

Implementation and Evaluation of a Dynamic Protocol for Interference Resolution in Naval Radar Units*

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Abstract: Radars are widely used in a variety of applications including communications, defense systems, air traffic control, etc. Previous work [1-4] by our group detailed the need for automated negotiation for interference resolution between the affected radar units and the choice of an appropriate coordination framework. Through the previous works, we developed a distributed, agent-based simulation environment in JAVA to study this problem. In this paper, we report the implementation and integration of a dynamic switching protocol for flexible coordination over the existing implementation.

I. Introduction

Radars are widely used in a variety of applications including communications, defense systems, air traffic control etc. and in a multi-radar environment, every radar requires a unique operating frequency. Two radars are said to experience interference, and hence distortion of the information they gather, if the radar frequencies do not operate beyond the interference threshold. This frequency interference may occur due to a variety of reasons, such as, change in atmospheric conditions, distance between the radar units, change in radar antenna parameters, and the bandwidth of the transmitter. To avoid this interference problem in naval radar units, currently the U.S Navy uses a personal computer-based program called the Electromagnetic Compatibility Analysis Program (EMCAP) for frequency assignment in radar units. EMCAP has a Central Frequency Manager (CFM) that sends messages to ships directing them to send their desired operating frequencies. The CFM receives these frequency requests from the ships and analyses them considering the positions of the ships and determines minimum distance separation between ships for the chosen frequencies to avoid

frequency interference. In this program, all the ships have a centralized control depending on the CFM for providing interference-free frequency. Because of this centralized control, any problem with the CFM would affect the entire group of ships connected to it. This process is an "extensive" human-in-the-loop system, thereby taking more time and often cannot perform "near" real-time coordination. Additionally, time delays make live testing expensive. Hence, automating the frequency allocation process with minimal human involvement within a distributed simulation environment can prove to be an effective solution in terms of reducing time delays, avoiding manual presence, and testing different coordination mechanisms between radar units. [2-4].

This paper is organized as follows: Section II briefly introduces the previous work and the motivations for this work. Section III provides a brief introduction to the design and implementation of the Dynamic switching algorithm. Section IV provides the preliminary results observed from the simulation and Section V concludes the paper.

II. Previous Work

The experimental results in [4-5] show that changing the interaction framework based on the available conditions may result in better system performance. Figure 1 shows the values of time for interference resolution for increase in number of ships [4] where, LA, MS, and NG represents Locally Autonomous, Master-slave, and Negotiation modes respectively. The time for interference resolution (IR) is the time taken to update the database of the group coordinator after resolving the frequency interference. This parameter is taken as a measure of performance of these three approaches. It can be observed from the figure that when the number of ships is two, the Master-slave and Locally autonomous approaches perform better than the Negotiation approach. But as the

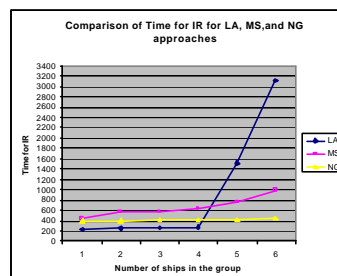


Figure 1. Different interference resolution approaches [4]

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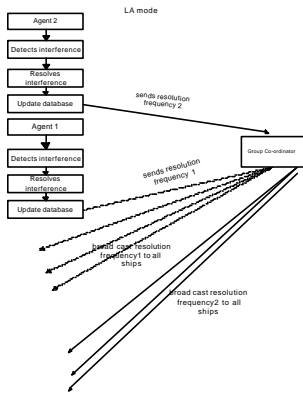


Figure 2. Communication in LA mode

number of ships increase, the locally autonomous approach has high values of ‘Time for IR’. This could be because for a given frequency range, when the number of ships increases the number of available interference-free frequencies decreases. Hence two agents involved in interference will generate their random frequencies and the probability of these new frequencies interfering again becomes higher. The agents have to resolve the interference again and hence the ‘time for IR’ becomes high. Also from Figure 1, it can be observed that the ‘Time for IR’ in negotiation remains almost constant. This is because only one agent detects the interference and the other resolves the interference. The Master-Slave approach takes higher than the negotiation because as the number of ships increases, the number of parallel processes in the master increases and hence the

interference resolution algorithm in the master, which also runs as a parallel process, takes more time to resolve interference. However, it is seen that at different points of time different coordination approaches work better (although the number of ships in the group is the only measure used).

