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A PRIORITY-BASED TRANSFER SCHEME BASED ON INFORMATION MODELS IN SWITCHED ETHERNET FOR SUBSTATION PROCESS-LEVEL

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ABSTRACT

In order to overcome the problem of flow collision of the integrative information transmission in the switched Ethernet for substation process-level (SESPL), this paper proposed a novel priority-based transfer scheme in the end-nodes based on the information model, in which different priorities are assigned according to different information types by using the user priority field defined in the standard IEEE 802.1, and first-come-first-served (FCFS) and static priority queuing (SPQ) scheduling algorithms are used in the switch and end-nodes respectively. An implementation method through introducing a prioritization mechanism into the protocol stacks is presented. Case study on a typical substation feeder bay verifies the validity and feasibility of the proposed schemer.

Keywords: *substation process-level, switched Ethernet, information model, priority-based transfer*

1. INTRODUCTION

In traditional substations, the communication between the process-level and bay-level devices adopts hardwired point-to-point mode, which has the defects of the necessity of multiple complex wiring and that intelligent electronic devices (IEDs) cannot exchange information freely among each other. Due to low cost and highly transmission speed etc., installing Ethernet in substation process-level is a growing trend [1]. With the use of switched Ethernet technology in the substation process-level, time-critical and no-time-critical information may implement integrative transmission and the information can be highly shared over a common SESPL network.

Recently, some scholars make study on the feasibility of the information integrative transmission via the SESPL and have confirmed that the SESPL based on FCFS can meet the real-time demands of substation automations under the network light-load condition [2]. Nowadays, switched Ethernet and the IEC 61850 standard [1] are of great interest for substation applications. If more and more IEDs access to the SESPL network based on FCFS, it may cause congestion, flow collision and data losses on the emergency. A suitable way is to introduce the

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traffic priority-based transfer control technique. The implement of priority-based transfer control can be classified into two groups: end-nodes and intermediate systems (i.e., switches). On the one hand, in order to assure time-critical information has the priority of sending and receiving, a prioritization mechanism into the protocol stacks should be set in the end-nodes. On the other hand, a prioritization process may be implemented in the switches based on the IEEE 802.1 [3]. But in the SESPL, a network packet spends a large percentage of its total end-to-end time in the end-nodes [2], internal packet prioritization may be effective in order to have maximal control over the total packet transfer time.

Recently, the service priority-based in the end-nodes can gained through the following three kinds of mechanisms: 1) implementing in the link layer according to the standard IEEE 802.1 [3], 2) utilizing the type of service in the IP header and 3) controlling the PSH bit in the TCP frame. The selection of the service priority-based depends on the requirements for different information transmission in the network.

Owing to these actual above problems of using the priority-based transfer control technique, a novel priority-based transfer scheme in the end-nodes based on information model is proposed in this paper. In this scheme, the different information types in the SESPL have different priorities and time-critical information has the highest priority, and FCFS and SPQ scheduling algorithms are used in the switch and end-nodes respectively. The paper is organized as follows. Firstly classifying and modeling information via the SESPL is introduced, and an information model based scheme in the end-nodes for the priority-based transfer is proposed according to the standard IEEE 802.1. Secondly the implementation method through introducing a prioritization mechanism into the protocol stacks is presented. Finally case study on a typical substation feeder bay model shows the validity and feasibility of the proposed scheme.

2. CLASSIFYING AND MODELING INFORMATIN VIA THE SESPL

The main difference between the substation automaton system (SAS) based on the pure switched Ethernet and traditional SAS is the former contain the SESPL. A typical architecture is shown in Fig.1. Where, BU= Bay controller, protection unit or integrated unit of control and protection, ECT/EVT= Electronic Current Transducer/Electronic Voltage Transducer, CB= Circuit Breaker, ComU= station-level communication unit, Workstation = station-level station, SU= station-level unit, D/ES= Disconnector controller/Earth Switch.

