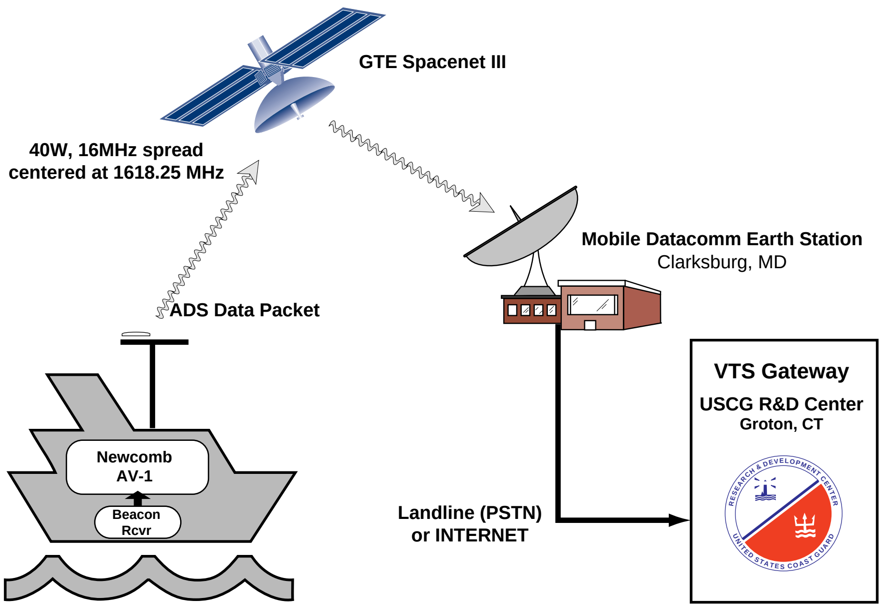

***Figure 4-3** Newcomb Satellite System Diagram. ADS data flow from ship to VTS Gateway over the Newcomb satellite link.*

station in Clarksburg, MD where they were placed into the R & D Center mailbox on the MDC computer system. A Link Control Computer at the VTS Gateway was connected to the MDC computer either via modem and the PSTN or via Internet and pulled data reports out of the R & D Center mailbox in real-time. This information flow is illustrated in Figure 4-3.

4.3.2 Testing Results.

Numerous data reports were acquired using the Newcomb satellite system. The *Vista Jubilee's* CP-1 transmitted ADS reports every 10 seconds, 24 hours a day for the entire test period (1 Aug – 14 Oct 94.). However, this data was not all logged. The data was generally only logged when the vessel was underway (100+ hours during the test period). Even so, some 38,000 reports were recorded. One thing this testing did show was the reliability of the Newcomb equipment—the unit worked 24 hours a day nonstop without fail for the entire test period.

The analysis of the data showed the system to work very well. Each data packet transmitted was sequentially numbered by the CP-1. Thus it was possible to measure the percentage of packets making it to the VTS Gateway. Overall, the figure was about 96%. The actual system performance was better than this though. It was discovered that the "omnidirectional" antenna had two nulls in the radiation pattern. Further testing and analysis showed that packets were received 99.9% of the time except when operating in the pattern nulls.

This system has the largest capacity of the three tested. Due to the extremely short transmissions and the nature of spread spectrum modulation a very large number of users can be supported in this bandwidth (>100,000). The real limit on the number of users is the processing power of the Earth Station. Currently this is around 20 transmissions per minute according to MDC [6], but based on our use of the system, this is underestimating the capability. There is also the future potential to increase capacity by using multiple earth stations, each one with it's own pseudo-noise (PN) code.

4.3.3 Newcomb System Conclusions.

The Newcomb system appears to be a good candidate for ADS based VTS systems. There are many advantages: The system has a high capacity as discussed above, there is room for future expansion by adding new earth stations using different PN codes for the DSSS signal, equipment is small and easily installed, and there is no infrastructure to create or maintain. Furthermore, a single Link Control computer at the VTS Gateway can handle any number of Newcomb transmitter equipped vessels, communications service costs are lower than for cellular, reports are received very quickly, and due to the high capacity of the system mobile units can report in at shorter intervals. Finally, the satellite footprint is CONUS plus 200 miles offshore [6], so the same system can be used all over the USA without any CG maintained shore installations. The only disadvantages to the system are the cost of the shipboard equipment and the cost of the MDC service which is still fairly expensive although it is less expensive than cellular.

5. VTS Gateway.

Since three different communications systems, each with their own proprietary formats, were being used, a VTS Gateway was developed to integrate them into a common format. The gateway concept enables the end-user (VTC) to utilize a variety of communications systems without regard to the individual traits of each system. Some specific advantages of using a gateway follow.

The VTS Gateway integrates multiple communications links. Any number of reporting systems can be used for ADS as long as the VTS Gateway has a Link Control computer to access the data and reformat it into some common data packet format. A data multiplexer is then used to combine a number of data streams into a single consolidated stream with the data packets output sequentially in the order received at the Gateway.

The VTS Gateway also provides a single common output format. No matter what the data format coming into the VTS Gateway through the Link Control computers, the data is converted and provided to users in a common data packet format. The data can then be output in real-time or stored in a database for later retrieval.

Another VTS Gateway feature is support for multiple simultaneous displays. These display systems can be different hardware and software as long as they understand the data packet format being provided by the VTS Gateway. The VTS Gateway can provide the data to local displays and also to remote displays via dial-up connections. Internet access, although not presently implemented, could be done as well.

Table 6-1 Comparison of the Three Communications Methods.

	AMPS Cellular	DSC	Newcomb Satellite
Coverage Area	Harbor area and 20+ miles offshore (cellular carrier dependent)	Harbor area and 30+ miles offshore (antenna site dependent)	Continental U.S. plus 200 miles offshore
Reliability	Poor	Very Good	Excellent
Integrity	Very Good	Very Good	Very Good
Reporting Interval	1 sec (subsampled at 5 sec intervals)	30 sec	10 sec
Latency	1 sec	4–5 sec	1–2 sec
Equipment Cost	$1200 plus DGPS	$700 plus DGPS	$4000 plus beacon rcvr (GPS integrated)
Useage Cost	38¢ / min local 75¢ / min roaming	Free	negotiable

6. Conclusions.

6.1 Comparison and Summary

The VTS Gateway allowed traffic analysis functions to be performed simultaneously from several different locations. Table 6-1 contains the comparison of the three systems.

This research has validated the ADS concept. Off-the-shelf, digital communications systems were used to transfer time-critical information, thus reducing the need for traditional voice reporting and radar tracking systems. Specific implementations of an ADS-based system must study coverage area, topography, cost, availability of commercial services, and volume of vessel traffic in determining which communication system or systems to employ. Regardless of the system(s) selected, the VTS Gateway concept has proven to be an excellent way to integrate different communication systems into one manageable data source.

6.2 Future Research

Future research into ADS for VTS applications has several different directions. Work is now in progress, to integrate ADS data into the VTS Upgrades being installed at various existing VTS sites. Research is also being conducted into extending the current one-way data transfer work to a full two-way system. New communications systems (such as the proposed LEOS systems) are continually being developed; as they come on-line they can be investigated for potential ADS use.

One system that is being implemented and investigated now is the Cellular Digital Packet Data system (CDPD). This is a new commercial system built on top of the current analog cellular system. It uses the existing cellular infrastructure to transmit TCP/IP protocol data packets on unused cellular channels at 19.2 kbps modulation with a predicted throughput of about 12 kbps. It appears to have the same advantages of the standard cellular system but without the disadvantages.

7. References

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