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TRENDS IN INTEGRATED SHIP CONTROL NETWORKING.

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Abstract: Integrated Ship Control systems can be designed as robust, distributed, autonomous control systems. The EU funded ATOMOS and ATOMOS II projects involves both technical and non technical aspects of this process. A reference modeling concept giving an outline of a generic ISC system covering the network and the equipment connected to it, a framework for verification of network functionality and performance by simulation and a general distribution platform for ISC systems, The ATOMOS Network, are results of this work.

Keywords: Distributed Computer Control Systems, Network Reliability, Real-time Communication

1. INTRODUCTION

As a new trend, Integrated Ship Control (ISC) suggests an architechture which integrates all control tasks on board a ship into a single concept (Dittmann, 1992). From this point of view an ISC system can be designed as a robust, distributed, autonomous control system. The EU funded ATOMOS and ATOMOS II projects involves both technical and non technical aspects of this process.

An ISC system is by nature (and history) a hetorogenic system, utilizing equipment from different vendors. In the ATOMOS project much effort is put into modeling a generic ISC system covering aspects from human factors to pure technical details.

Our part of the project covers mechanisms for integration of different subsystems such as main engine, power management, maneuvering (rudder, thrusters), navigational equipment, etc. into a homogeneous system.

This paper presents following results from this work:

- A reference modelling concept giving an outline of a generic ISC system covering the network and the equipment connected to it. For the purpose of verifying the network system, traffic information must be specified as a part of the model.
- The model enables a verification of the network functionality and performance by simulation. The framework and goals for the simulation are presented briefly.
- To serve as the general distribution platform in ISC systems the ATOMOS network is designed and prototyped. The key features of the ATOMOS network is presented.

2. THE ATOMOS NETWORK

The network serves as the environment for integrating the different ISC subsystems into one distributed control system providing high quality real-time services as the main goal (Nielsen *et al.*, 1995).

Due to the real-time nature of the traffic, extensive non real-time traffic (like file transport) is restricted. A gateway functionality to non real-time networks is thus provided.

Classification societies, as 'Lloyds' and 'Norsk Veritas' defines strict demands on functionality, timing and robustness for ISC systems. Following key demands exists for ISC networking:

- Ability to mask at least one failing component.
- Ability to support a one second maximum end to end alarm notification time.
- Deterministic response time, allowing time critical communication as syncronisation and closed loop control.
- Graceful degradation in case of faults and overloads including traffic priorities.
- Dynamic connection and disconnection of nodes with a minimum of interruption.

In collaboraton with our industrial partners following demands on capacity and timing has been evolved:

- Recovery time after critical communication error (ex. token loss) max. 200 ms.
- Total network segment capacity on at least 2000 messages/second.
- At least 30 nodes allowed on each network segment,
- At least 1000 m segment length. (Non intelligent repeaters allowed.)
- Medium access time less than 5 msec. on a network segment with 10 nodes.
- Low price of network controllers (ie. max. 80 US$).

No general demands exist on capacity of the individual network nodes, but at least 200 messages/second are suggested.

The listed figures are an estimation of communication needs in a medium to large cargo vehicle with a high degree of automation and integration. Large passenger and cruising vehicles is estimated to have higher demands on traffic. To meet higher traffic demands a segmentation of the network can be necessary.

2.1 *Selection of Standards*

Available standards for control networks and field busses were extensively examined (Jensen and Granum, 1993) (Hansen and Granum-Jensen, 1993) to find either a complete solution, or components fitting our needs. In the examination the above listed demands were used together with the following design criterias:

- To maintain the view of ISC systems as true distributed systems, it was decided at an early stage to disqualify pure master-slave structures in the communication system.
- Commercially available controllers or interface components should exist.

Following standards was examined: IEEE-802.x, Proway C, ARCnet, Cambridge Ring, Lon Works, MAP, MiniMAP, FMS, MIL-STD 1553B, IEC/ISA SP50, Profibus, InterOperable Systems Fieldbus and CAN Bus. The fact that the standards differs a lot (some covers all OSI layers, some just a few) makes direct comparisons difficult. For standards including OSI layer 1 and 2 figures comparable to the list of capacity, timing and price demands was calculated. For standards including application interfaces, characteristics of these was recorded.

Following selections was made:

- For OSI layer 1 and 2 ARCnet was selected. ARCnet uses a simple token bus protocol, it offers up to 2.5 Mbit bandwidth and cheap LSI controllers are available.
- As application interface FMS was selected. FMS is derived from MAP and is used in some fieldbusses (as Profibus).

2.2 *Design*

To enable single fault masking a dual network approach using dual network controllers was selected. All network functionality was made independent of host loads and timing by imploying a local processor for protocol handling. To support this structure, software covering OSI layer 3-6 was developed (Granum et al, 1993).

It was found that having two separate networks, although more expensive would give a more flexible solution than just using double cabling. Bearing in mind that the network is designed to exist in heterogenious environment it was decided to make all network functionality independent of host loads and timing by imploying a local processor for protocol handling. The system was also designed to allow uncritical, cheap equipment using non redundant connections. Figure 2 shows the structure of network and network nodes.

