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To present the Navy's interest in distributed computer systems, this paper first discusses the nature of Navy systems and some of the constraints created by Navy philosophy. Secondly, some of the requirements of naval systems are presented. A couple of busing systems being investigated by the Navy are mentioned briefly, and some of the problems to be faced, as the author views them, are presented.

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FOREWORD

This publication constitutes an invited paper presented at the "Distributed Systems--Trends" session of the Computer Software and Applications Conference (COMPSAC 78) held in Chicago on 13-16 November 1978. The author's parent organization is the Computer Programming Division, Strategic Systems Department, Naval Surface Weapons Center.

Released by:

R. H. HUGHEY, Jr., Acting Head
Strategic Systems Department

CONTENTS

INTRODUCTION

The U.S. Navy is looking forward to distributed computer systems for the solution of many of its problems in shipboard command and control. Like any new technology, however, this concept is creating its own set of problems--problems that must be looked at very closely, or the ensuing chaos could be worse than the present situation. This paper presents the Navy's interest in distributed computer systems as discussed at the Navy Distributed Computer Systems Workshop held in June 1977.

To present the Navy's interest in this technology, the nature of Navy systems and some of the constraints created by Navy philosophy are discussed. Secondly, some of the requirements of naval systems are presented. A couple of busing systems being investigated by the Navy are mentioned briefly, and some of the problems to be faced, as the author views them, are presented.

THE NATURE OF NAVY SYSTEMS

The Navy did not do very well in the past when it came to putting different systems aboard a ship and making them work as a unit. In order to correct this deficiency, Navy philosophy today considers the whole ship, with all of its systems, as one unit called a combat system. This is more significant to Navy contractors than it may sound at first. Once, a developer could work independently and build a system, such as a missile system, without being concerned about how the other systems on the ship were going to be configured or how they were going to be used. The Navy was then left with the problem of integrating these systems into an operational unit. Today, with the whole ship being considered one unit, all of the pieces of that unit must be compatible and must work together to conduct the mission of the ship. Distributed systems technology can be the adhesive that bonds all the pieces together and permits them to function as a unit.

Figure 1 shows the basic elements of one such combat system, the AEGIS Ships Combat System, which is under development for the Navy. Both the ship and the weapon systems acquisition are being coordinated by the same Navy project office.

Most of the component subsystems are not new, but the idea of integrating them into one functioning combat system is new. There will be more than 50 computers in the AEGIS system, which is not presently a distributed system but the technology is being considered for future versions. It should not take too much knowledge of distributed systems technology to see how helpful it would be in integrating so many subsystems into an operational combat system under unified control.

The architecture shown in Figure 2 is one way that has been proposed to connect the pieces of a combat system. This architecture was conceived at the Naval Surface Weapons Center (NSWC) in response to the new naval ship "operational philosophy" put forth by the Chief of Naval Operations (CNO).* This philosophy calls for a federated combat system in which control is by delegation and negation, a concept which is not possible with configurations on present Navy ships. Note that all the sensors are on one bus, the weapons on another bus, and all the command and control information is on a third bus.

