COMPARISON OF P-NET WITH OTHER NETWORKS.

Jens Dalsgaard Nielsen * **Niels Jørgensen** *

* *Aalborg University*
Department of Control Engineering
Fredrik Bajersvej 7C, 9220 Aalborg E, Denmark
mailto: {jdn,nj}@control.auc.dk, http://www.control.auc.dk

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

1. INTRODUCTION

As part of the EU founded project ATOMOS a work about real time networking for use onboard ships for Integrated Ship Control(ISC) was developed. Integrated Ship Control (ISC) suggests an architechture which integrates all control tasks on board a ship into a single concept. From this point of view an ISC system can be designed as a robust, distributed, autonomous control system.

A part of this work was to investigate and evaluate existing fieldbusses.

In this paper the demands for the ISC network as well as the evaluation of different networks is presented.

2. NETWORK DEMANDS

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.

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 define 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 collaboration with our industrial partners following major demands on capacity and timing have been evolved:

- Recovery time after critical communication error (ex. token loss) max. 200 ms.
- Total network segment capacity on at least 2000 messages/second.
- Approx 200 msg/sec node-node under special circumstances
- 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$).

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 are estimated to have higher demands on traffic. To meet higher traffic demands a segmentation of the network can be nescessary.

A more detailed evaluation scheme will be presented later in this paper.

Measures like the above can be extracted for other control systems than ISC systems. It is belived that medium to large industrial plants will arise similar measures.

2.1 *Selection of Standards*

Because of lack of standarization and many different needs there exist many fieldbusses and networks developed by control companies and organizations.

Available standards for control networks and field busses were extensively examined to find either a complete solution, or components fitting the needs. In the examination the above listed demands were used together with the following selection 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 (in the periode 1992-1994):

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 these 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.

2.2 *Analysis requirements*

The key properties selected for the prelimenar selection was:

Medium Access Method (MAC)
Topology (TOP)
Transmission Method (TRANS)
Transmission Medium (MEDIA)
Bandwidth bitrate. (BANDW)
Max number of Nodes (NRNODES)
Max length of segment (LENGTH)

The above metrics focuses on the properties of the lower OSI layers as most important in determing the real-time capabilities of the network.

In the following a short pre-evalaution of each net is given:

2.2.1. *IEEE 802.3 "Ethernet"*

MAC: Contention - CSMA/CD
TOP: Bus
TRANS: Baseband
MEDIA: coax cable, TP, fiber
BANDW: 10(100) Mbit/sec
NRNODES: 32768
LENGTH: 1.5 km (by use of 5 repeaters)

NOT selected for further investigations because of CSMA/CD which arise problems about max transmission time. Because of the "back-off" principle a node can achive very long delays before attaching the net.

2.2.2. *IEEE 802.4*

MAC: Token Passing
TOP: Bus
TRANS: coax cable, TP, Fiber
MEDIA: Broadband
BANDW: 1/5/10 Mbit/sec
NRNODES: 32768(when 15 bit adressing)
LENGTH: $<$ 100 km (under special cases)

Selected for further investigations.

2.2.3. *IEEE 802.5 "IBM token ring"*

MAC: Token Passing
TOP: Ring
TRANS: Baseband
MEDIA: TP
BANDW: 1/4/16 Mbit/sec
NRNODES: 250
LENGTH: Depends.

All though the token method has many interesting features, the ring principle where node failures can give the ring problems leads to the conclusion that it is NOT selected for further investigations.

2.2.4. *ISO 8802-7 "Slotted ring"*

MAC: Empty slot
TOP: Ring
TRANS: Baseband with two mediums
MEDIA: Not specified
BANDW: 10 Mbit/sec
NRNODES: 254
LENGTH: 4 km

NOT selected for further investigations with same arguments as 802.5

2.2.5. *PROWAY C*

Proces data "highway" for distributed control systems. Standard IEC 955. It is based on IEEE 802.4 MAC: but with only one possible type of phsycial layer. LLC layer is like 802.2.

MAC: Token Passing
TOP: Bus
TRANS: Coax cable
MEDIA: Broadband
BANDW: 1 Mbit/sec
NRNODES: 100
LENGTH: 2000 m

Selected for further investigations.