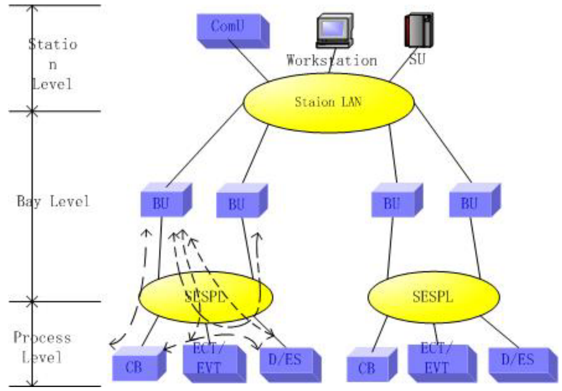


Fig.1 SAS typical structure based on Ethernet

2.1 Information Classification

As shown in Fig.1 (dashed line with the bidirectional arrow), the information transmissions exist in the bay-level devices, process-level devices, and between bay- and process-level devices. Because the time synchronization information of the sampled values via the SESPL using standard components is not possible today [4], this information type is not considered in this paper. The information via the SESPL can be classified into four types (IT_i), as shown in Table 1.

Table 1. Information classification

Type	Description
IT_1	Cyclic sampled measured values
IT_2	Acyclic transmission of events (e.g., trip command and interlocking information)
IT_3	Acyclic transmission of operational information
IT_4	Acyclic transmission of file or program segments

In the SESPL network, the information transmission of sampled value from ECT/EVT to BU forms the major part of the IT_1 with its short user data lengths. The events, such as trip commands and blocking signals for the mutual interlocking, are included in the IT_2. Operational information IT_3 (e.g., status indications, control, measured values, etc.) and maintenance information IT_4 (e.g., file transfer, setting, etc.) also need be transmitted from process-level devices to BU.

2.2 Information transmission Models

In IEC 61850 [1], the information transmission of IT_1 and IT_2 utilize Enhanced Performance architecture (EPA) model, which provides a 3-layer architecture with the fast response. These information transmissions adopt the Publisher/Subscriber model and Ethernet multicast mode.

For IT_3, real-time-oriented UDP may be effective for the upstream initiative monitor information transmission. In addition, TCP/IP model and acknowledged service on application level for the downstream control information transmission can be employed.

In order to ensure the integrity of IT_4, this information transmission relies on TCP/IP using the Require/ Response service model.

2.3 Information Models

Because of the fact that the seamless communication in substation will use the standard IEC 61850, and in practice, the IEC 60870-5 series standard has been generally adopted widely, it is practical scheme that the application layer adopts IEC 60870-5-104 protocol (IEC..104)□ 61850. In this scheme, concerning IT_1 and IT_2, the transmission requirements and application services data unit (ASDU) defined in the IEC 61850 standard is adopted and for IT_3 and IT_4, the ASDU defined in the IEC..104 is used, but the application protocol control information (APCI) defined in the IEC..104 is used for four information types.

The transmission delay of IT_1 information is around 3~10ms [1] depending on different sampling rates. Its Media Access Control (MAC) frame payload size L_{IT_1} is 66 bytes, which can be broken down the following two areas: APCI (6 bytes) and the typical measurement data ASDU (60 bytes) of ECT/EVT defined in IEC 61850-9-1 [1]. In addition, this information's frame arrival distribution is constant distribution owing to determinate arrival; however, other information's frame arrival distribution is exponential distribution due to random arrival.

IT_2 has the strict deadline requirements, which must be sent within 1~4 ms [1] via IEC 61850-7-2 [1] GOOSE (Generic Object Oriented System Event) messages. Its typical MAC frame payload size L_{IT_2} is 72 bytes, which is composed of the following two areas: APCI□ 6 bytes□ and GOOSE data ASDU (66 bytes). The content of the GOOSE data includes message header (50 bytes), Dynamic Network Announcement state information (8 bytes) and User State information (8 bytes).

The transmission delay of IT_3 is around 100~500 ms [1]. IT_3's upstream MAC frame payload size $L_{IT_3}^{up}$ is 66 bytes, which includes IEC..104 ASDU (32 bytes) and total protocol overhead (34 bytes). Its downstream MAC frame payload size $L_{IT_3}^{down}$ is 53 bytes, which is consisted of IEC..104 ASDU (7 bytes) and total protocol overhead (46 bytes).

