FLEXRAY NETWORK UTILIZATION EVALUATIONS
BASED ON STATIC AND DYNAMIC SEGMENTS

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ABSTRACT

This paper proposes a FlexRay system model that is based on communication cycles with both static and dynamic segments. Based on this model, equations for computing the network utilization are derived. Matlab simulation results show that the FlexRay network utilization is affected by various factors, such as the length of message frames, the percentage of the number of message frames in static or dynamic segments, and the number of static slots and minislots. Furthermore, the effects of these factors are illustrated through figures and analyzed.

Index Terms— FlexRay, Static Segment, Dynamic Segment, Network Utilization.

1. INTRODUCTION

In recent years, FlexRay, a new time-triggered in-vehicle communication protocol, has been introduced to support time-critical applications in vehicles. It is developed by the FlexRay Consortium, which consists of worldwide automotive and communication labs [1]. The latest version of FlexRay is “Version 2.1 Revision,” which was released in December 2005 [2]. This standard is capable of supporting multiple network topology structures, in addition to support the bus topology. The media access control (MAC) scheme combines the advantages of both time-driven and event-driven protocols. Avoiding untimely transmission, bus-guardians therefore (the hardware electronic equipment monitoring data transmission) increase FlexRay’s reliability. So far, FlexRay has achieved a data rate of 10 Mbps [3].

Timing analysis and network utilization evaluation are significant for FlexRay to guarantee predictability and reliability. T. Pop studied the timing properties of message frames transmitted in static and dynamic segments in [4]. K. Schmidt, E.G. Schmidt, and Kwang-Ho Jung studied message frame scheduling problems in static and dynamic segments in [5, 6, 7]. Bongjun Kim focused on the analysis of message frame delay probability based on a Markov Chain model in the dynamic segment in [8]. In the field of network utilization evaluation, the network utilization of FlexRay static segments was studied in [9]. However the work in [9] was based on a dedicated system model with only static segments. It did not address dynamic segments and other factors.

This paper evaluates the FlexRay network utilization using a new comprehensive system model. It also identified and analyzed the factors that affect network utilization. Section II describes the basic knowledge of FlexRay communication cycle and message frame. Section III defines the system model, which consist of not only static segments, but also dynamic segments and other factors. Section IV describes Matlab simulation based on the system model and the network utilization evaluation results. It computes and compares network utilization in different cases with various parameters. The results show that besides the length of message frames, several factors affect network utilization. These factors include the number of message frames and the percentage of the number of message frames transmitted in static and dynamic segments. Section IV presents the conclusions.

2. THE FLEXRAY COMMUNICATION PROTOCOL

2.1. FlexRay Communication Cycle

In the FlexRay protocol, MAC schemes are based on repeatedly executed communication cycles. Within one communication cycle, FlexRay offers the choice of two media access schemes. One of them is a static time division multiple access (TDMA) scheme, and the other is dynamic mini-slotting based scheme [2]. The structure of communication cycles is shown in Fig. 1.

As shown in Fig. 1, a communication cycle is divided into a static segment, a dynamic segment, a symbol window, and network idle time (NIT). The symbol window and NIT provide time for the transmission of internal control information and protocol-related computation. This paper does not address these phases of the cycle.

A communication cycle always includes a static segment that offers the TDMA scheme for time-triggered message frame transmission. The static segment is divided into many
Fig. 1. FlexRay communication cycle

static slots of equal lengths. A single node is allowed to transmit no more than one message frame in each static slot. When the TDMA is applied, the duration time of one static slot is spent even if no message frame is transmitted in this static slot. The length and number of static slots in one static segment are configured offline and fixed over communication cycles.

A dynamic segment is an optional segment in a communication cycle, and it offers a flexible time division multiple access (FTDMA) media access scheme. The dynamic segment is divided into many minislots of equal lengths. Generally, the length of one minislot is much shorter than that of one static slot or message frame. Thus, one message frame occupies integer minislots to transmit in the dynamic segment. Moreover, the message frame transmission must start at the beginning of one minislot. If there is no message frame to transmit at the beginning of one minislot, the duration time of this minislot is still spent. As in the case of a static segment, the length and number of minislots in one dynamic segment are configured offline and fixed over communication cycles.