2.2.6. *ARCNET*

Simple fast cheap token based network. No protocol above layer 3/4.

MAC: Token Passing
TOP: Bus
TRANS: Baseband
MEDIA: TP or Coax cable
BANDW: 2.5/5 Mbit/sec
NRNODES: 254
LENGTH: 6 km (when very low bitrate)

Selected for further investigations.

2.2.7. *Cambridge Ring*

MAC: Empty slot
TOP: Ring
TRANS: Baseband
MEDIA: not specified.
BANDW: 10 Mbit/sec
NRNODES: 254
LENGTH: Depends on media

Fails on same argument as ISO 8820-7/802.5.

2.2.8. *LonWorks "Local Operating Network"*

A bus for remote (intelligent) I/O.

MAC: CSMA/CD with optional priority
TOP: Bus
TRANS: Not specified
MEDIA: Not specified
BANDW: Max 1.25 Mbit/sec
NRNODES: 127 (possible up to 255 segments)
LENGTH: Depends on bitrate

NOT Selected for further investigations because of use of CSMA/CD admittance method like 802.3, which gives problematic acces time to the network.

2.2.9. *MAP and MiniMAP*

ISO Layer 1 and 2 is IEEE 802.4.

For layer 1-2 see 802.4.

Selected for further investigations because the use of IEEE 802.4 as lower levels.

2.2.10. *MIL-STD 1553B*

Designed for aircraft use. It is stated as very robust reliable master/slave principle.

MAC: Master/slave
TOP: Bus
TRANS: Baseband
MEDIA: Shielded TP
BANDW: 1 Mbit/sec
NRNODES: 31
LENGTH: Not specified but "short"

Selected for further investigations.

2.2.11. *IEC/ISA SP50 Fieldbus*

Modern 4-20 mA instrument bus to replace 4-20 mA installations. It covers layer 1,2 and 7 (collapsed). For pure remote instrumentation it can be very interesting.

NOT suited for real networking and is therefore rejected.

2.2.12. *Profibus*

"German" fieldbus based on a master/slave principle. It can give high security by parallel cabling. The higher layer is based on the FMS standard.

MAC: Hybrid Token Bus and master-slave
TOP: Bus
TRANS: Baseband
MEDIA: Shielded TP
BANDW: 9.6 kbit/sec $\rightarrow$ 0.5/2.5 Mbit/sec
NRNODES: 127
LENGTH: 4800 m/9.6kbit/sec $\rightarrow$ 800 m/0.5Mbit/sec

Selected for further investigations.

2.2.13. *FIP*

French/Italian fieldbus standard.

MAC: Master/slave
TOP: Bus
TRANS: Baseband
MEDIA: Shielded TP
BANDW: 31.25 kbit / 1 Mbit / 2.5 Mbit /sec
NRNODES: Totally 256 - 1 master.
LENGTH: 2000 m at 31.25 kbit/sec

Because of the very stringent master-slave principle FIP is NOT selected for further investigation.

2.2.14. *P-NET*

Open standard.

MAC: Virtual token and master/slave
TOP: Ring
TRANS: Baseband
MEDIA: TP
BANDW: 78.6 kbit/sec
NRNODES: Totally 125 - 32 masters.
LENGTH: 5 km with repeaters

Selected for further investigation.

2.2.15. *Bitbus*

MAC: 1 Master/slave
TOP: Bus
TRANS: Baseband
MEDIA: TP
BANDW: max 2.4 Mbit/sec
NRNODES: 250
LENGTH: 30 m at 2.4 Mbit/sec, 4800 m at 62.5 kbit/sec

NOT selected for further investigation because on the "lonely" master.

2.2.16. *CAN bus*

MAC: CSMA/CA
TOP: Bus
TRANS: Not spec
MEDIA: Not spec
BANDW: Max 1 Mbit/sec
NRNODES: Not spec. 2032 msg identifiers which can be used for either point-point, multicast or broadcast
LENGTH: Less than 200 m at 1 Mbit/sec

Because of the special way of transmission where each bit must propagate on the whole segment before the next is sended, a very limited bandwidth is foreseen when using long cabling, and it also use CSMA /Collision Advoidance which means non predictable access time to the network. NOT selected for further investigations.

