Analysis and Evaluation of Fieldbus Communication and Protocol Static Characteristic

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ABSTRACT

The MAC mechanism, communication data type, and communication reference model which are very important to fieldbus communication are summarized and analyzed. A set of fieldbus static performance indices described by layered concept are proposed. Through diagram and simulation method, the evaluation results of the static performance indices for several mainstream fieldbuses are presented; furthermore, the scope of application of some fieldbuses in industrial control field is discussed. Through the way of layered description and diagram comparison, lots of static performance indices can be decomposed and classified effectively, and the favorable mapping relationship between application requirement and static performance indices is achieved.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design – Network communications
C.2.2 [**Computer-Communication Networks**]: Network Protocols – Protocol architecture (OSI model)
C.2.5 [**Computer-Communication Networks**]: Local and Wide-Area Networks – Buses

General Terms

Performance, Design

Keywords

MAC mechanism, communication data type, protocol static characteristic, protocol efficiency

1. INTRODUCTION

Because of the variety of fieldbuses, each fieldbus has the most suitable applications. When choosing a fieldbus, users should compare the fieldbuses, and understand their respective characteristics as well as the scope of application. At the same time, user also should analyze and extract the requirement of their own, so as to get the most fundamental and important goals and choose the most suitable fieldbus[1].During the selection and application of fieldbus, grasping and understanding the service performance of fieldbus is absolutely essential, it can help user make use of fieldbus more effectively and play a greater fieldbus performance advantages. The service performance of fieldbus can be divided into two categories, namely, protocol static characteristic and network dynamic characteristic.

So far, some evaluation and analysis work for the fieldbus performance has been done in many papers, such as [2][3][4]. In [2], an improved method of computing actual pass token circulation period and the determining setting pass token circulation period are proposed and presented separately. In [3], it presents a mathematical performance model to calculate communication delays of the Profibus FMS network when the timer value and the traffic characteristics are given. In [4], two parameters of the data link layers have been in particular considered: cycle time and the medium access efficiency. There are two limitations in these research work, one is that the main issue considered in these work is the enhancement and improvement of one or two network performance indices and/or time performance. However, the research results are very difficult to realize both technically and economically, so it is not valuable to fieldbus users in some sense. The other is that they are short of the analysis of protocol static characteristic, which does not directly affect the control performance of fieldbus system but have important influence on the scope of application, ease of development, expandability and system cost during system selection and development.

Thus, the aim of this paper is: through the analysis and discussion of some key technologies that related with fieldbus communication, propose the specific indices that can be used to analyze and evaluate fieldbus static performance, then completely evaluate the protocol static characteristic of some mainstream fieldbuses by the method of diagram comparison and simulation, so as to provide valuable instructions to fieldbus users' type selection and application.

2. FIELDBUS MAC MECHANISM

In fieldbus communication, usually, a number of nodes use the same communication medium jointly. The MAC（Medium Access Control）sub-layer of data link layer is the most important in fieldbus three-layer protocol, it directly controls all

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communication nodes on the right of using communication medium. Namely, the features of MAC sub-layer are directly related to fieldbus real-time capability [5][6]. In accordance with the capability to support real-time, fieldbus MAC layer protocol can be divided into two major categories, event triggered mode and time triggered mode. Further, event triggered mode can be divided into Carrier Sense Multiple Access /Collision Detection (CSMA/CD), Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) and Carrier Sense Multiple Access/Collision Resolution(CSMA/CR), its representative protocols are Ethernet, CAN and Lonworks. Fieldbus protocol of time triggered mode commonly adopts token mode which is directly supporting real-time, it can be further divided into: (1)Centralized Token， representative protocols are WorldFIP and FF; (2)Distributed Token, representative protocols are FDDI and Profibus; (3)Virtual Token, representative protocols are ControlNet and P-NET.

3. REQUIREMENT OF FIELDBUS COMMUNICATION DATA TYPE

In the field of industrial control, the transmitted data on fieldbus include real-time I/O data, as well as some non-real-time data such as control program and configuration data etc. Generally, the transmitted data on fieldbus can be classified from two aspects.

（1）According to the rigorous degree of time requirement

- Time-critical data

Such as controller I / O signal, alarm signal, interlock signal between controllers, partial system and/or device status monitoring data and so on. The time requirement of time-critical data is very rigorous, delay time of second is generally disallowed, in certain special conditions, not even a millisecond delay. On the other hand, for most time-critical data, only the latest data are meaningful. If in a specific period of time, the data for some reason are not transmitted before the next data are produced, then the data will be discarded, and the latest data are coming into use.

