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Design of Time Synchronization Method for Real-Time EPON

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Abstract

Real-time performance problems are mainly obstacles on Ethernet used in industrial control. In this paper, a RT-EPON concept can be proposed, and the frame structure, the protocol of RT-EPON MAC, and time slot allocation mechanism have been designed. In a test system, the designed Mac protocol and time synchronization method have been tested, it is shown that the RT-EPON system is stable and reliable, and the BER (Bit Error Rate) is below 10^{-10} on the physical layer of fiber link.

Keywords: *real-time Ethernet*, *time synchronization, EPON*

1. Introduction

The industrial Ethernet is one of LAN technology which Ethernet used for industrial control and management. If the response time of application is less than 5ms, Industrial Ethernet can not competent. In order to meet the high performance real-time application, companies and standards organizations have put forward various enhance real-time industrial Ethernet technology solutions. All of them builds on the IEEE 802.3 standard, improving real-time performance from modified related standards, and achieve seamless connectivity with standard Ethernet, which is called real-time Ethernet [1-4] (Real Time Ethernet, referred to as RTE).

Ethernet PON (EPON) is a PON-based network that carries data traffic encapsulated in Ethernet frames [5-6] (defined in the IEEE 802.3 standard). It uses a standard 8b/10b line coding (8 userbits encoded as 10 line bits) and operates at standard Ethernet speed [7]. EPON became the first optical technology cost-effective enough to justify its mass-deployment in an access network [8].

Therefore, this paper will integrates structure of Real Time Ethernet and Ethernet passive optical network (EPON), and proposed real time Ethernet passive optical network (RT-EPON). The RT-EPON structure has full advantages of both, not only can meet the stringent requirements of industrial real-time control, but also be applied to the real time business field of home control network, information network [9].

And compared with existing real-time Ethernet solutions, the RT-EPON network has the following advantages:

1.1. Low Transmission Loss

Using optical fiber as the transmission medium, transmission loss is a low and long distance (up to 20km); security performance; anti-electromagnetic interference;

1.2. Low Cost

Using passive optical network structure, saving the trunk fiber, making the reduction of failure points in the network, maintenance of facilities, equipment; cheaper than traditional optical transmission equipment, network construction and low cost;

1.3. Higher Real-Time Performance

Real-time protocol in the data link layer, more accurately reflects real-time data transmission and controls to achieve higher real-time performance;

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1.4. Real-Time Services

If the protocol stack implemented by FPGA, real-time response time and jitter can be controlled less than 100ns, can be applied to high-performance real-time data transmission or fast synchronous motion control applications [9].

2. RT-EPON Network Structure

RT-EPON network structure shown in Figure 1, the use of multipoint PON topology [10]. It consists of central node, access node, and optical distribution network (ODN). By fiber optic and passive branching devices connected through a central node in the tree network and multiple access nodes. Each access node is connected to the subnet number of user services, each user real-time business subnets passive optical network for data exchange.

Central node is the core part of RT-EPON, its role is to implement communication between the access nodes. The central node provides operations, monitoring information, time slot allocation, schedule, maintenance and management for all the access node. In the downstream direction (from the central node to access node direction), the central node received coupled data from the ODN and forward to the downstream wavelengths, and broadcasts to each access node.

ODN consists of the optical splitter and fiber. Works with single fiber bi-directional mode in each fiber link, it can transfer upstream and downstream data with two wavelengths in a fiber. In the downstream direction, the main function is to complete the distribution of optical signal power, the signal will be distributed one fiber into several roads, the central node will forward the data broadcast to all access nodes. In the upstream direction (from the access node to the central node), the various branches of the optical signal coupled into the higher fiber, all the data from access node coupled together to form the upstream data transmission to the central node.

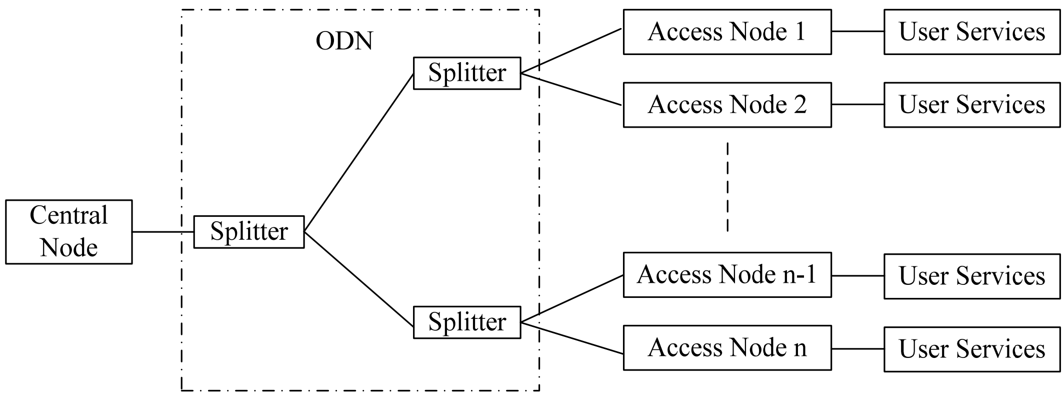

Figure 1. RT-EPON network structure

Access node as the ending part of the network service, closing to the user, whose role is to provide the user side interface for the RT-EPON, processing the data frames from the central node, the downstream data forward to the variety of business users, while the variety user data adapt to RT-EPON frames and send to the central node in the allocated time slots.