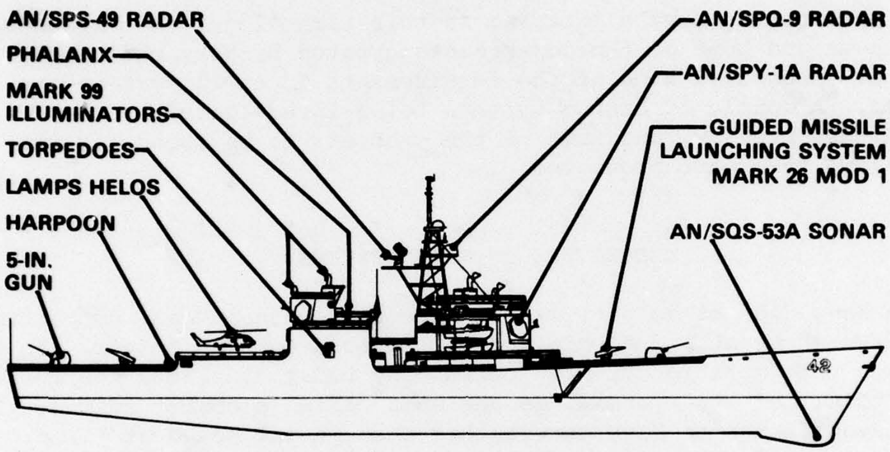

Figure 1. AEGIS Ship Configuration

Figure 3 illustrates another new concept in ship design called the SEA System MODification and MODernization by MODularity (SEAMOD).** The platform and the payload are considered separate entities. The platform consists of the hull, propulsion, and other equipment that normally lasts the entire nominal 30-yr lifetime of the ship. The payload includes the weapons, sensors, computers, command, control, and communications equipment, which is usually replaced with more modern equipment about every 10 yr.

One of the keys to the successful implementation of SEAMOD is a permanent data bus and electrical power distribution system installed in the ship for its lifetime. In the past during modernization, the ships have essentially been gutted and rewired point-to-point. A Navy cruiser has approximately 1000 miles of cables. The cost of cable acquisition and replacement during an overhaul is estimated at $35 a foot.

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* CNO ltr Ser 031702528 dated 8 Nov 1976, subject "Surface Ship Combat Systems Operational Philosophy."

** S.E. Veazey, "SEAMOD Combat Systems for Advanced Platforms," *Naval Engineers Journal*, February 1978, p.53.

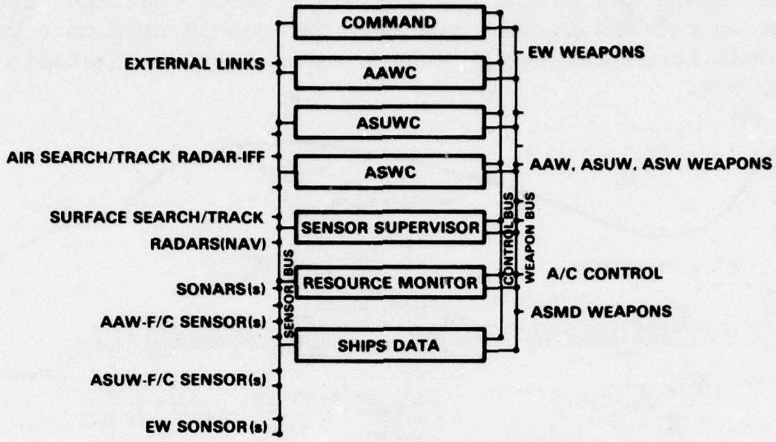

Figure 2. New Combat System Configuration

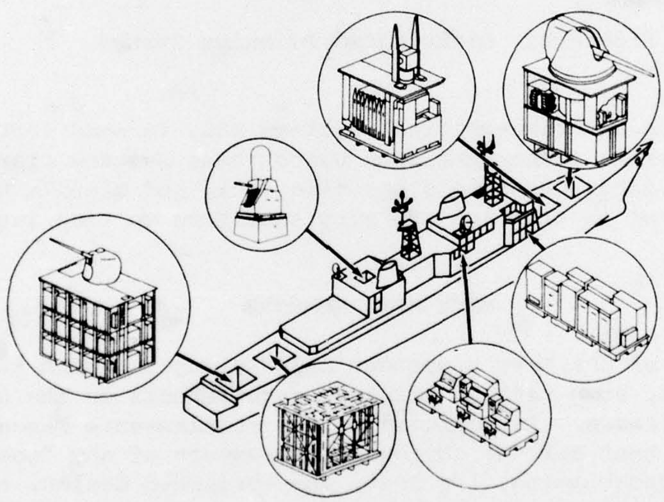

Figure 3. SEAMOD Concept

The subsystems are to be built as modules, installed in standard slots on the hull, and connected into the bus and power. One can see the importance of standard busing protocols and interfaces for such a system.