IT_4 is usually adopted the multi-frame transfer, its transmission delay may exceed 1000 ms [1]. Its response MAC frame payload size $L_{IT_4}^{req}$ is 295 bytes, which includes maximal IEC..104 ASDU (249 bytes) and total protocol overhead (46 bytes). Its require MAC frame payload size $L_{IT_4}^{res}$ is 103 bytes, which includes IEC..104 ASDU (57 bytes) and total protocol overhead (46 bytes).

As indicated above, the information models are established (see Table 2).

Table 2. Information models

Type	Delay (ms)	MAC frame Payload Size□ byte□	Frame Arrival Distribution
IT_1	3~10	L_{IT_1} □ 66	Constant
IT_2	1~4	L_{IT_2} □ 72	Exponential
IT_3	100~500	$L_{IT_3}^{up}$ □ 66 $L_{IT_3}^{down}$ □ 53	Exponential
IT_4	≥ 1000	$L_{IT_4}^{req}$ □ 295 $L_{IT_4}^{res}$ □ 103	Exponential

3. PROPOSED SCHEME

As we can know from the analysis in section 2 that the transmission of the time-critical information (IT_1 and IT_2) adopts EPA model, and therefore the priority-based transfer scheme in the end-nodes that would be carried out in link layer may be more effective. This scheme is based on the IEEE 802.1standard.

3.1 Overview of The IEEE 802.1 Standard

A major step toward deterministic behavior in Ethernet networks is to eliminate the random CSMA/CD bus arbitration. This can be achieved by using the latest Ethernet switch technology instead of a hub-based infrastructure. Switch technology divides collision domains into simple point-to-point connections between network components and end-nodes. This effectively eliminates collisions, significantly reducing delay, and the random backoff algorithm is no longer required. The concept of switching or of MAC bridging, which was introduced in standard IEEE 802.1 in 1993, was expanded upon in 1998 by the definition of additional capabilities in bridged LANs [3, 5]. The aim was to provide additional traffic capabilities so as to support the transmission of time-critical information in a LAN environment. In addition, the standard describes the user priority field of MAC-Frames (formerly 802.1p). The up to 8 available output queues per port inside the switch are called traffic classes. The scheduling strategy inside the switch in case of more than one queue per port is not determined by the standard. Two queue scheduling algorithms are usually used: FCFS and SPQ. The SPQ algorithm assigns a strict priority to important traffic. It flexibly prioritizes traffic according to network protocol, the incoming interface, the packed size, the source or destination address, and so on.

3.2 Proposed Scheme

In order to meet different transmission requirements of four information types via SESPL, in this paper, an information model based scheme for priority-based transfer is proposed, which priority level is assigned according to the different information types by using the user priority field of MAC-Frames, in addition, FCFS and SPQ scheduling algorithms are used in the switch and end-nodes respectively. The following several aspects is considered in the proposed scheme:

1) Because the transmission of trip and blocking information（IT_2）requires high reliability and speed and the information transmission shall not be influenced by other information flows, this information is given the highest priority (user priority = 7) according to IEEE 802.1;
2) The sampled information within IT_1 is assigned with user priority = 6;
3) The operational information (IT_3) is assigned with user priority = 5;
4) The maintenance information within IT_4 has the lowest priority (user priority = 4);
5) In order to ensure the transmission requirement of the high priority information, SPQ algorithm in the end-nodes is used;
6) The number of available traffic classes in the end-nodes is identical with the number of user priorities, and the number depends on the information types in the end-nodes.

4. SCHEME İMPLEMENTATİON

The proposed scheme is implemented in the end-nodes by introducing a priority software thin layer (PSL) between the Ethernet controller driver and the protocol multiplexer level (the level where the network packets are routed to the appropriate protocol handle software). PSL can regulate the information passing through the protocol suite. This optimized protocol stack model would be implemented in a VxWorks RTOS environment (VxWorks is used for illustration purposes only). Fig.2 shows the protocol stack implementation model and PSL software structure.