- Non-critical data(message)

Such as user program data, configuration data, system or nodes installing and initialization information and so on. These data are relatively large and infrequently appeared. Time requirement of non-critical data is less rigorous than that of time-critical data, and it can therefore be transmitted using the residual bandwidth remaining after time-critical traffic has been allocated[7].

（2）According to the mechanism of data generation

- Periodic data

There are a lot of periodic data in industrial process, such as sensor acquisition data, the transmission of controller control signal and instruction and so on. The features of these data are: communications cyclical happening, relatively fixed point-to-point transmission of information, and the happening moment is generally predictable; they are time-critical and have higher priority; the frequency of occurrence is very high compared to that of paroxysmal data and statistical data.

- Paroxysmal data

Paroxysmal data, such as alarm signal and event notification signal, must be transmitted within a very short interval of time and are generally very short in length. These data are randomly generated, occur infrequently, and must be transmitted with the highest priority.

- Statistical(random)data

Such as database management message, numeric control program, client request service. The features of these data are: communication is random, and the happening moment is generally unpredictable; the transmitted data are non-critical and have lowest priority. Paroxysmal data and statistical data are also known as aperiodic data.

4. RESEARCH OF FIELDBUS PROTOCOL STATIC CHARACTERISTIC

4.1 Fieldbus Communication Reference Model

In order to realize interconnection operation and data exchanging among different manufactures and devices, International Organization for Standardization (ISO) issued “Open System Interconnect Reference Model” in 1983, known as OSI model. This model divides system communication function into seven layers, and the research of details of each layer is independent. In this way, communication function can be easily expended and modified inside layers without affecting other layers’ protocol[8].

On account of complicated operation and conversion between layers, and high cost of network interface, in full accordance with OSI reference mode to design fieldbus is obviously not suitable for the needs of the industrial field. In order to meet the real-time requirement of industrial field and reduce the cost at the same time, fieldbuses generally adopt simplification OSI reference model, that is, remove the general and non-time-critical application from the model, only reserve physical layer, data link layer and application layer. In general, according to the needs of industry specific application, many fieldbuses also add user layer to OSI model. At present, with the emergence and development of industrial EtherNet, TCP/IP clusters are also listed into fieldbus communication model, they use TCP and UDP to transmit non-real-time data and real-time data respectively. OSI reference model and several mainstream Fieldbuses communication model are shown in figure 1.

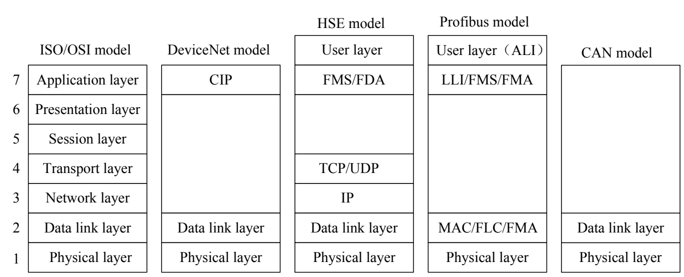

Figure 1. Comparison of OSI and fieldbus communication model

4.2 Layer Description of Fieldbus Protocol Static Characteristic

Fieldbus protocol static characteristics mainly include maximum data rate, maximum bus length, medium type, topology structure, protocol efficiency, development platform support, interoperability support and so on. The reason for called static characteristic is that it is protocol inherent and irrelevant with the dynamic change of bus load. Based on the description of fieldbus communication reference mode in section 4.1, the indices and corresponding explanations used for analyzing and evaluating fieldbus static performance can be proposed through layered description method, as shown in table 1.