The following standards was selected for further investigations:

- IEEE 802.4
- PROWAY C
- ARCNET
- MIL-STD-1553B
- P-NET
- Profibus

3. ANALYSIS OF SELECTED STANDARDS

The next analysis adds the following key items to the prelimenary analysis. It is outside of the scope of this paper to cite all the figures, so only som e major facts are referred.

- Description of MAC: layer and error handling as well as physical layer
- The previous investigations with a more detailed key figures added
- Evaluation on requirements for layer 1,2 and 3:
  - Simple, resilient
  - More than 1 kV galvanic isolation
  - At least 1000m segments
  - At least 30 nodes.
  - Segmentation possible at the network layer
  - Broadcast and/or multicast should be possible(at layer 2)
  - Real-time routing shall be possible
  - Routing tables shall be static because of performance
  - Routing must be at network layer
  - Four to seven priorities implemented at datalink layer or higher - which implies that no priority is demanded at MAC layer
  - Accept of reduced performance but not loss of critical data
  - Receiver must not accpet corrupted data
  - Detection by CRC-16 or better
  - Error detection i layer 3 or higher
  - Check for legal PDU/Address/mailbox/duplication of frames/receiver malfuntion/failure in components and cabling
  - Redundancy on both cabling and controllers. Must be implemented at layer 3 or higher, so it is not a requirement for layer 1 and 2 (which is implemented so in Profibus)
- Criterias for layer 4:
  - Async communication with negative acknowledge
  - Time syncronization (physical and logical clocks)
  - Common available cabling
- Capacity:
  - At least 16 bytes data field
  - At least 2000 packets/sec at a segment
- Timing:
  - Max network access time under normal conditions less than 5 msec
  - Max trans time less than 0.5 msec (given 64 byte data equals at least 1 Mbit/sec)
  - 10 msec * nr-of-routers to pass for critical communication
  - Recovery time less than 200 msec
  - Time skew on a segment less than 10 msec

3.1 *IEEE 802.4*

It supports CRC-16, has data field up to 8182 bytes, 16/48 addressing scheme.

Transmission charateristics:

msg(byte)	capacity (tlg/sec)	
	1Mbit	5 Mbit
1	2786	7873
16	2088	6596
64	1158	4378

Transmission of 50 bytes is less than 0.5 msec and 300 bytes for the 5 Mbit version.

Immiediate acknowledge is provided as a part of the token protocol.

The 1 Mbit version has slight problems to reach the demands, because this is only layer 1 and 2 figures.

Recovery time is worse. Even with 10 nodes the 1 Mbit version can not reach the 200 msec demand. The 5 Mbit version can reach the 200 msec border with 10 nodes.

Due to the complex protocols for handlign errors on the network and the rather high pricing of controllers 802.4 is rated to only 3 (in scale 1 to 5).

3.2 *PROWAY C*

Very close to 802.4 wih some restrictions: less than 100 stations, less than 2000 m cabling, less than 100 byte user message field, less than 16 usec station delay.

Rating as 802.4 : 3 (in scale 1 to 5)

3.3 *ARCNET*

Supports CRC-16, data field up to 507, 8 bit addressing. 2.5 Mbit/sec

msg(byte)	capacity(tlg/sec)
1	5562
16	4068
64	2188
73	2014
128	1353
255	770

Maximum access time can be calculated as number of nodes present multiplied with above measurements.

Based on max 73 bytes messages, acces time is less than 5 msec with 10 nodes operating.

Immediate acknowledge as part og the token system is provided.

Token loss will be repaired within 0.1 msec to 62.5 msec. Worst case with two nodes with ID 254 and 253 is 28.5 msec. If they are numbered 0 and 1 it takes 62.5 msec.

An excluded node will max wait 840 msec before it is back in the ring.

Rating 5 (in scale 1 to 5) allthough the upper layers is missing.

3.4 *MIL-STD-1553B*

Supports only parity check not CRC-16 or equivalent.

The concept is based on Bus controller (BC) and remote terminals(RT). There excist only one BC (and backup BCs) on one segment along with several RTs. The BC controls all traffic like BC → RT, RT → BC, RT → RT. So the BC must be aware of all traffic (like a static schedule).