The concept of distributed systems will also find its way into naval aircraft. Figure 4 illustrates an avionics system that has even more stringent space and weight constraints.* Note that the processing is totally decentralized in this system. The bus is used to communicate between regional terminals (RTs); subsystems and other functions (F_n) are tied into the RTs.

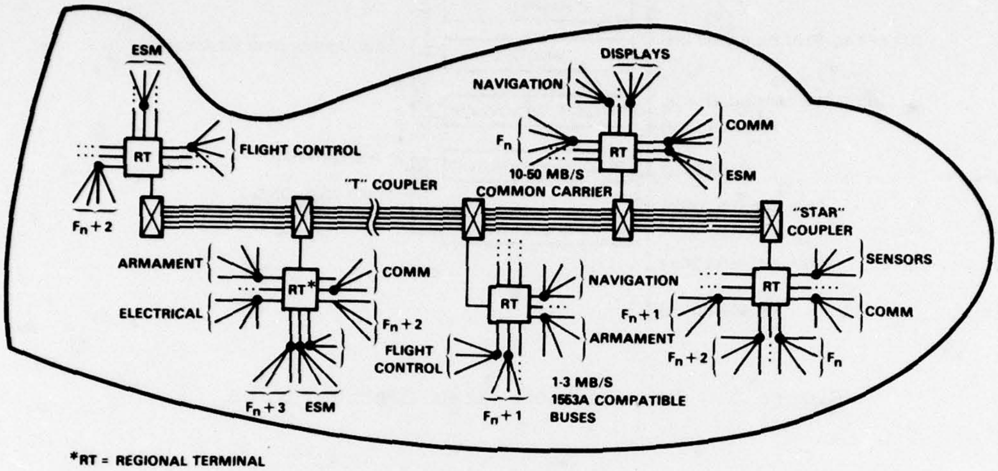

Figure 4. Distributed Avionics System

Navy systems are time-critical systems and, in some instances, real-time control systems. The data upon which these systems operate (e.g., target position data, own-ship's position data, and missile aiming data) must be correlated in time and are very sensitive to time lags.

NAVY REQUIREMENTS

The nature of the Navy's systems and the way in which the Navy functions present some rather stringent requirements on the design of hardware and software. In addition to the requirements discussed here, it is also true that all the obvious requirements of any "good" system (e.g., ease of programming, low cost, user-oriented design, etc.) are also requirements of Navy systems. Time and space do not permit elaborating on each of these.

Obviously, Navy systems must be reliable. They must also be fault tolerant. If a fault does occur while a weapon system is firing at an incoming missile, the system must be able to recover immediately and carry on its function (fault tolerance). If one part of a system becomes

* W.P. Warner and W.J. Dejka, *Navy Distributed Computer System Workshop*, Naval Surface Weapons Center Technical Report NSWC/DL TR-3790, Dahlgren, Virginia, April 1978.

inoperable because of battle damage or other reasons, the whole mission must not be aborted. The priority functions being performed by the system must be continued, even at the expense of some other less-important functions (graceful degradation).

When a system does break down, it must be repaired by sailors and not by company customer engineers (CEs). If a CE can't solve a problem, he calls in a factory expert. A sailor 1000 miles from shore can't do that. Deployed systems have to be built in such a way that faults can be isolated quickly and repaired easily by persons with a minimum of training (maintainability). The average time a sailor serves in this capacity is 4½ yr.

It presently takes about 14 yr from the conception of a combat system until that system is seen in the Fleet. This fact implies that the technology is old before it is implemented. A typical weapon system has a 10- to 15-yr operational life. It is modified many times during this life cycle to expand its "computational capacity" and conduct additional or modified functions. Systems not developed with this in mind are extremely difficult and expensive to modify and can take the ship out of operation for extended periods of time.