Table 1. Layered description of fieldbus protocol static characteristic

Layer	Static Performance Indices	Description
PHYSICAL LAYER	Maximum data rate	This is one of the indices that measure data communication system's validity. When channel is definite, the higher message transmission rate the better validity.
	Maximum bus length	The bus length is inverse proportional to the data rate.
	Maximum node number	This index reflects the node capacity of a fieldbus.
	Topology structure	Fieldbus topology structure is the node interconnection mode, mainly includes bus, tree, star and ring. For those fieldbuses supported several topology structures, choosing which topology depends on many factors, such as reliability, expandability and performance.
	Medium type	For the great majority of fieldbuses, the standard communication medium is twisted pair wire. Coaxial cable, optical fiber, power line and RF are other options.
	Intrinsic safety support	This index is a important feature for measuring the differentiation between fieldbus and ordinary business network.
	Bus powered support	Fieldbus that supports intrinsic safety almost adopts bus powered technology.
DATA LINK LAYER	Maximum data size	Some fieldbus message can be transmitted by multi-frame, but the maximum data size per frame is fixed[9].
	Communication mode	Different types of data have different transmission requirements, so a suitable communication mode is very necessary for satisfying these requirements[8].
	Cyclic data support	Because there are many cyclic data in industrial process, so whether a fieldbus supporting cyclic data or not directly affects its real-time performance.
	Message priority support	Priority is a mechanism to transmit message according to importance, it is a important index to measure the static characteristic of data link layer.
APPICATION AND/OR USER LAYER	Acknowledged service support	For certain important data transmission, acknowledge service is a necessary link to ensure reliability.
	Interoperability support	Fieldbus interoperability is a property that allows the equipments from different manufacturers to work together for a given goal, it is a important feature of open system[10].

The data transmitted in fieldbus communication system must use specific frame format of data link layer. In the frame format, except for data bit, it also includes control bit, checking bit, and/or stuffing bit etc..Thus, protocol efficiency is another important index to measure the fieldbus static performance, it is the measurement of effective data transmission efficiency. Herein, protocol efficiency is defined as the ratio of the effective data size to the whole data frame size, it can be described by the following equation (1):

$$P_{peff}=\frac{N_d B}{N_d B+(\left\lceil \frac{N_d}{N_{f\max}} \right\rceil+1)L_{ovhd}} \qquad (N_d>0) \quad (1)$$

Where N_d is the effective data size(bytes) transmitted in data frame, N_{fmax} is the maximum data size per frame; B is the number of bit contained in one data byte, L_{ovhd} is the size of overhead, i.e. the additional number of bits used to transmit the data ; $f(x) = \lceil x \rceil (x \in R)$ is Gauss function, which denotes the biggest integer that is smaller than or equal to x.

However, in some industrial control networks, the data field is relatively large. When data information is less than certain bytes, padding bytes are required to ensure each data package meeting a minimum size, such as industrial EtherNet. The purpose of using this approach is to differentiate available data from network fragment and ensure that the happening of information collision can be detected. In this case, protocol efficiency can be described by the following equation (2):

$$P_{peff}=\begin{cases}\dfrac{N_d B}{\left\lceil \frac{N_d}{N_{f\max}} \right\rceil \times \left(N_{f\max}B+L_{ovhd}\right)+L_{ovhd}+N_{stuff}B} & \left(N_d>0, 0\le N_d-\left\lceil \frac{N_d}{N_{f\max}} \right\rceil \times N_{f\max} \le N_{stuff}\right) \\ \dfrac{N_d B}{\left\lceil \frac{N_d}{N_{f\max}} \right\rceil \times \left(L_{ovhd}+1\right)+N_d B} & \left(N_d>0, N_d-\left\lceil \frac{N_d}{N_{f\max}} \right\rceil \times N_{f\max} > N_{stuff}\right)\end{cases} \quad (2)$$

4.3 Diagram Comparison and Simulation Analysis of Fieldbus Protocol Static Characteristic

In section 4.2, the layered description of fieldbus static performance indices are presented, now, we can apply them in the case study of specific fieldbus. The six selected fieldbuses are FF, Profibus, Lonworks, ControlNet, DeviceNet and CAN, they are all very popular in the field of industrial control, and the comparability among these fieldbuses is good. The comparison of the static performance indices of selected fieldbus are shown in table 2.

Table 2. The comparison of static performance indices of six selected fieldbuses

Name / Indices	FF（H1）	Profibus（DP）	Lonworks	ControlNet	DeviceNet	CAN
Max. data rate （Kbps）	31.25	12000	1250	5000	500	1000
Max. bus length （meter）	1900	1200	2700	100	500	10000
Max. node number （per segment）	32	126	127	99	64	110
Topology structure	bus/tree	bus	bus/tree	bus/star/tree	bus	bus
Typical medium type	twisted pair/fiber	twisted pair / fiber	twisted pair / power line	coaxial cable/ fiber	twisted pair	twisted pair
Intrinsic safety support	yes	no	yes	no	no	no
Bus powered support	yes	no	yes	no	yes	no
Max. data size （byte）	251	246	228	510	8	8
Communication mode	C/S;P/S;RD[1]	C/S;P/S	P-to-P	P/S;P/C	P/C[2]	P-to-P[3]
Cyclic data support	yes	yes	no	yes	yes	no
Message priority support	yes	yes	yes	yes	yes	yes
Acknowledged service support	yes	yes	yes	yes	yes	Yes
Interoperability support	yes	yes	yes	yes	yes	No