2.3 *Implementation and Test*

To demonstrate the functionality a small prototype series of network interfaces was produced and tested to meet the demands. An integration into two different propriatary hardware and software platforms were performed by two independent control equipment vendors. Applications tested using these platforms conluded the functionality in a heterogenious environment (Granum and Hansen, 1994).

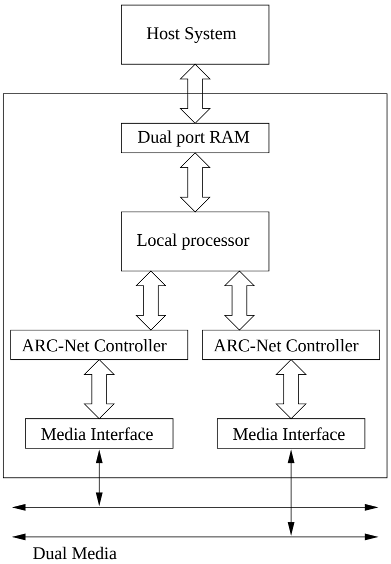

Fig. 1. Structure of network and network nodes.

3. REFERENCE MODEL

Used on an ISC system, a reference model paradigme, like [ISO TC184] (ISO-TC184 SC5 WG1, 1986), could be extended to cover items ranging from logistic to technical details. Our model is limited to cover the information flow in the distributed system. The functionality of the nodes/subsystems is described only to the extent needed to specify communication patterns and the traffic generated. A simple model is a key issue. To achieve simplicity the information which has to be supplied to describe a model element is limited to key parameters.

To ease the task of constructing a model of a target system, the reference model is structured as building blocks. The specification of a building block has to adhire to a set of rules which makes all blocks structural simular. Using this approach conformance classes for a generic set of standard components can be offered, leaving only modelling of more complex systems to the designer. The basic model elements offered to the designer are found to be:

- Network specifications.
- Specifications of connected equipment, including conformance classes for basic equipment and design guidelines for modelling complex equipment.

3.1 *Network specifications*

A target ISC system includes one or more network segments. For each segment information on replication strategi, selected bandwith and timing for reconfiguration has to be supplied. To make it possible to include other network technologies in the model also information on alternative topologies and medium access protocols can be supplied.

3.2 *Specifications of connected equipment*

In an ISC system conformance classes can be specified as generic descriptions of equipment as:

- GPS navigator.
- Autopilot.
- Heating systems.
- Power generators.

The conformance class for a specific type of equipment is expandable in a simple and structured way by using the rules given in the 'Design guidelines' for complex systems. A specific piece of equipment is allowed to cover more conformance classes (ie. a combined GPS navigator and autopilot). To make an instance of a component of a conformance class the designer has to add naming and values for variable parameters.

Complex and individual systems (as the main engine) cannot be covered by the relative simple properties of conformance classes. For these systems the reference model specifies guidelines for description and integration.

3.3 *Model proporties*

A description of connected equipment covers at least following items:

Functional description:

- Functionality of the specific equipment.
- Functions offered to other equipment (as server).
- Functions required from other equipment (as client).
- Coding and semantics of communicated information.

Traffic description:

- Type, amount and timing requirements of network traffic generated.

The functional description serves mainly as a source of information for calculating the traffic information needed for simulation. The structure of the information, which has to be supplied, is selected close to the physical structure of the ATOMOS network, imploying network adapters, data channels and eventually individual tasks executed in the equipment. Figure 1 shows the relationship between network, adapters, channels and tasks.

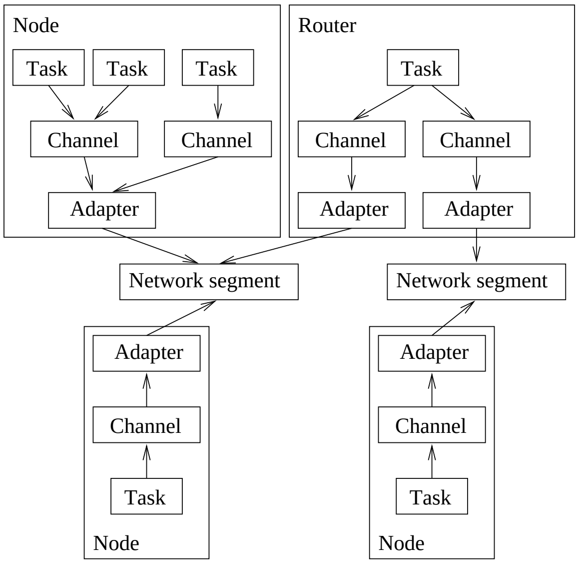

Fig. 2. Relationsship between modelling entities.

3.4 *Adapter*

Equipment is connected to the network through at least one network adapter. For each type of network adapter replication strategi, bandwith, timing parameters and buffer capacity has to be supplied. For each adapter used, information on naming, segment connection and addressing, has to be supplied.