The operation of Navy systems can involve large amounts of data and very high data rates. During a full antisubmarine operation, for example, data transmission rates of 30 million bits per second can be required. The data in these systems also may have various levels of security classifications ranging from highly classified intelligence data to unclassified maintenance information. All personnel aboard ship do not have the same level of security clearance or need-to-know. The system must be designed so that it is possible to protect some of the data from other operators in the system.

EXAMPLES OF PRESENT APPROACHES TO BUSING

A key factor in any distributed system is the communications network. The following are examples of the different kinds of data busing systems being considered for Navy systems.

One of the busing systems is called the Shipboard Data Multiplex System (SDMS) (Figure 5). There are five physical buses in SDMS, and each bus has its own traffic controller, which polls the area multiplexers to see if there are any messages to be transmitted. Each bus has four data channels and a separate control channel. Each area multiplexer is connected to every bus. To enhance the survivability of the system in case of battle damage, each of the five buses would be routed the length of the ship by different paths. The system provides graceful degradation, since the failure of one of the buses does not affect the operation of the remainder.

Honeywell's experimental distributed processor (XDP) (Figure 6) is also being considered by the Navy. All processing elements are tied into the global bus by bus interface units (BIUs) at any point on the bus. Every BIU has a synchronized clock counter, and each is assigned specific clock times during which it has control of the bus. The schedule is stored in each BIU and can be changed in the field. The busiest BIUs can be assigned the greatest number of clock times.

