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산업공정환경에서 Mini MAP 을 기준으로한 실시간 네트워크의 성능해석

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Performance Analysis of Real Time Network based on Mini MAP in Process Control Environment

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요 약

산업공정현장에서는 독립적으로 운영되고 있는 프로그램식 단위제어기기들에 대한 연계운영을 위하여 실시간 처리 소규모 네트워크가 도입되어 구축운영되고 있다. 특히 제조생산공정에서는 계층화된 분산구조로서 공정정보처리를 위하여 공장환경에 적절한 네트워크 구축을 MAP등의 표준화된 규격에 의하여 권고되고 구현되어 운영되고 있다. 본 논문에서는 공장 환경에서의 표준규격으로 제안된 Mini MAP 을 기준으로 하여 물리 및 데이타 링크계층을 Petri-Net 기법을 활용하여 실시간 처리를 위한 개선된 모델을 제안하고 네트워크의 성능측정 및 시뮬레이션을 수행하였다. 또한 이 모델에 의하여 토큰버스 네트워크를 구성하여 전송 서비스시간과 메세지 처리율을 분석하고 Mini MAP 규격과 함께 성능을 해석하였다.

1. Introduction

Automation of production in modern manufacturing is based on the integration of the various stage of the production process by means of processing systems. Communication systems are of fundamental importance in modern automation activities, as they are essential in order to achieve the required level of integration and coordination.

The most of manufacturing industry has completed the development of a local area network for industrial process. The LAN was implemented to Mini-MAP specification, but it is'nt fully compatible with it. Functionally, the realization includes lower two layers of the ISO-OSI model, i.e. physical and datalink layer(MAC and LLC)

Each node has two layers resident in the module of the communication microcomputer level. Communication to users is confirmed through microcomputer network adaptor and shared memory and it is controlled by software for interprocessor communication(user interface).

Node management(NM) is responsible for normal functioning of network message exchange process. It is in charge of user commands execution : LLC, MAC and physical layers parameters set up, entering and leveling the logical ring and maintenance of the list of active nodes.

2. Industrial Process Communication Methology

2.1 Industrial Process Communication

In the actual discussion three types of MAP a node are distinguished[6] :

Type 1 : Full MAP node with
- .physical network : IEEE 802.4 broadband, 10 Mbps
- .protocol architecture : all 7 layers as specified by MAP 3.0
- .pros: - full functionality
  - long distance communication benefits of broadband
  - communication with other networks
- .cons: - no real time capabilities expansive pilots
  - disadvantage of broadband
  - complex integration of protocol into network

Type 2 : EPA node with
- .physical network : IEEE 802.4 phascoherent carrierband, 5 Mbps
- .protocol architecture : all 7 layers as specified by MAP 3.0 with one L_SAP
  (or)MMS, LLC with one L_SAP, MAC
  (or)MMS, LLC with multiplexing service, MAC
- .pros :- improved performance
  - direct communtication with backbone
- .cons :- increased complexity
  - no Proway option used

Type 3 : Mini MAP node with
- .physical network : IEEE 802.4 phase coherent carrierband 5 Mbps
- .protocal architecture : layer 1 and layer 2 immediate response and LLC type 3
- .pros :- real time performance(time critical)
  - Proway options(MAC,PLC and physical layer)
  - individual soulutions
- .cons :- no direct commnunication with backbone
  - poor functionality
  - restricted addressing capabilited

This paper deals with the investigation of Mini-MAP nodes in the carrierband environment. It is intended to analysis these performance limitation of the message throughput, service time in the time critical application. The user shall be enable to decide whether the network fits his requirement, whether he needs a real time or an alternative comunication solution. These 3 type network are presented in Fig.1

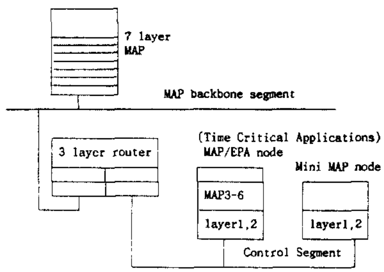


Fig.1 Industrial Network Types
(Full MAP,EPA/MAP, Mini MAP and carrier network)

2.2 Time Critical Network Parameters

A control network has to provide a high level of reliability in hostile environment, guaranteering a low bit error rate and a minimum number of re-transmission together with the capacity to acheive resilence.