3.5 *Channel*

All traffic is modelled as simplex data channels. A client server relationship is modelled as two channels, A data subscripsion service is modelled as a set of channels from the source to each of the destinations. This approach is selected due to the lack of a simple multicast service in the ATOMOS network, requiring that all multicasts are performed as series of point to point transmissions. For each channel imployed, source and destination together with characteristics and timing requirements of the dataflow has to be supplied.

3.6 *Task*

Normally, traffic is only specified on 'channel level'. In special cases, where the internal funtionality of af network node is wanted as a part of the model, modelling on 'task level' is possible. When modelling at task level traffic on the related channels is derived from the connected tasks. For each task imployed characteristics of scheduling, generated dataflow and timing requirements has to be supplied.

3.7 *Use of the Model.*

A model of a target system will include:

Structual information on network segments and equipment attached. Structual information on communication patterns in the system. Traffic information covering type, amount and timing requirements.

The structure and characterisics of the target system described by the model is used as input for the simulation process.

4. SIMULATION

The purpose of the simulation is to verify the behaviour of the communication system including the network segments and the attached adapters and data channels. For ISC systems especially the possibilty of simulating situations which cannot be runned "in vito" because of hazards etc. is vital.

For ISC systems normally three different working conditions are taken into account:

- Steady state at sea and no rolling.
- Manoeuvring in narrow water.
- Heavy weather.

These conditions will impose quite different activities in the ISC system. Simulations has to be done for each of these conditions including a variety of error conditions.

Two major assumptions for the simulation can be made based on the structure of the simulated system:

- As all protocol handling runs on a local processor all network characteristics are independent of host loads, making it possible not to include any host load parameters in the simulation of the network functionality.
- To make the simulation of data 'channels' independent of host load, data recieved at a node is always considered delivered instantaniously (ie. either consumed or discarded). Verification of the individual equipments ability to process recieved data is considered a separat task, normally covered by the vendor of the equipment.

These assumptions to a great extent decouples the simulation from the functionality of application software running in specific equipment, making the simulation task much more simple.

4.1 *Simulator Input.*

As input for the simulation, data extracted from the reference model and eventually recorded live data, are used.

The reference model sources following component information for a target system:

Network segment:

- Name and ID.
- Topology and MAC protocol used.
- Timing for reconfiguration in case of node adding/removal.
- Timing for regeneration in case of network errors (ie. token loss).
- Worst case access time, no network load (ie. token rotation time).
- Maximum token/network hold time.
- Maximum frame size.
- Bandwith (transmitted bit/second).
- Transmission overhead, total (ie. frame spacing, data frame headers and checksum, free buffer enquirement frame and acknowledgement frame)
- Replication strategi used.

Adapter:

- Name and ID.
- Network ID for attached network.
- Transmission setup time, average and max.
- Receiver latency.
- Bandwith for the controller (ie. bit/second or
- frames/sec).
- Buffer size on controller.
- Replicated network connection (A, B or A+B)

Channel:

- Name and ID.
- ID for source and destination adapter.
- Real-time requiremments (hard/soft/none).
- Periodic transmission: Period and max. allowed send skew.
- Non periodic transmission: Distribution (sporadic/burst) and average
- traffic (bits/second).
- Average packet length in each transmission.
- Send buffer space

Recorded live data can substitute traffic characteristics specified for selected equipment, refining the simulated runs and making comparison of simulator output and live data possible.

4.2 *Simulator Output.*

The simulator output is designed to focus on the modelled systems ability to meet the specified temporal behavoir. Output shall at least encourage:

- Statistics for individual or series of runs
- Traces for events where specifications were not met.
- Detailed trace of a simulation run.

The simulation is still on an experimental state. Preliminary work on two different approaches are in progress: An event based approach using modified timed colored Petri nets and a language orientated approach based on PROMELA/SPIN (Holzmann, 1991).

5. DISCUSSION

The ATOMOS network is based on exististing standards for MAC and application interface with redundancy and error handling added. The designed network interfaces, imploying LSI network controllers and local processor power, makes to a great extent network functionality host independent, providing better predictability and performance.

In ISC systems predictability and garantied properties are key issues. In practice, for an asynchronious network, as the ATOMOS network, verification can only be done by simulation due to the complexity of the system. To serve as an infomation source for the simulation a reference model covering the information flow in the distributed system is developed. The level of details included in the model is a balance between the need of a fine granularity of the model and practical problems associated with specifying detailed information for a target system. It is found that the level of details included in our model is the outmost that can be expected for practical use.

Although final conclusions on the simulation cannot be drawn at this state, the prelimenary results shows that the concept is feasible as a tool for design as well as for verification purposes. Using simulations for verification implie that properties are presented on a statistical basis. It is found that this is sufficient for most purposes in an ISC system. In situations where formal guaranties for functionalities should be demanded, an approach using 'guaranties by design', as in time triggered systems, would be more feasible. (Koepetz and Grunsteidl, 1994)

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