MODELING THE BEHAVIOR OF PROFINET IRT IN GIGABIT ETHERNET NETWORK

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ABSTRACT: This article deals with the control device sending control information in separate frames to IO devices that are connected to it via Ethernet comprises one approach to transmitting control data when it comes to real-time Ethernet communication systems. Today's modern industrial Ethernet networks enable such a cycle time that may be shorter than 1ms in hard real time systems.

KEY WORDS: Ethernet network, control device, communication systems.

1 INTRODUCTION

The control device (master) sending control information in separate frames to IO devices (slave) that are connected to it via Ethernet comprises one approach to transmitting control data when it comes to real-time Ethernet communication systems. This approach is used by PROFINET IRT. In this case, control data that is smaller than 36 bytes does not influence transmission time because this way the frame size cannot exceed the minimal Ethernet frame size of 64 bytes. A disadvantage of this method is that due to the frame size mentioned above, the payload factor may amount (by 36 bytes and small data packets) up to only 56% [1]. In this article, I analyze the frame forwarding method of PROFINET IRT in Ethernet networks from the perspective of the following question: What impact does an increase of the bitrate have on the performance of the system?

2 A METHOD TO ESTABLISH THE PROFINET IRT CYCLE TIME

In the following, I analyze the principles of the IRT protocol and of determining the bus cycle time in various situations..

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For example, I explore the impact of the payload and the length of the network segment on bus cycle time

2.1. The profinet irt frame format

The frame format of Profinet IRT is based on the standard structure of IEEE802. Ethertype 0x8892 is used in order to identify the protocol. 2 bytes (Frame ID) from the available data storage space identifies the cyclic IRT frame; other 8 bytes contain the devices attributes (IOPS, IOCS), and the ADPU status bits [2]. This leaves a space of 36-1490 bytes for the actual control data (Figure 1).

Pre-amble 7 Byte	SFD 1 Byte	Dest. Addr. 6 Byte	Surce Addr. 6 Byte	Ether-type 2 Byte	Frame ID 2 Byte	**IRT Data 36-1490 Byte**	FCS 4 Byte

Figure 1. The structure of the IRT frame [2]

The minimal frame size amounts to 64 bytes without the preamble according to the standard. The maximal size is 1518 bytes. When calculating cycle time, one must also consider the interframe gap (IFG) which amounts to 12 bytes.

2.2. Calculating cycle time

Considering that the Profinet IRT controller sends or receives a separate frame for each IO device, one must take four important factors into account when establishing the cycle time:

1. the order of frame transmission,
2. the size of the control data that determines the size of the frame,
3. the bitrate,
4. the frame forwarding time and the delay time of the device and the medium.

The following diagram (Figure 2) shows the space-time model of the Profinet IRT frame forwarding, which provides the basis for determining the cycle time [3].

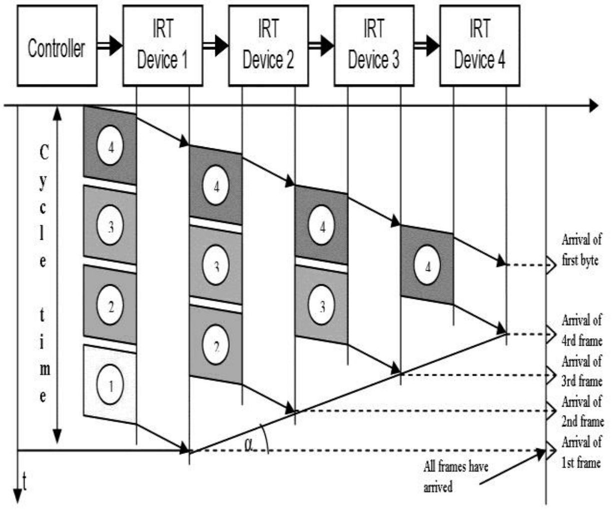

Figure 2. Space-time diagram if α >0.

Based on figure 2 the following relationship can be established:

$$T_{CT} = T_M + T_D + N \cdot (T_F + T_{IFG}) \ ; \ \text{if} \ \alpha > 0 \qquad (1)$$

- TF – frame forwarding time; it depends of the frame size and bitrate,
- TIFG – inter frame gap (IFG),
- TD – delay time coming from the network switch of the IRT devices
- TM – delay time of the medium (cable) approximately 5ns/m),
- TCT –IRT cycle time,
- N – the number of IRT devices.

An important observation is that α then equals a value of zero, being optimal for data transmission, if the frame forwarding time equals the delay time of the devices and the medium.

$$T_F + T_{IFG} = T_M + T_D \qquad (2)$$

This results in a complicated situation because the frame forwarding time depends, for one, on the frame size and, second, the bitrate. Further, it may occur that α will become lower than zero (Figure 3) [3, 4].