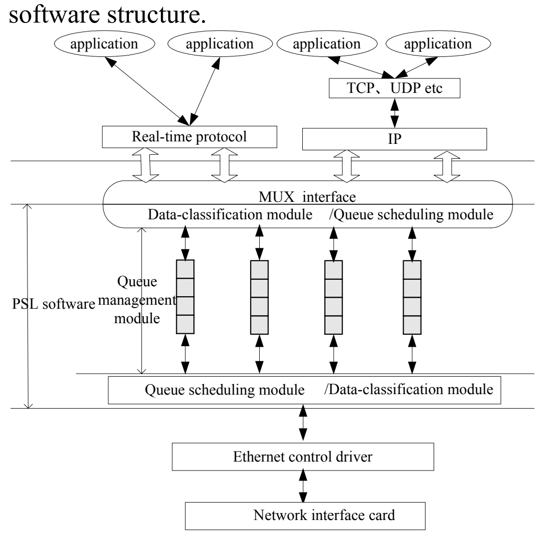


Fig.2 Plot of the protocol stack implementation model and PSL software structure

In Fig.2, MUX interface is the standard interface for Ethernet in VxWorks [6]. PSL software is composed of three modules, such as data-classification module, queue management module, and queue scheduling module. Data-classification module places all transit and receive packets in different queues corresponding to their priority. Queue management module provides the necessary algorithms for managing different queues. Queue scheduling module selects the next packets to be passed to the next layer by the SPQ algorithms whenever the end-nodes resources are able to handle it.

The implementation of PSL software adopts Middleware technique, which has the following advantages: easy-to-use, easy-to-expandable, etc. PSL middleware software architecture is shown in Fig.3. This architecture is composed of API (Application Programming Interface), MUX interface and PSL software. API provides the following three library calls for the applications: Init(), OnSend() and OnRecv().

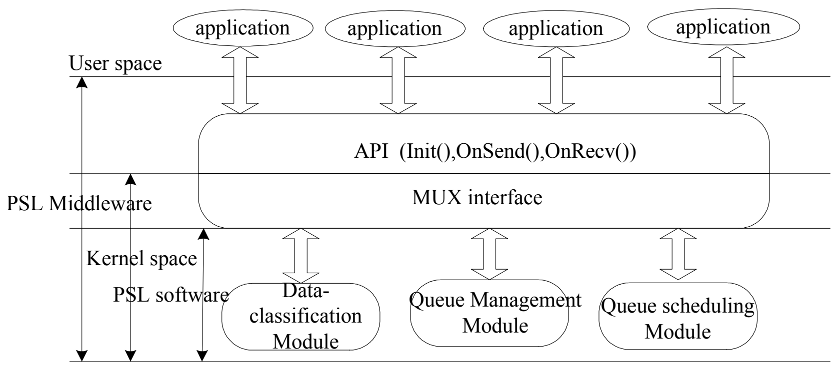


Fig.3 PSL middleware software architecture

When system is initialized, multiple queues for both transmit and receive is implemented by calling Init() API. The number of queue depends on the information types of the end-nodes. When the end-nodes send data, by using OnSend() API, each application maps the application priority-tag into the user priority of MAC-Frame, and transmits the data frame to the transmit queue of PSL software, where data classification, queue management and scheduling are carried out. After that, the data frames are sent to the hardware queue in Ethernet driver controller through the MUX interface. The end-nodes receive data by the following three steps: Firstly, data arrives the buffer of the Ethernet driver controller through the physical layer, and the data frames are sent to the receive queues of PSL software through the MUX interface; Secondly, the data frames are transmitted to the higher protocol layers after processed by PSL software; Finally, the applications receive data by calling OnRecv() API.

5. CASE STUDY

The commercially available OPNET 8.0 network simulator [7] is used for the simulation study. A case of typical substation feeder bay is given to test the feasibility and validity of the proposed priority-based transfer scheme. This feeder bay consists of three ECT/EVT PISAs (Process Interface for Sensors and Actuators), three disconnector PISAs, two earth switch PISAs, one fast earth switch PISA, one circuit breaker PISA, one bay controller, one protection unit and one differential protection unit. This above devices is connected over the SESPL. The following assumptions are made in the simulations: 1) the data-sampling rate of ECT/EVT is specified as 1,000 Hz and this data is transmitted at a rate equivalent to the sampling frequency; 2) the performance level of protection and control is class P2/P3 defined in IEC 61850 [1] and 3) each PISA also does a file transfer and the file size is 1Mbytes (25% of the total transfer send and 75% receive). In this case, the maximum transmission delay requirements of IT_1 and IT_2 are all bounded within about 3 ms based on the above supposition. In the simulation study, the information models established in section 2 and the below SESPL models are adopted, in addition, file transfer begins at 109s and lasts 10s.