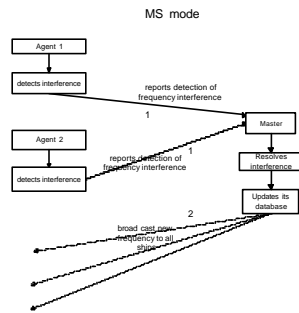


Figure 3. Communication in MS mode

III. Dynamic Switching Protocol for Coordination

III. A. Design of the Switching Protocol

Various conditions such as the number of ships in the group, available frequency range, bandwidth of the transmitting radar, and availability of direct connection between ships may influence the need for different coordination mechanisms at different times. The communication methodology using the three approaches is shown in Figure 2, Figure 3 and Figure 4. The preferences of the user would be to minimize the following:

1. Time for interference resolution, and,
2. Number of messages passed between agents during the process of interference resolution.

The user may choose some percentage combinations of the based on her/his relative preferences at any given time. An evaluation index; which is a multi-valued utility function, is formulated based on the available conditions and preferences to evaluate the three resolution approaches before making a final decision on the best approach to be used. The approach with the lowest value is selected as the best mode for interference resolution. The following sequel discusses the development of this evaluation index.

III.A.1. Time for Interference Resolution

This measure can be defined as the time period between the detection of interference and resolution the interference by assigning a new random interference free frequency to the affected radar. It also includes the time to update the group coordinator, which synchronizes the group's databases. This factor again depends on the following two factors.

1. **Frequency regeneration (f)**: This factor refers to the number of iterations by the two agents before generating a new interference-free frequency. This factor is significant only in LA mode. In MS and NG mode $f = 1$. In LA, $f \geq 1$.
2. **Delay in communication (d)**: This refers to the propagation delay of the data during the transmission of the new Interference free frequency from the resolving agent. Distance between agents affects this delay. If D is the distance between conflicting agents, the delay is given by

$$d = D / (3 * 10^8) \quad (01)$$

Before proceeding further let us define the following terms.

1. Let $T1$ be the time taken for one iteration of the resolution algorithm
2. Let $T2$ be the time for communication between the agent and the Group Coordinator. During $T2$ the agent sends its generated interference-free frequency to the group coordinator.
3. Let $T3$ be the time for communication between the ship in question and the other affected ship.
4. Let $T4$ be the time for communication between the group coordinator and the other affected ship.

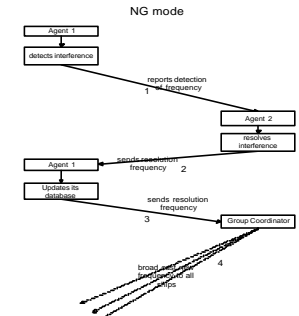


Figure 4. Communication in NG mode

Then the time for interference resolution will be given by

$$TIR = \text{Algorithm time} + \text{Communication time} \quad (02)$$

Thus, the time for interference resolution for the three approaches would be

$$T_{LA} = T1, \text{ if } f = 1 \\ = f * (T1 + 2 * T2), \text{ if } f > 1. \quad (03)$$

$$T_{MS} = 1 * (T1 + T2 + \max(T2, T4)) \quad (04)$$

$$T_{NG} = 1 * (T1 + 2 * T3 + T2 + \max(T2, T4)) \quad (05)$$

Note that in equations in 4 and 5, the highest value among T2 and T4 is chosen. This is because the greater the time delay, the higher the distance between the ships. Hence, the distance of the farthest ship from the Master/Group Coordinator is considered for the computation.

III.A.2. Number of messages passed.

The number of messages transferred between agents during the process of resolving interference in LA, MS, and NG modes respectively, can be determined using Figure 2, Figure 3 and Figure 4. These are derived below.

$$M_{LA} = (2 * x + 2 * (N * x)) \quad (06)$$

$$M_{MS} = (2 * x + (N * x)) \quad (07)$$

$$M_{NG} = (3 * x + (N * x)) \quad (08)$$

where, N is the number of agents (ships) in the system and x is the size of the message in bytes.