RT-EPON offers a variety of real-time services of single network transmission platforms, such as CAN, the unified voice and other data transmission, using a fixed time division multiple access (TDMA) way to access the network.

3. Frame Format Design

Compared with the absolute distance and time delay compensation method in standard EPON network time synchronization, the relatively time synchronization method makes the nodes time shift and the network delay as a whole, using the time difference which the central node receive data adjust each node to the appropriate slot. Thus, it is more simple and easier to achieve, no separate time stamps synchronization and ranging delay compensation.

According to the RT-EPON medium access control mechanism, two formats frames are defined, one is control frame; another is data frame[11], shown in Figure 2. The control frame can be divided into GATE, REPORT and START, they are used for time slot allocation and network management. The definition of control frames types and data frame types are shown in Table 1.

GATE frame and REPORT frame

SFD	SA	DA	Type	Reserved	FCS
1B	1B	1B	1B	1B	1B

START frame

SFD	SA	DA	Type	Reserved	Time Stamp	PAD	FCS
1B	1B	1B	1B	1B	4B	nB	1B

DATA frame

SFD	SA	DA	Type	Reserved	Time Stamp	Message	FCS
1B	1B	1B	1B	1B	4B	52B	1B

Figure 2. Frame formats of RT-EPON MAC

Table 1. Definition of frame type

	Name	Value(HEX)
Control Frame	GATE	01h
	REPORT	08h
	START	02h
Data Frame	User Data Frame	04h
	IP	Reserved
	Other	Reserved

4. Time Synchronization Mechanism

Time synchronization is a critical issue in network systems composed of numerous distributed nodes. In general; a node clock drifts away from real time by 10^{-6} to 10^{-4} seconds per second [12]. In the Internet, NTP is commonly used for rigid time synchronization [13-14].

4.1. Time Slot Allocation Mechanism

RT-EPON used fixed time slot mechanism in its medium access control (MAC) protocol, unified by the central node for slot allocation and maintenance. According to the type of business and real-time requirements of each access node, central node assigns the corresponding time slot width, and downstream information via the central node broadcast to all access nodes, chooses to receive the corresponding node, and access node forwards the data to the user.

Because of the distance difference between central nodes and every access node, and starting time difference of each access node, in order to avoid data conflicts between access nodes, synchronize access nodes is needed , its transmission time is adjusted to the appropriate time slot.

4.2. Relatively Time Synchronization

In this paper, a relatively time synchronization method is proposed, shown in Figure 3. Central node sends the GATE frame to access node i in the slot allocation window, and the corresponding access node sends REPORT frames, also record the sending REPORT frame time ts0. Central node receives REPORT frame, and records the receiving time t0. If central node does not received frame REPORT in the time, the corresponding access node is not present. Then central node is continuing to probe the next node.

After the query has finished, the central node computes the amount of adjusted time for each access node which was found, $\Delta ti = ti-t0$, ti is the scheduled arrival time from access node i to the central node. Subsequently, the central node will broadcast the amount of each access node adjusted time Δti by START frame.

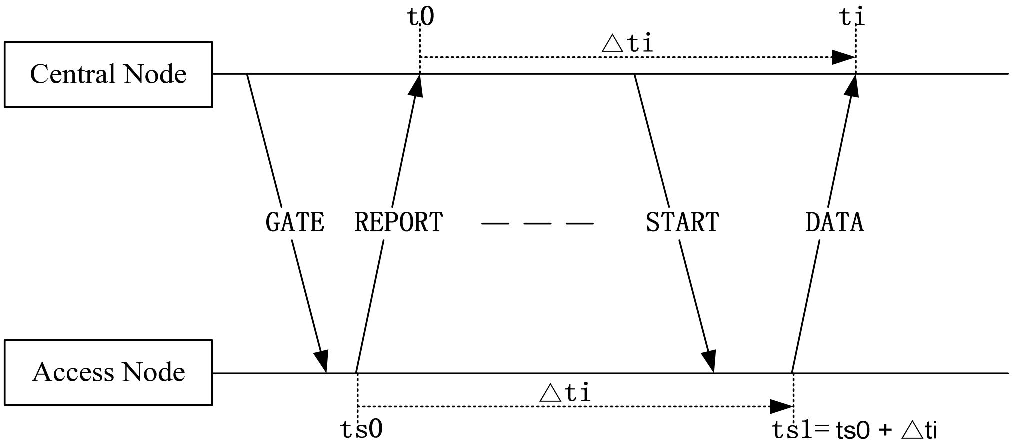

Figure 3. Relatively time synchronization

The corresponding access node receives START frame, extracting each adjustment time, and then determines the time of the first uplink data transmission: ts1 = ts0 + △ti.