The term time critical implies the existence of a certain time interval within which one or more actions have to be completed. Response times in manufacturing range from seconds to milliseconds and go from hours to microseconds, so it is impossible to define a time interval universally acceptable for all manufacturing application. However, three general requirments can be identified for the various kinds of manufacturing activity:

- the network must be capable of guaranted message delivery in hostile conditions and robust interworking
- it must be able to handle cyclical or repetitive polling or data transmission
- it must provide for dynamic impredictable communication sequencing, both over the whole network and between atached nodes

We can identify three basic time parameters associated with communications : acess, transfer and disengagement time. [8,9]

2.3 Requirements for Data Transfer

A time critical comunication has to be able to periodic time critical, aperiodic time critical and non time critical transfers. The sequence of the PDUs(Protocol Data Units) will be established by the different applications using the system. In any case,bandwidth must be availble for time critical communication.

With a reservation MAC strategy, it is possible to establish an upper bound for delivery time in non fault conditions. The upper bound is not provided for in most connection MAC strategies, but it may be possible to establish the probability that a message will be delivered by a given time. Even if a reservation strategy is adopted, a fault such as a broken cable or a lost token may the delivery time exceed the upper bound established. Performance must thus be measure according to the probability of failure to deliver a message within this upper bound,regardless of the MAC strategy adopted.

A message can be defined as belonging to a certain category or using a certain time frame. The various kinds of data traffic control networks have to handle are ; Alarm PDUs, Normal Event PDUs, Regular Periodic Time Critical PDUs, Random Non Time Critical PDUs.

The critical communication system has to be capable of distinguished between time critical and non time critical PDUs and provide the appropriate service.This can be acheived by attaching attributes to the PDUs and/or by using open system with multiple stacks of OSI layers, each suited to non time critical and time critical messages.

In order to respect the established message transfer times. PDUs should be assigned priority attribures. Various priority levels can be taken into considering: two level, for example, would distinguished between time critical and non critical PDUs : three would distinguish between periodic time critical PDUs,aperiodic time critical PDUs and all other PDUs.

Although an even greater number of level might be required, it would make the architecture and its management excessively completed.It is clear, however, that time critical PDUs should have priority over less time critical ones and so must be distinguished as such on all the layers.

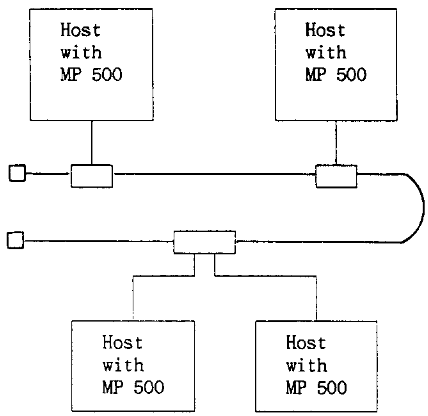
In the Full MAP architecture the physical layers ISO 8802.4 for token passing bus access method [ISO 8802.4]. In this architecture, ISO 8802.2 Logical Link Control (LLC) class 1 services are used at the datalink layer[ISO 8802.2]. In Mini-MAP and MAP/EPA nodes class 1 services are used at the datalink layer to generate greater reliability, as in this reduced architecture these are no network, transport, session and presentation layers.

Priority problem are not completely solved in Mini-MAP nodes, which are used for time critical applications, as none of the ISO 8802 MAC standard access algorithms can meet priority requirements. The token bus scheme in ISO 8802.4, which reserves a higher fraction of the bandwidth for high priority messages, would seem relativley appropriate for priority requirements, but frames have to be received and respected by each station. IEEE 802.5 can support 8 priorities, as compared with ISO 8802.4's capacity for 4, which is fewer than required number.