5.1 The SESPL Models

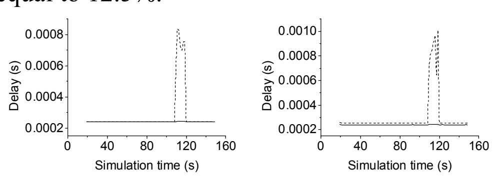
SESPL can adopt the network topology structure as follows: star, bus-like, ring and multilevel. In this paper, the network topology is confined to star topology, with one centralized switch connected to one end-node on each physical port. Full-duplex transmission channels with a transmission capacity of C=100 Mbps are assumed. The end-nodes model is implemented by extending the standard models for switch and MAC to incorporate priority queuing. In the switch and end-nodes the scheduling strategies FCFS and SPQ are considered. Packet processing is assumed to be store and forward. The application is directly coupled to the data link layer, so that influences from the higher protocol layers (e.g., network, transport layer, etc.) are considered by selecting a corresponding payload size.

5.2 Definition of The SESPL Load

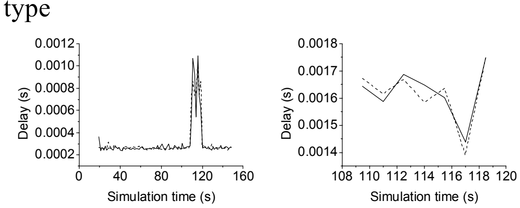
It would be too time-consuming to examine all the connections in the SESPL, and therefore we need to focus on the connection with the highest load. The information transmission analysis in section II shows that the bay units have the highest load in the SESPL due to the aggravation information flow distribution, and therefore the load of the bay units can be taken as the load of the SESPL (P_{load}).

5.3 Analysis of Simulation Results

Fig.4 plots the transmission delay of four information types via the SESPL with and without priority control. In this case, P_{load} is equal to 12.5%.



(a) IT_1 Information type (b) IT_2 information type



(c) IT_3 Information type (d) IT_4 information type

-·-·-· Without priority control

——— With priority control

Fig.4 Transmission delays of four information types with and without priority control

The following conclusions can be drawn from Fig.4: Without the priority control, the transmission delay of IT_1 and IT_2 is affected by the transmission of IT_3 and IT_4, especially the file transfer of IT_4; However, with the priority control, the transmission delay of IT_1 and IT_2 are less affected than that of IT_3 and IT_4. This may thank to the higher priority level assigned for IT_1 and IT_2 so that their delay is not seen increasing drastically.

5.4 Impact of the SESPL Load

The results above are obtained under the network light-load, and therefore the performance evaluation should be studied under heavy-load condition. Fig.5 plots IT_1 and IT_2 individual transmission delays under the heavy-load condition (in this case, P_{load} = 82.5%).

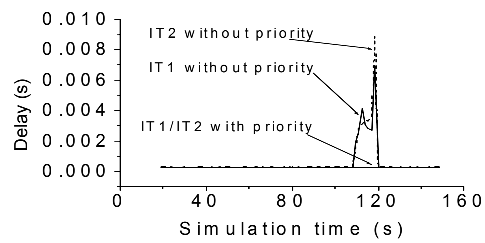


Fig.5 Transmission delay of IT_1 and IT_2 under heavy-load condition with and without priority

It is obvious from Fig.5 that IT_1 and IT_2 cannot keep their delay constraints without the priority control, and their transmission delay exceed 6 ms; However, the transmission delay of IT_1 and IT_2 stabilizes around an average value of 260 μs with the priority control, even under network heavy-load condition.

6. CONCLUSION

A scheme based on information models in the end-nodes for the priority-based transfer is proposed to solve the flow collision problem in the information integrative transmission via the SESPL, and further the implementation method of this scheme is introduced. The scheme proposed is successfully applied to a typical substation feeder bay. Simulating results show that the effectiveness of the proposed scheme.

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BIOGRAPHY

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