Compared with the absolute distance and time delay compensation method in standard EPON network time synchronization, the relatively time synchronization method makes the nodes time shift and the network delay as a whole, using the time difference which the central node receives data adjust each node to the appropriate slot. Thus, it is more simple and easier to achieve, no separate time stamps synchronization and ranging delay compensation.

4.3. Dynamical Time Slot Synchronization

When the network is running, the existence of two small clock frequency offset, transmission path delay and other dynamic changes, all access nodes must be dynamically synchronized to avoid neighbor conflicts. The specific process is shown in Figure 5. The central node receives the uplink data frame from the access node, records the actual arrival time t1', calculates time difference between the actual arrival time t1' and the scheduled arrival time t1, △t = t1-t1', and this difference as a time stamp of the data frame, and forwards data frames to the access node. If corresponding access node receives data frames from downlink, after the extraction of time stamp, it will send the next cycle time, and adjust from ts2 to ts2': ts2' = ts1 + T + △t (T for the whole time slot cycle), achieving dynamic synchronization [15].

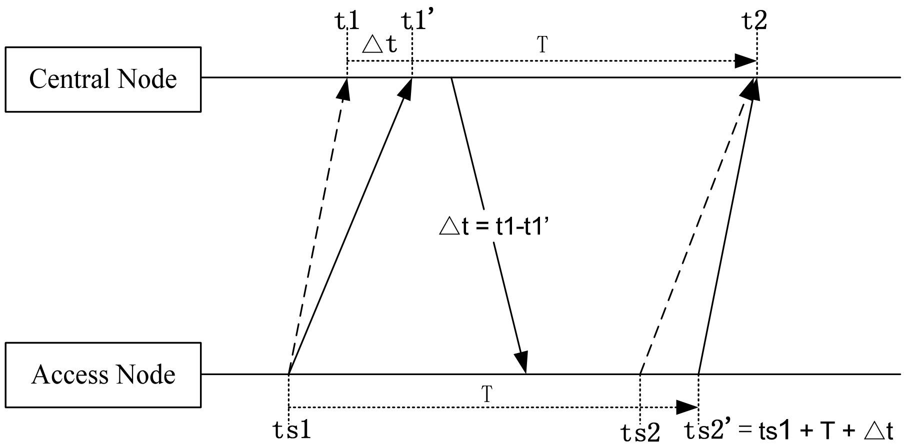

Figure 3. Dynamical time synchronization

5. Experimental Test

In order to verify the performance of real-time MAC and time synchronous method, a RT-EPON test network is built. The experimental network consists of a central node, 16 access nodes, and optical fiber. The optical link speed is 100Mbps with a single fiber bi-directional mode, the wavelength of upstream is 1310nm, downstream is 1490nm. The central node calculates offset time for every access node. The adjustment time of each access node is shown in Table 2. 6 cycles adjustment time is selected, T1 is the first period, Δt_i is the adjustment time of access node i. It shows that the time synchronization mechanism is feasible.

Table 2. Adjustment time of each access node in 6 cycles

	△t1	△t2	△t3	△t4	△t5	△t6	△t7	△t8	△t9	△t10	△t11	△t12	△t13	△t14	△t15	△t16
T1	3	-5	4	-1	2	-3	3	2	4	-1	-2	5	2	1	-2	-5
T2	-3	2	-2	4	3	-2	4	-4	5	3	4	-2	-3	3	5	3
T3	-1	-2	-4	3	1	5	2	-2	-2	5	1	4	-2	-2	1	4
T4	4	-3	5	-2	-5	2	3	3	3	4	3	-2	5	4	-4	-2
T5	1	2	1	2	-2	3	-3	2	1	2	-2	3	1	-5	-2	5
T6	-2	3	-1	1	3	-1	-2	-1	-2	-3	-4	-1	-3	-3	3	2

6. Conclusion

The automation technology user would like to see just one standard solution for industrial Ethernet. In this paper, RT-EPON network structure has been proposed and the frame structure and protocol of RT-EPON MAC has been designed, which are based on multipoint to point passive optical network structure. And the corresponding time slot allocation mechanism has been designed.

Acknowledgement

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