As mentioned above, the network must always serve a part of the communication resoures for transmitting time critical PDUs, and non time critical PDUs must not interface with the delivery of time critical ones. Time critical messages may be short enough to be sent across the network in a single MAC frames, as most exist MAC methods allow a station gaining control of the medium to send only the frame before it has to relinquish control of the medium to another station.

3. Network Configuration in the Model System

The configration is made up of four nodes with IBM PC/AT with INI MAP board host processor module. The nodes use processor module for task of communications.(Fig.2)



Host : IBM PC/AT or its compatible
Communication Processor : INI MP 500
- Intel 80186
- Token Bus Controller
- 32 K byte EPROM (MAC, LLC, MM, Interprocessor Communication & Diagnostics)
- 32 K bytes dual port SRAM
- 100K bytes local SRAM
- cable kit (2 & 4 way taps)

Figure 2. Network Configuration of Model system

The software of two lower layers, along with interprocessor communication, node management and diagnostics is stored in a 2Kb on-board EPROM. Each layer and other parts of software is implemented as a task. Task, memory and interprocessor communication management is controlled by a real time multitasking process. The task communicate by exchaging message. Similiarly, host applications wishing to use communication services also exchange message with INI MP 500 across the bus.

4. Data Link Layer and Modeling

4.1 MAC Sublayer

All nodes in the network perform a sequential exchange of token and thus make a logical ring. They have the same rank. The node owing the token has the right to send message to any node or to all network participants(broadcast) simultaneously.

Datalink sublayer provides two kinds of services through MAC sublayer : Send Data with Acknowledge(SDA) and Send Data with No Acknowledge(SDN).

Although the node is process in the network, it becomes active only when user wants to enter the ring. After that, its address(MA) will be inserted in the list of active nodes. Each active node has got the address of its next node(NA). In the case that(NA-MA) > 1, the node will try every second to pass the token to nodes with address for interval(NA,MA). In this way, the nodes updates the list of active nodes.

Main characteristic of MAC sublayer are
- Max. number of nodes : 32
- Protocol : token pass
- Data transmission rate : 1 Mbits/sec
- Length of information field : <= 512 bytes
- Buffer sizes : 16 Kb
- Max. length of data highway : 500 m

4.2 LLC Sublayer

A formal desciption of the data link sublayer (LLC : Logical Link Control) is based on Petri Net,Fig.3.The extension of classical PN is done with addition of buffers :
- buffer B1 contains service data coming from LLC to MAC(Ma_data_request)
- buffer B2 contains service request coming from user to LLC(L_data_request)
- buffer B3 contains confirmation coming from LLC to user(L_data_confirmation)
- buffer B4 contains confirmation coming MAC to LLC(Ma_data_confirmation)
- buffer Bra is queue of SDA services waiting for the right to send to station with address ra
- buffer B5 contains received data coming from MAC LLC(Ma_data_indication)
- buffer B6 contains received data coming from LLC to user(L_data_indication)
- buffer Bsm contains message for Node management

Each buffer can be consideration as a PN state. This state contains a mark if a buffer is not empty. Every LLC external event is described by presence of non empty buffer B2,B4 or B5.

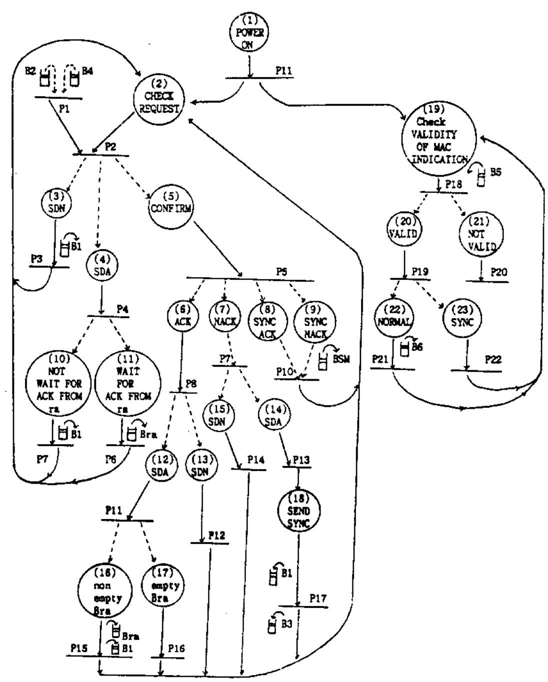


Fig.3 Formal Description of LLC Sublayer

Firing of transition starts by execution of a suitable procedure P.