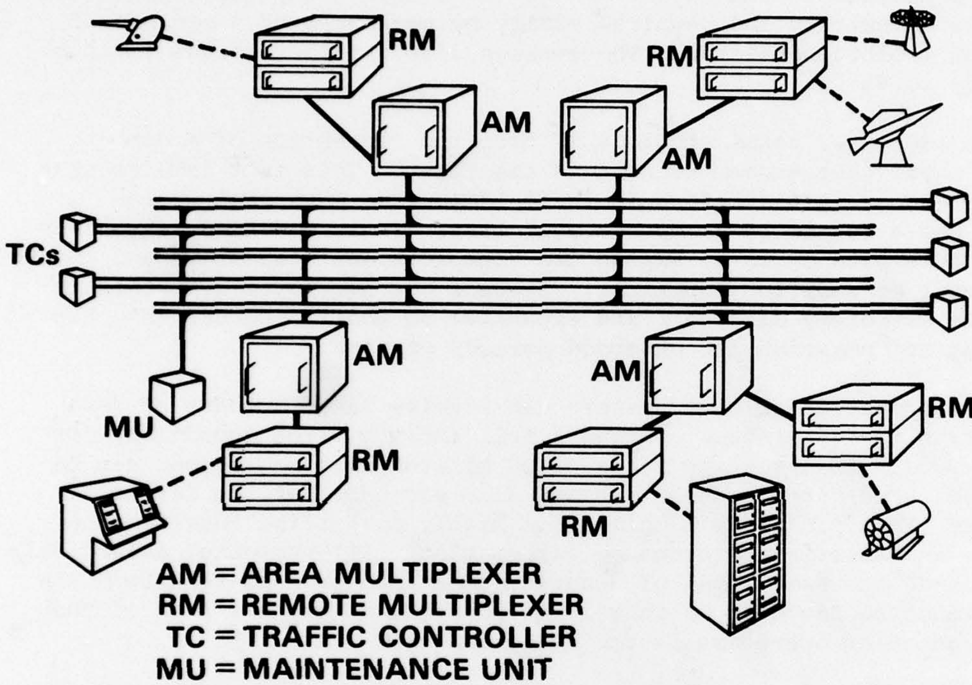

Figure 5. Shipboard Data Multiplex System

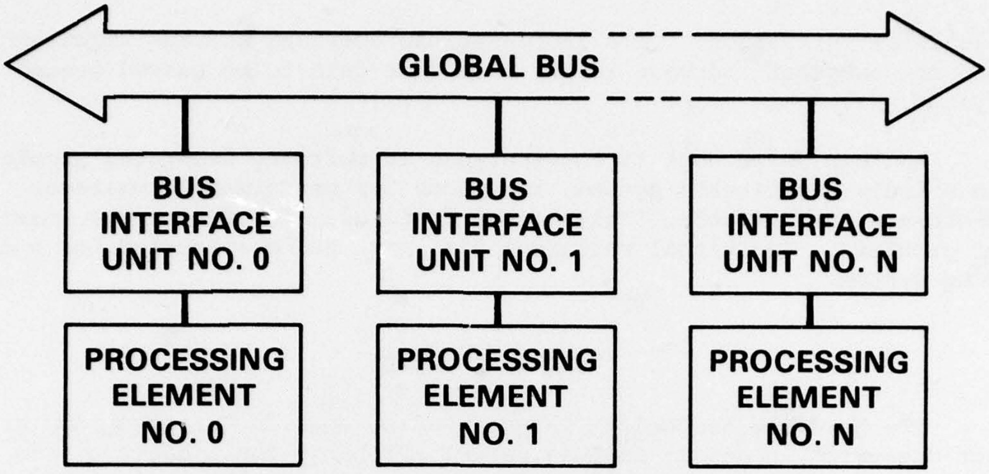

Figure 6. Experimental Distributed Processor

The XDP was designed with distributed processing in mind. It has the capacity of associative addressing (addresses the process, not the processor, and the location of the process can migrate from one processing element to another). Honeywell has also developed an XDP-type bus without the associative addressing feature for a foreign Navy.

Other developments include the General Electric Trident Trainer Data Mulitplex System (TDMS) and the UNIVAC Shipboard Integrated Processing and Display System (SHINPADS). There are undoubtedly several others.

SYSTEM COSTS

Distributed systems show promise in solving some of the Navy's problems, but additional costs that are not found in a system with central processing may be incurred. In a centralized system, the operating system is contained in only one memory. In a distributed system, at least a portion of the operating system has to be reproduced in every processor, taking up valuable system resources.

Distributed systems also show promise of improved reliability and survivability because by their nature all components need not be centrally located. But there are added costs to making any system survivable. A system needs overall control, and this requires the availability of systems status data. There are from 5000 to 10,000 such pieces of systems data in a combat system. In a distributed system, this data must be stored in more than one processor or memory in case the processor or memory involved in system control becomes inoperable or gets involved in a "deadlock" situation. This increases the overhead storage requirements and can cause an increase in the amount of data to be passed around the system.

Another added cost is the increase in software debugging problems. In a truly distributed system, functions are performed in whatever processor is available. This causes difficulty in tracing the sources of problems. Additional resources will have to be allocated for a debugging system.

UNSOLVED ISSUES

The hardware technology issues needing solution are many and are not discussed in detail in this paper. Probably the biggest system issue to be solved is the question of how to control a distributed system. This includes not only the usual operating system functions but the problem of synchronizing all of the processors and the data they produce. The configuration of the system should be completely transparent to the application software developer and not require any action on his part to coordinate the system.

There are many tools that need to be developed. Tools are needed to assist in making effective partitioning and distribution of the functions and data involved in the solution of the problem for which the system is being developed. Tools are needed for system trade-off studies and performance estimation and evaluation. Tools are also needed for our continuing problem of developing software, but now it will be complicated by the parallel computing characteristic of distributed systems.

CONCLUSION

Distributed systems technology holds many exciting possibilites for the solution of Navy problems, but no one in the Navy or elsewhere views distributed systems as a panacea. Whereas this technology may approach a solution to several problems, such as modifiability and survivability, it introduces a whole new set of problems of its own. The problems of distributed systems technology need a long, hard look by both the military and private industry, and good solutions must be developed. An initial attempt at this by the Navy was the Navy Distributed Computer Workshop* from which much of the preceding material was obtained.

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* Ibid.

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