Since the message size is constant in all the messages in the protocol, we may assume x to be

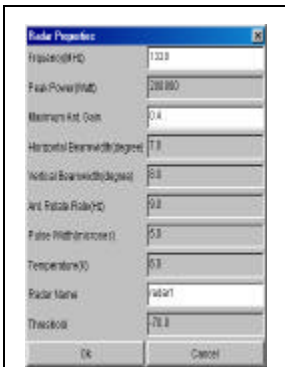


Figure 6. Radar Information entry



Figure 7. Ship Information Interface

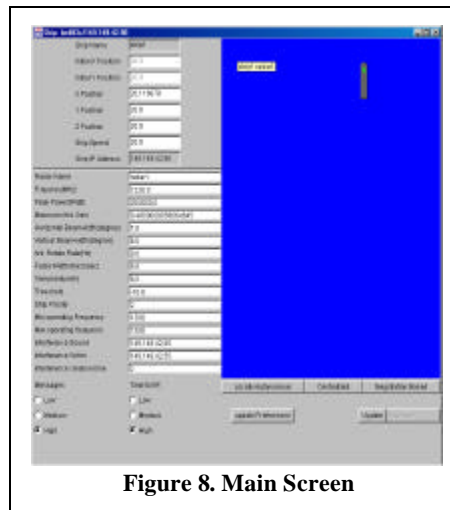


Figure 8. Main Screen

1. Thus the above reduces to the following:

$$M_{LA} = (2 + 2 * N) \quad (09)$$

$$M_{MS} = (2 + N) \quad (10)$$

$$M_{NG} = (3 + N) \quad (11)$$

III.A.3. Evaluation Index

An Evaluation Index, P, to determine the differences between the various approaches, viz. LA < MS < NG, and choose the most suitable coordination mechanism may be calculated using the above parameters. Let W_T and W_M represent the weights of the two chosen parameters; i.e. time for interference resolution and number of messages passed. These are normally given by the user (operator on the ship) depending on the situation at hand. Let V_T and V_M represent the values of the parameters that is calculated by the algorithm.

V_T can be calculated based on the positions of the ships using equation 1-5. V_M for the different approaches can be calculated from equations 9-11. Hence, P is given by the following:

$$M_{NG} P = W_T * V_T + W_M * V_M \quad (12)$$

From equation 12, the value of P for the different approaches can be determined and the protocol with the lowest value of P is chosen.

III.A.4. Software design

Figure 5 illustrates the working of the interference resolution (IR) process. It can be observed that the switching protocol executes in parallel with the detection algorithm. The switching algorithm takes the required parameters, evaluates the best approach, stores the selected approach for each ship into a data structure that can be referenced on demand. When the detection algorithm detects interference, it checks the data structure to ascertain the selected approach. Before executing the appropriate resolution algorithm. Note that the switching algorithm is

accessed only by the ship which becomes the source for interference; i.e. the ship which changes its frequency to interfere with another ship.

III. B. Implementation of the Switching Protocol

The current implementation [4] has been revamped to automate the interference creation

process. Also, in addition to the fields required to implement the dynamic switching protocol, several new fields have been added to improve the simulation environment. These include the following:

- a. Priority: Ship priorities have created to represent the priority of the ship; the ship with a high priority is given preference during interference by assigning a new frequency compared to the ship with a low priority in the Master-slave mode.
- b. 'Minimum' and 'Maximum' frequencies: These fields represent the range of frequencies for the group to use.
- c. Finally, three new parameters to automate the interference creation process.

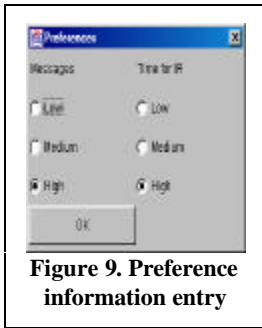


Figure 9. Preference information entry

The interference source and interference victim parameters represent the IP address of the source and victim ships for which interference is to be created. The interference creation time parameter represents the time period in minutes during which the interference is to be created. All of the above parameters, except "priority" are enabled only in the master-ship (group coordinator).