1：Client/Server; Publisher/Subscriber; Report Distribution, 2：Procucer/Consumer, 3：Peer-to-Peer

The results of above indices can be directly acquired through studying protocol itself. However, protocol efficiency is related to the actual transmitted data size. Therefore, we choose three types of representative event triggered protocols and time triggered protocols respectively to simulate and analyze when they transmit N (N⩾0) bytes of data their protocol efficiency. Comparisons of three event triggered protocol, CAN, EtherNet and Lonworks are shown in figure 2; Comparisons of three time triggered protocol, Profibus, ControlNet and FF are shown in figure 3.

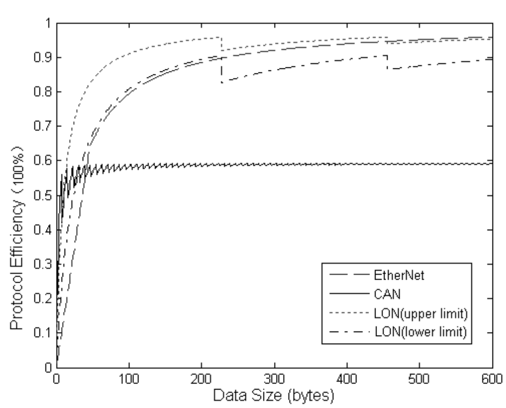

Figure 2. The comparison of protocol efficiency vs data size for EtherNet, CAN and Lonwoks

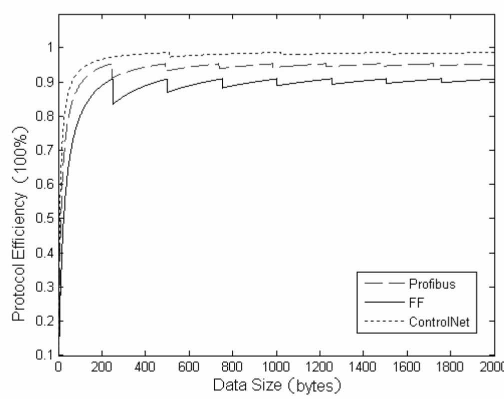

Figure 3. The comparison of protocol efficiency vs data size for Profibus, FF and ControlNet

Figure 2 illustrates that CAN protocol efficiency is best for small data size. For large data size, CAN is lower than Lonworks and EtherNet, this is because CAN needs more bits (overhead) to transmit the same size of data. With the increasing of data size, jitter will be appeared in these three cases. The jitter interval for CAN, Lonworks and EtherNet is 8bytes, 228bytes, 1500bytes respectively, this is exactly the maximum data size per frame. When data size is greater than 456 bytes, the rank of protocol efficiency is that EtherNet(98%)>Lonworks(96%)>CAN(59%).

From this we can conclude that EtherNet is more suitable to transmit large data information. However, for the small data information in industrial control, Ethernet requires more overhead than Lonworks and CAN, so its efficiency is not high. For using CAN bus to transmit large data information, we can split the large data information into small package, and transmit by muti-frame, but it is not convenient.

As shown in figure 3, whether the data size is large or small, the protocol efficiency of FF is always the lowest, Profibus is slightly higher than FF, ControlNet is the highest. With the increasing of data size, jitter will come into existence，this is also caused by the limitation of maximum data size per frame. For large data size, FF protocol efficiency is 91%, Profibus is 95%, ControlNet is 98%. Therefore, only looking from the aspect of protocol efficiency, the differentiation among these three time triggered fieldbuses is not big.

5. CONCLUSION

（1）In industrial control field, time triggered and event triggered MAC mechanism are all in demand. To meet the transmission requirement of all data type, in theory, it should be the mixture of the two modes. However, because they are totally different in principle, it is unpractical to unify them into a general MAC mechanism. Therefore, we should treat different problems with different ways according to the specific situation.

（2）The data transmitted in actual industrial field are very complex, and their real-time requirement and communication traffic are all different. On this account, when selecting fieldbus, users must firstly understand the major data type transmitted in the actual application.

（3）Through the way of layered description and diagram comparison, lots of static performance indices can be decomposed and classified effectively, and the favorable mapping relationship between application requirement and static performance indices is achieved.

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