As it is shown in Fig.3, the mark is state 1 after the node power is on. LLC is initialized by executing the procedure p11. Then, LLC pass into state 2 and state 19 to wait for exeternal events. When a user message arrives, LLC takes a services request from B2,P1. If it is SDN service, P2, it puts a frame into B1,P3. If it is SDA service, P4, and LLC has been waiting for acknowlege of previously sent frame,service is put into Bra, P6; otherwise, service is put into B1,P7. When LLC receives Ma_data_confirmation,5,it will send a L-data_confirmation to user, P8,P17,P14. If service performed was SDA, LLC detects an out of order sequence_number bit it concludes that the frame is duplicated or lost. LLC always waits for acknowledgement before sending the next frame. In case that no reply or an information on unsuccessful transmission is received,LLC will try to synchronize itself to remote LLC 18,8,9. The reception of synchronizing frame means for remote LLC that it will have to reinittialize the sequence_number bit.

5. Performance Measurement and Simulation Model

The Simulation model is described in Fig.4. The model is found on the following environment parameters :

- A Mini-MAP carrierband architecture
- Protocol profile of the Mini-MAP specifications
- Network load can be designed independently for each node with
  (message type, message length, number of nodes, buffers sizes, controller delay)

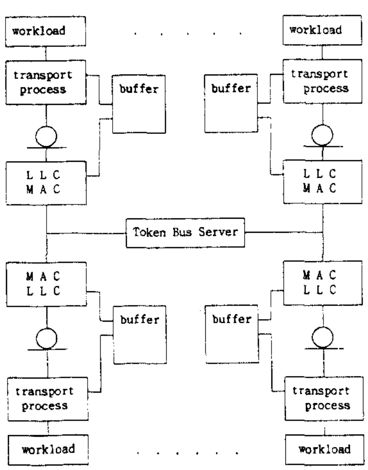


Fig. 4. Simulation Model

The following values were measure experimentation

1) The throughput e.g. the amount of transmitted data per a time unit

   $TH = N_S / E$ (1)

   - where N_S is the counter counting the amount of successfully transmitted data bytes for all network
   - E stands for the time of measurement

2) The service time, time interval from the moment when the LLC accepts a message from the user to the instant this frame is delivered is defined as

   $ST = T_{bt} + N * N_t * T1 + T_s$ (2)

   T_{bt} : time between two subsequent received tokens ($<$ 1ms for 4 active nodes)

   N : number of active nodes

   N_t: max. number of consecutive data frames the node any transmitting during possession a token

   T1 : necessary time interval for sending a frame from buffer B1 one retransmission

   T_s : necessary time interval from taking message from B2 to it is input to buffer b1

6. Results of Performance Measurement

6.1 Results of Throughput Measurement

The program for throughput mesurement was conceived as an application on the host processor. It was in charge of two tasks : to generate message transmission, and to receive message from other nodes. The experiment performed in three phase :

1) Synchronization of measurement

   The initializing node sends brocast message to all nodes (Ta) The application program in the nodes reply and, after having reply (instant T_b), the initializing node calculates the synchronization delay t :

   $t = (T_b - T_a)/2$ (3)

2) Start of measurement

   The start of measurement is initiated by the brocast command initalizing node. After having received the brocast command, network participants start to send message and count successful transmission Nsi. The initializing node starts to transmit and count as well, but with delay t.

3) End of measurement

   On expiration of the measurement time E, the nodes stop to transmit and count. The throughput TH is then calculated by taking a sum Ns of counts Nsi performed in N network nodes.

$$N_S = \sum_{i=1}^{N} N_{Si} \quad (4)$$

and by diving N_S the measurement time E.