The radar and ship information dialogues shown in Figure 6 and Figure 7. All information entered are displayed in the Main screen shown in Figure 8; the ship, radar, and preference information can be updated in this screen. The Preferences screen is displayed next and is shown in Figure 9. While the ship and radar information are sent to the group coordinator for broadcasting to other ships in the group, the preference information is stored only in the local database and not sent to other ships.

IV. Results

Various weights for W_T and W_M were used to check how the chosen parameters; viz. time for interference resolution and number of messages passed influenced the choice of a coordination mechanism under different loads (number of radars / ships). In this experiment, other parameters which

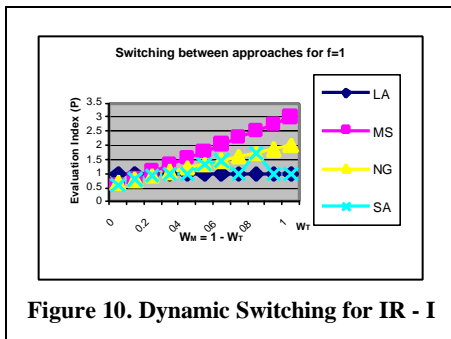


Figure 10. Dynamic Switching for IR - I

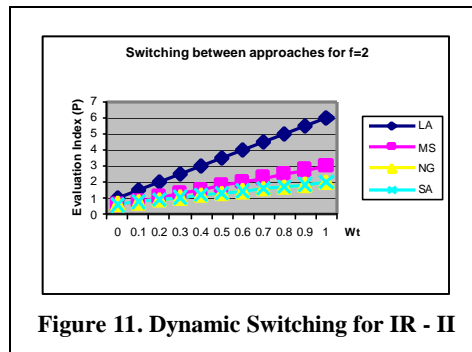


Figure 11. Dynamic Switching for IR - II

can influence the selection of an interference resolution approach, such as bandwidth of the transmitting radar, available frequency range were kept constant. From the graphs it can be observed that the change in weights (W_t and W_m) causes change in the approach that is selected.

V. Conclusions

The major contribution of this work is the following: (i) A chosen approach for interference resolution need not be predetermined during simulation setup, i.e. it is dynamically determined during the system simulation. (ii) Conditions such as the availability of direct connections between all ships in a group, changing distances between ships, atmospheric factors, availability of interference-free frequency slots, bandwidth of the transmitting radars etc can be considered in such a simulation to adhere to and reflect more real-time constraints. For changing conditions, a pre-fixed approach, such as the one proposed in [4], for interference resolution may be inappropriate. The preliminary simulation results indicate that in general, the negotiation-based protocol did work best for most situations. However, sometimes for low and medium load situations, as well as situations wherein the number of messages must be minimized, i.e. conflicts, the locally autonomous and master-slave techniques may be better approaches.

VI. References

1. Habib Adnan, S. Ramaswamy, R. Macfadzean, " An Agent-Based Distributed Simulation Environment for Frequency Assignment in Mobile Radar Units", *1998 SCS Conference*, Reno, NV, July 1998.
2. K. Srinivasan, J. Cherry, T. Scalf, N. D. Cannon, S. Ramaswamy, "A Two-level Distributed Interactive Simulation Architecture for Radar Frequency Assignment" *1999 SCS Conference*, July 1999.
3. K. Srinivasan, S. Ramaswamy, " Implementation and Evaluation of a Distributed Interactive Simulation Architecture for Group Interaction and Coordination: A Case Study in Interference Detection and Resolution in Naval Radar Units", *2000 SCS Conference*, July 2000, Vancouver, Canada.
4. S. Ramaswamy, K. Srinivasan, P. K. Rajan, R. MacFadzean, S. Krishnamurthy, "A Distributed Agent-based Simulation Environment for Interference Detection and Resolution",

Special Issue on Software Agents in Simulation, SIMULATION, June 2001, to appear.

5. K. S. Barber, A. Goel, and C. E. Martin, "The Motivation for Dynamic Adaptive Autonomy in Agent-based Systems", Technical Report, The Laboratory of Intelligent Processes and Systems, The University of Texas at Austin, Jan 1999.