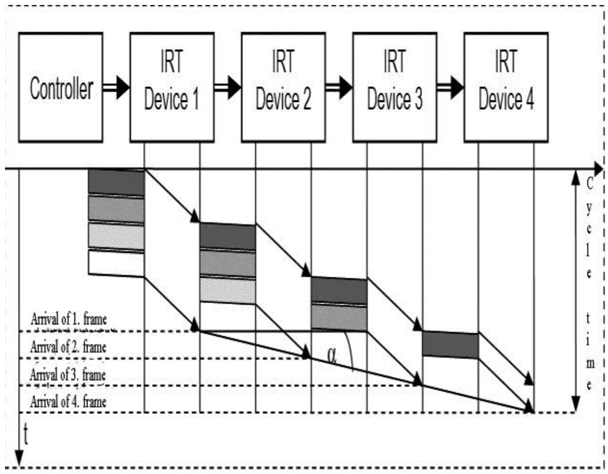

Figure 3. Time-space diagram if α < 0.

It follows from the figure above that: First, the order of arrival of the frames has changed. Second, the equation for calculating cycle time has changed as well as shown below:

$$T_{CT} = T_M + T_D + N \cdot (T_F + T_{IFG}) \ ; \ \text{if} \ \alpha > 0 \qquad (3)$$

Depending on the payload, in a Gigabit Ethernet network, equation (3) is to be applied if the frame forwarding time is lower than the delay time of the devices and the segments (α < 0). If α > 0, equation (1) is to be used.

The theoretical assumptions can be made applicable if the frame forwarding time is described as a function of the bitrate (b=1Gbps) and the control data size (d_{DATA}). For a control data size that is smaller than 36 bytes, the following equation is to be used:

$$T_{CT} = N \cdot (T_M + T_D) + 0{,}672 = 1{,}1 \cdot N + 0{,}672 \ ; \qquad (4)$$

T_M and T_D denote the delay time of the medium and devices respectively. The delay time of the devices is 0,6μs in the case of Profinet IRT systems with a 1 Gbps network. The delay time of devices in a segment of a maximal length of 100 meters equals approximately 0,5μs (to be accurate: 0,454 μs).

If the control data size exceeds 36 bytes, the following can be established:

$$T_{CT} = \frac{8 \cdot (48 + d_{DATA}) \cdot N}{b} + T_D + T_M ; \ \text{if} \ \alpha \geq 0 \qquad (5)$$

$$T_{CT} = \frac{8 \cdot (48 + d_{DATA})}{b} + 1{,}1 \cdot N = ;$$

$$= 0{,}384 + 0{,}008 \cdot d_{DATA} + 1{,}1 \cdot N \text{ if } \alpha < 0 \qquad (6)$$

The previous models underline the importance of determining what data quantity makes data transmission the most optimal; in other words, at what data quantity will cycle time will reach its minimum. In order to establish this, relation (2) will provide the starting point; if α = 0. In practice, this looks like the following:

$$d_{OPT} = 27 + 0{,}5657 \cdot L ; \qquad (7)$$

As shown above, L denotes the length of the segments (max. 100 meters). I calculated with a constant of T_D = 0,6μs and a segment delay time of τ = 0,00454μs per meter of cable [5].

At this point an interesting conclusion can be drawn: In contrast to logical expectations that a shorter segment produces a more optimal data transmission, in a Gigabit Ethernet network, the most optimal data payload will result from the use of the maximal cable length of 100 meters. As an example a network consisting of 50 m long segments, the optimal payload will be 55 bytes (Figure 6). Further, since under the level of 36 bytes the frame size does not depend on the data quantity, it logically follows that relation (7) is hereby not applicable. Consequently, segments shorter than L_{min} ≈ 16m, in effect, do not influence data transmission.

3. ANALYZING CHANGE IN CYCLE TIME

In order to analyze changes in cycle time I used a model which I developed in Labview 8.2 [6]. It allows for studying cycle time in relation to a theoretically unlimited number of node devices (N) and a payload range from 1 to 1024 bytes. It can be equally applied to Fast Ethernet and Gigabit Ethernet networks. Similarly, one can set up the device delay time (T_D) and the segment length.

3.1. Cycle time as a function of the number of io devices

As a first step, I analyzed how cycle time varied as a function of the number of IO devices both when transmitting lower data quantities (36 bytes or less) and higher data quantities (128 and 256 bytes) in Gigabit Ethernet network.

In each case, I used the maximum length of 100 meters as segments (Figure 4). The result was that, at a constant payload, cycle time increased linearly with the increase of the number of IO devices, similarly to Fast Ethernet networks [1]. Increasing the bitrate, cycle time decreases considerably. At larger payloads (128, 256 byte), it decreases to one tenth of its former value, whereas at smaller data quantities (32 bytes) to its one sixth. That is, as also shown by equation (7), in this case, a segment length of 16 meters would be most ideal and not 100 meters. Further, according to (3), if α < 0, cycle time is greatly influenced by the delay time in the medium (the length of the segments).