Measurement are performed for differnt values of certain internal parameters :

- measurement time[E] was 50 s
- message length[D]was varied (50,100,200,300,400,500)
- message generating rate[B] was varied
  (10,20,30,40,50,60,70 message per second)

The total throughput (kbytes/s) for SDA services versus message (bytes) is presented in Fig.5. It can be seen that the message generated 40 message/s and message length of 500 bytes led to a saturation.

The influence of N_t (max. number of transmit data frame per token)and of the algorithm for calling the inactive nodes with address from interval(NA-MA) to enter the network was tested too. No significant influence of these upon network throughput was observed. The network throughput (kbytes/s) for SDN services verse message is presented in Fig.6. A higher SDN throughput verse SDA throughput, as expected, came as a result of the absence of any flow control.

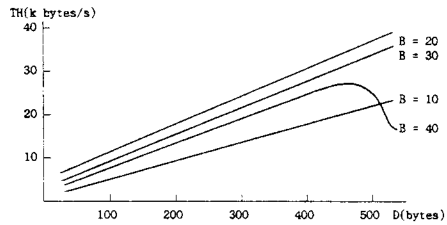


Figure 5. Throughput versus message length for SDA services

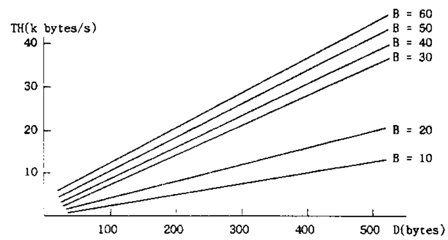


Figure 6. Throughput versus message length for SDN services

6.2 Results of Service Time Measurement

It can be seen from ST formula that the influence of T_{bt} (time between two received tokens) and Tl (time between MAC frame transmit and the reception of acknowledgement with one retransmission) can be neglected with a high number of station in the network and higher values of N_t. Proway recommandations state that service time should be less than 20ms. An example illustrating a short service time is when the station has been given token just when it is ready to send a frame, or other stations are not ready to send frames, then the service time is :

$$ST = 1 + 10 = 11 \text{ ms}$$

However, in an other arrangement with 32 nodes, with N_t = 10, and with a retransmission per each frame transmitted, the service time is :

$$ST = 1 + 32 * 10 * 2 + 10 = 651 \text{ ms}$$

The high service time from the latter example came because the node lost the right to send just prior the instant it was ready to send a frame. The node had then to wait until all network participants have sent their frames and until it received the token again. Such example of high service time have a low probability of appearence in real situation.

7. Conclusion

This paper has outlined the main characteristics and requirements of industrial networks involved in time critical applications based on MAP 3.0.

As time critical applications need response times faster than a complete OSI structure could produce today, we have to use a reduced set of OSI services to guarantee performances adequate for these applications.

In this paper, examples of new services classes could be :

- a sort of "null service",useful to formally describe with the OSI model a communication structure with a reduced number of layers (e.q. Mini-MAP)
- service classes capable of distinguisting between time critical and non time critical PDUs.

Throughput the analysis, the following facts could be observed :

- the use of bus and interprocessor communication software drives the communication channel into saturation: in other words, making of necessary copies associated with moving data across the bus from user data space to the shared memory on the communication board and from the shared memory to the local board memory is time consuming transaction.
- the depth of shared memory can have a great influence on characteristic of communication appear with a rate of 20 -50 messages/s, the typical value being 20 messages/s. The typical message length is about 100 bytes.

The main requirement of a process control network is to send message within a short service time. This can be accomplished with low throughput figure only. The requirement is also influences by the network configuration, because the service time increase proportionally to the number of active nodes.

The results permit us to conclude that the network configuration of 4 nodes for max. throughput of SDN services, channel efficiency is 60 percent, and for SDA services, it is 33 percent.

This approach tends towards inclusion of time critical services in existing ISO-OSI communication models, which cannot readily accomodate time critical application in their current state, due to the fact that its service classes were defined for differnt kinds of applications.

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