2.2. FlexRay Message Frame

In FlexRay, a message frame consists of three segments: a header, a payload, and a trailer. The lengths of the header and trailer are 5 and 3 bytes, respectively. The length of the payload can range from 0 to 254 bytes. When transmitted physically on a FlexRay bus, message frames add extra bits, as shown in Fig. 2.

Here the transmission start sequence (TTS) is 3-15 bits, the frame start sequence (FSS) is 1 bit, the byte start sequence (BBS), and the frame end sequence (FES) are 2 bits, respectively. Moreover, extra bits are added when message frames are transmitted in static or dynamic segments. These include 11 bits for a channel idle delimiter (CID), 2 bits for action point offset before and after message frames in both segments, and several bits of dynamic trailing sequence (DTS) only in dynamic segments.

The addition of extra bits changes the length of the message frame, which can be calculated using Equation (1).

\[ \text{Length.Message.Frame.ST} = 31 + 10n \]
\[ \text{Length.Message.Frame.DY} = 31 + 10n + \text{Length.DTS} \]  \hspace{1cm} (1)

where \text{Length.Message.Frame.ST} and \text{Length.Message.Frame.DY} are the lengths of an \( n \)-byte message frame with extra bits in the static segment and the dynamic segment, respectively. The sum of 15 bits of TTS, 1 bit of FSS, 2 bits of action point offsets, and 11 bits of CID is 31 bits. The length of the \( n \)-byte message frame with 2 bits of BBS in each byte is 10 bits. The only difference between equations for static and dynamic segments is the variable \text{Length.DTS}, which indicates the length of DTS and appears only in dynamic segments.

3. SYSTEM MODELS FOR NETWORK UTILIZATION EVALUATIONS

Message frames transmitted in static and dynamic segments add different extra bits and follow distinct MAC schemes. Thus, a FlexRay network utilization evaluation requires two system models, one for the static segment and the other for the dynamic segment.

3.1. System Model of Static Segment

Over communication cycles, the lengths of static segments, \text{Length.ST}, are identical and can be computed using Equation (2).

\[ \text{Length.ST} = \text{gdStaticSlot} \times \text{gNumberOfStaticSlots} \]  \hspace{1cm} (2)

where \text{gdStaticSlot} is the length of one static slot, and \text{gNumberOfStaticSlots} is the number of static slots in one static segment. Their values are configured offline and fixed over communication cycles. The parameter \text{gdStaticSlot} is determined by the length of the longest message frame transmitted in static segments. Thus, the actual occupied length of one static segment, \text{Occupied.Length.ST}, is shorter than \text{Length.ST} and can be computed using Equation (3).
\[ \text{Occupied\_Length\_ST} = \sum_{i=1}^{\text{gNumber\_of\_Static\_Slots}} (31 + 10n_i) \] (3)

where \( n_i \) is the number of bytes contained in the message frame transmitted in the \( i \)-th static slot.

### 3.2. System Model of Dynamic Segment

Over communication cycles, the length of each dynamic segment, \( \text{Length\_DY} \), is identical and can be computed using Equation (4)

\[ \text{Length\_DY} = \text{gdMinislot} \times \text{gNumber\_of\_Minislots} \] (4)

where \( \text{gdMinislot} \) is the length of each minislot, and \( \text{gNumber\_of\_Minislots} \) is the number of minislots in one dynamic segment. The parameter \( \text{gdMinislot} \) can be set in the range of 2 to 63 bits, and \( \text{gNumber\_of\_Minislots} \) can be set to up to 1023. These values are configured offline and fixed over communication cycles.