The standard notes that a passing BC scheme can be implemented, but not how, so a token based system can be established.

BC to RT and vice versa:

msg(byte)	capacity(tlg/sec)
2	11905
8	6944
16	4464
64	1420

RT to RT:

msg(byte)	capacity(tlg/sec)
2	7194
8	5025
16	3584
64	1317

Max 50 bytes (of 20 micro sec) can be transmitted if the 0.5 msec limit has to hold.

The standard says nothing about max recovery time.

Rating 3 (in scale 1 to 5).

3.5 *PROFIBUS*

Profibus is inspired from 802.4 allthough only priorities are available and adressing is limited to 7 bit. Also handling of errors divide.

Broadcats and multicast is possible, and a addressing space up to $2\ ^19$.

It supports pure redundancy on the cabling level with dual line interface.

Max segment length at 500 kbit/sec is 200m, with three repeaters t is extended to 800m which is below the demands.

Capacity at 500 kbit/sec:

msg(byte)	capacity(tlg/sec)
1	411
16	361
64	261
128	191

It should be noted that these numbers is based on a sepcific profibus implementation. Parameter tuning can change these figures.

Access time is difficult to calculate for the Profibus. A simplified example gives that with 10 masters each transmitting one byte acces time is 24.6 msec which is much more than the wanted 5 msec.

Rating: 1.5 (1 to 5)

3.6 *P-NET*

P-NET has some interesting figures. The virutal token system is based on assumptions like max 390 micro sec before a slave is responding. No time is wasted on token circulation etc, as well as the immediate translation of incoming telegrams.

Also token regeneration is of high speed.

Only one major parameter turns P-NEt down. it is the rather low bandwith. Allthough P-NET can handle more than 200 16 bytes telegrams pr second this is alos the actual net bandwidth. One of the demands was a net bandwidth of more than 2000 telegrams pr second.

It has been discussed about a "P-NET" with a higher bit-rate. This will put som e stronger demands on net handling of the nodes, which will restrict possible CPUs to 68xxx eq.

It was also decided not to reinvent layer 1-2 in the project.

Rating: 2(4) (1 to 5)

4. SELECTION OF ATOMOS NETWORK

In short a ARCnet solution was selected. It is low priced, and has more than enough capacity according to the investigation.

ARCnet supplies with layer 1 $\rightarrow$ 2. It was decided to use with a FMS as API. Due to economic reasons a solution was delivered from Softing, Hamburg.

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.

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. he system was also designed to allow uncritical, cheap equipment using non redundant connections. A controllerboard based on a Intel 80186 and onboard kernel and OSI layer 1-7 was designed and implemented.

4.1 *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.

Test results did show good and bad figures.

The FMS layer could transport 16 bytes telegrams with the rate of 53/second between two nodes.

A fast access profile with AAU API was then implemented and did give:

214 telegrams/seconds of 32 byte. About 4 times the FMS performance.

The network did show literally no load in the tests, which was also predicted.

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 proporties 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.

6. REFERENCES

[1] T. Jensen and M. Granum, *Analysis of Current and Proposed International Standards for Data Transmission*, ATOMOS - Aalborg University, 1993,

[2] Granum et al, *Detailed Description of Services and System Specification*, ATOMOS - Aalborg University, 1993,

[3] M. Granum and T. Hansen, *ATOMOS Network Final Report*, ATOMOS-Aalborg University, 1994

[4] T. N. Hansen and M. Granum-Jensen, *Analysis of Basic Transmission Networks for Integrated Ship Control Systems*, ATOMOS - Aalborg University, 1993,

[5] Kjeld Dittmann, *Open Automation Architecture*, CAMS92, 1992

[6] Gerard J. Holzmann, *Design and Validation of Computer Protocols*, Prentice Hall, 1991,

[7] J. Dalsgaard Nielsen and K. Mølgaard Nielsen and N. Jørgensen, *Real-time Communication Networks Onboard Ships*, journal=Cams95, 1995,

[8] ISO-TC184 SC5 WG1, *The Ottowa Report on Reference Models for Manufactoring Standards*, ISO-TC184 SC5 WG1, 1986,