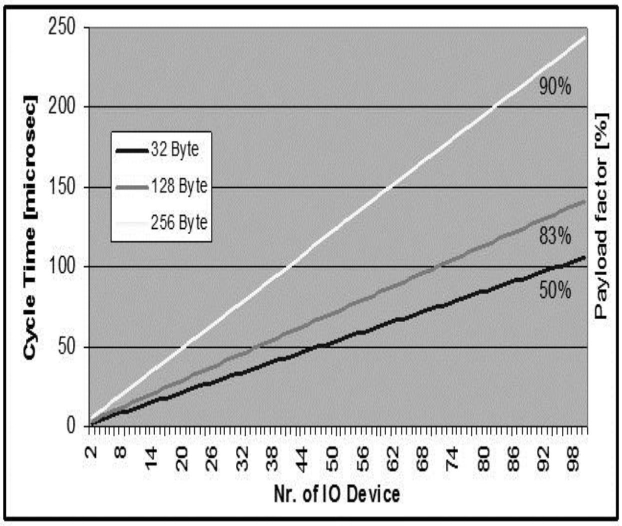

Figure 4. The variation of cycle time as a function of nodes.

It appears to be a further advantage that the cycle time is lower than 250μs even with 100 node IO devices and at payload of 256 bytes. In other words, cycle time is by far within the time limit (1ms) of the hard real-time system even with a 50% IRT time gap [1].

3.2. Cycle time as a function of payload and the length of segments

Let us turn the attention to a variation of cycle time as a function of the payload. For this analysis, let us consider three cases of the same bus typology network, which is connected with a segment of 100 meters and has a bitrate of 1Gbps (Figure 5). The cases however differ in the number of nodes: 10, 50 and 100.

The figure included above shows that the cycle time does not vary when an optimal payload (with

100 meters long segments, 83 bytes) is applied as stipulated by (7). It can be argued that cycle time does not depend on the payload. This presents a great advantage – beside the decrease of the cycle time – over a Fast Ethernet, where the variable was unaffected by payload only under 36 bytes.

Further, one should take note of the change of the ideal payload as a function of the segment length (Figure 6).

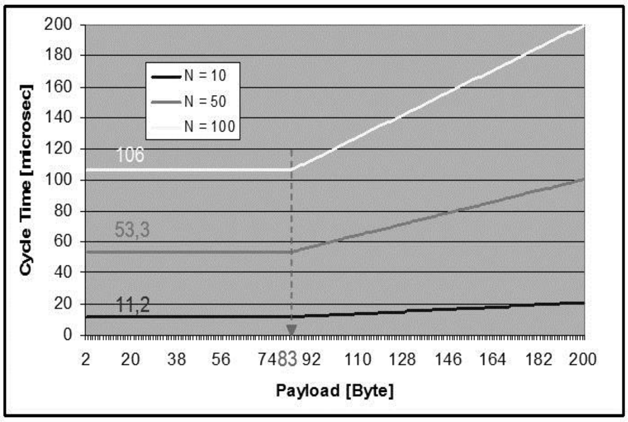

Figure 5. The change of cycle time due to a change in payload.

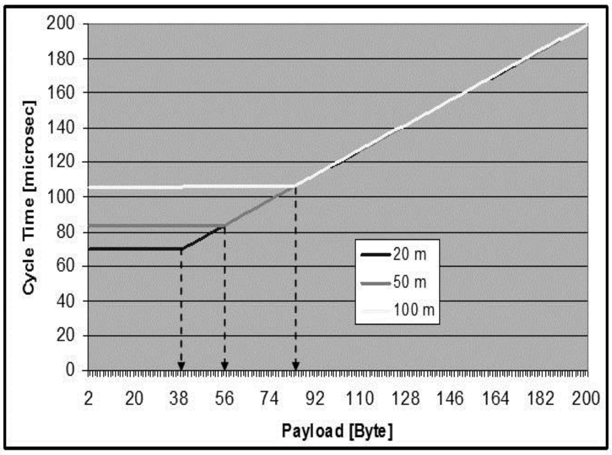

Figure 6. The change of the optimal payload according to segment lengths.

It may be a somewhat surprising result at first glance that increasing the segment length entails an increase in the value of the optimal payload: from 36 bytes to 83 bytes (36 bytes is realized at 16 meters). However, if equation (2) is correct, this should actually occur.

4 CONCLUSIONS

Today's modern industrial Ethernet networks enable such a cycle time that may be shorter than 1ms in hard real time systems. The applied model sheds light on an intensely discussed question; that is whether it is worth increasing the bitrate of industrial Ethernet networks and thus to utilize the advantages provided by Gigabit Ethernet in such industrial contexts where the size of data to be transmitted is considerably small. Two basic factors were identified: The delay time that originates from the typology (TD and TM) and the transmission time. The former is independent on the quantity of data, and increasing the bitrate does not result in reductions, while the latter is considerably influenced by the data quantity, but it can be reduced by increasing the bitrate. The presented analyses show that, Profinet IRT will become efficient when a payload that is close to the optimum (between 36 and 83 bytes).

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