Generally, \( \text{gdMinislot} \) is smaller than \( \text{gdStaticSlot} \), and it is often set as several bits. The advantage of short length minislots is that the waste of a minislot has little effect on network utilization even if there is no message frame transmitted during that minislot. Moreover, message frames of different lengths take as few as minislots possible, and the total lengths of minislots meet transmission requirements. The minimal use of minislots avoids the waste of network capacity that can be caused by a fixed and relatively large \( \text{gdStaticSlot} \) in static segments. Thus, the network utilization in dynamic segments should be higher than that in static segments. Based on Equation (1) and the characteristics of dynamic segments, the actual occupied length of one dynamic segment, \( \text{Occupied\_Length\_DY} \), can be computed using Equation (5).

\[ \text{Occupied\_Length\_DY} = \sum_{i=1}^{\text{Num\_Msg\_Frame\_DY}} (31 + 10n_i + \text{Length\_DTS}_i) \] (5)

where \( \text{Num\_Msg\_Frame\_DY} \) is the number of message frames transmitted in one dynamic segment, which is variable over dynamic segments, and \( \text{Length\_DTS}_i \) is the length of DTS in the \( i \)-th message frame.

### 3.3. Computation of FlexRay Network Utilization

Based on system models of static and dynamic segments, FlexRay network utilization, \( U \), can be calculated using Equation (6).

\[ U = \frac{\text{Occupied\_Length\_ST} + \text{Occupied\_Length\_DY}}{\text{Length\_ST} + \text{Length\_DY}} \] (6)

### 4. Network Utilization Evaluation and Results

Given the system models described in Section III, various factors affect network utilization. These factors include the length of message frames, the percentage of the number of message frames in static or dynamic segments, and the number of static slots and minislots. Network utilization evaluations take these factors into consideration, and each result is obtained by simulating 5000 FlexRay communication cycles.

The Matlab simulations used the following parameters: The length of message frames, \( n_i \), was a random variable following Gaussian distribution, \( N(m,\sigma^2) \), where \( m \) was the mean of \( n_i \), and \( \sigma \) was the standard deviation of \( n_i \). For the static segment, all static slots were assumed to be occupied. The \( \text{gdStaticSlot} \) was configured to be longer than 99% of message frames. The term \( \text{gNumber\_of\_Static\_Slots} \) was equal to the number of message frames transmitted in the static segment, and it was a known constant. For the dynamic segment, the number of message frames transmitted in a segment, \( \text{Num\_Msg\_Frame\_DY} \), was a random variable following a Poisson distribution, \( \text{Pois}(\lambda) \), where \( \lambda \) was the mean number of message frames transmitted in the dynamic segment. The terms \( \text{gNumber\_of\_Minislots} \) and \( \text{gdMinislot} \) were configured to meet the transmission requirement with a 99% probability.

Simulations results are shown in Fig. 3, where \( \sigma \) is the standard deviation of the length of message frames, and \( (\text{gNumber\_of\_Static\_Slots} + \lambda) \) is the mean number of message frames transmitted in static and dynamic segments. Three figures in each row are arranged in increasing order of the percentage of message frames transmitted in the dynamic segment. Two figures in each column have different mean lengths of message frames.

In all six figures, as the standard variance of length of message frames \( \sigma \) increases, network utilization decreases. Moreover, among the figures in a single row, increasing the percentage of message frames transmitted in the dynamic segment can cancel some effects of \( \sigma \) on network utilization. Specifically, when the mean length of the message frames increases, \( \sigma \) has less effects on network utilization.

Among figures in the same row, when \( \sigma \) is relatively large, as the percentage of message frames transmitted in the dynamic segment increases, the network utilization increases. But if \( \sigma \) is small, increasing the percentage of message frames transmitted in the dynamic segment may reduce network utilization. Moreover, when the mean length of message frames increases, a larger percentage of message frames transmitted in dynamic segments can cancel more effects of \( \sigma \) on network utilization.

As the mean number of message frames increases, the network utilization increases dramatically. Moreover, if the percentage of the number of message frames transmitted in dynamic segments increases, network utilization will increase, especially when the mean number of message frames is large.
Fig. 3. FlexRay network utilization with different parameters

5. CONCLUSIONS

This paper describes the construction of a FlexRay system model, which is employed to evaluate FlexRay network utilization. Matlab simulation results indicate that network utilization is related to the number of message frames, the length of message frames, and the percentage of message frames transmitted in static and dynamic segments. FlexRay network utilization can be improved by increasing the number of message frames and the percentage of message frames transmitted in dynamic segments, or by decreasing the standard deviation of the length of message frames.

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7. REFERENCES


