

# Research of FlexRay Dynamic Segment Network Optimization Based on Composite Deadline Message Scheduling Algorithm

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**Abstract:** FlexRay is a new standard of in-vehicle communication network system, which provides a high speed serial communication, time triggered bus and fault tolerant communication between electronic devices. This paper proposes a network optimization scheme for the composite deadline algorithm for the FlexRay dynamic segment. The priority of the message transmission is allocated by the ratio of the deadline to the message length ratio, which effectively shortens the transmission time and thus improves the network utilization. By analyzing the dynamic segment transmission characteristics and transmission conditions, the most suitable dynamic segment length and minislot number are obtained. By building a network topology architecture model based on CANoe, FlexRay network utilization is up to 31.11% under the condition of many different length messages.

**Key words:** FlexRay, dynamic segment, composite deadline, network.

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## 1. Introduction

As the degree of intelligence of automobiles becomes higher and higher, the number of electronic control units installed in automobiles is gradually increasing, and intelligent electronic control systems such as advanced driving assistance systems (ADAS) and lane departure detection systems with more communication information are also passed through the vehicle bus. The network system communicates. The CAN bus network, which has been widely used in the past, has a limited transmission rate and belongs to a low-speed network, which has suppressed the development of the automotive industry [1]. In 2000, DaimlerChrysler and BMW introduced and developed the FlexRay bus technology. FlexRay has two channels, each of them has a maximum speed of 10Mbps, a total data rate of 20Mbps, and is divided into time trigger and event trigger, with real-time, flexibility and fault tolerance. At present, the FlexRay bus system is used in the electronically controlled shock absorber system of the BMW X5 series, the advanced driver assistance system and chassis control system of the Audi A8 vehicle [2]. The scheduling mode of FlexRay dynamic segment directly affects the real-time performance and network utilization of the network. With the expansion of network application scope, scheduling optimization of FlexRay dynamic segment becomes an important issue.

In [3], [4], the worst response time is calculated by the FTDMA mechanism, and the schedulability analysis is performed. On this basis, the time slots are multiplexed. In [5], the transmission delay is taken as

a performance index. The influence of the length of the dynamic segment on this problem is studied. A more general method for analyzing the dynamic worst-case response time is proposed. In [6] the timing model of dynamic messages, based on the analysis of dynamic message time response, the allocation frame priority and optimal ID allocation scheme are proposed. In [7], the dynamic segment parameters are optimized. First, the slot length design is constructed, and then the communication cycle length is calculated, and the parameters are optimized indirectly. Literature [8] proposed a scheduling method for pre-reservation of dynamic segments, which solves the problem of high transmission of sporadic messages, but does not analyze the worst response time. In [9], two algorithms are proposed in the literature [10]. By changing the position of the message transmission, the platestTx value is increased to achieve more message transmission, but there is no improvement in the algorithm scheduling level.

This paper proposes a composite deadline dynamic-segment scheduling algorithm, which considers both the deadline and the message length. At the same time, the frame ID allocation method is fast and convenient, which saves bandwidth utilization and improves network utilization.

Chapter 2 analyzes the network structure of FlexRay; Chapter 3 proposes the composite deadline message scheduling algorithm for FlexRay dynamic segment; Chapter 4 simulates the algorithm proposed by building the network topology architecture; Chapter 5 summary of the full text.

## 2. FlexRay Communication Protocol

### 2.1. FlexRay Timing Hierarchy

The FlexRay data frame consists of four parts: static segment, dynamic segment, symbol window, and network idle, as shown in Fig. 1. By cyclic transmission, there is a cycle counter on the bus for counting, and each node has a minislot counter as a global time parameter. The dynamic segment has an event-triggered feature for transmitting aperiodic signals. The length of the dynamic time slot is equal to the length of the transmission when there is a message transmission. When there is no message transmission, there is no need to wait too much, and only one spare time slot is needed, makes it suitable for communication requiring high flexibility and high real-time [11]-[13].

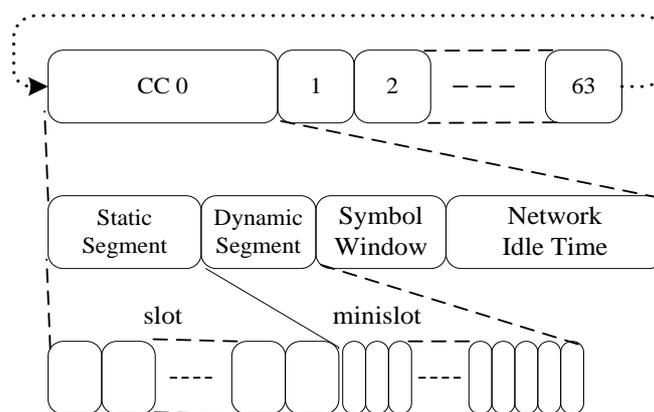


Fig. 1. FlexRay timing hierarchy.

The length of each time slot of the dynamic segment is uncertain, and the message is transmitted when the priority of the data itself corresponds to the slot number. Each data frame of FlexRay consists of a frame header, a frame tail, and a payload segment, as shown in Fig. 2. The total length of the frame header is 40 bits, and the load segment ranges from 0 to 254 bytes. In order for a frame to be transmitted in a dynamic segment, it is also necessary to encode the frame. Add a 3 to 15 bit transmission start sequence, a 2-bit frame start sequence, and add a 2-bit byte start sequence before each byte. The network idle is used to fill the time between the end of the frame and the end of the time slot. The length is 11 digits.

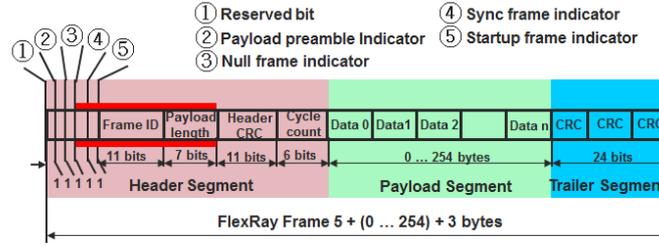


Fig. 2. FlexRay frame format.

The dynamic message set is set to  $F_{DS} = \{m_1, m_2, \dots, m_{F_{DS}}\}$ ,  $m_j$  is the  $j$ th dynamic message and  $m_j \in F_{DS}$ . When the length of message  $m_j$  is  $w_j$  bit, the dynamic frame length  $L_{F_{DS}}$  is as shown in Equation 1.

$$L_{F_{DS}}(m_j) = TSS + FSS + 80\text{bits} + 1.25w_j + FES + DTS \quad (1)$$

The TSS is a transmission start sequence, which is used to initialize the start point of a transmission sequence, which is sent at the beginning of the static segment, the dynamic segment and the symbol window, and the length is determined by the system parameter  $gdTSSTransMitter$ ; the FSS is the frame start sequence, used for Indicates the starting point of the frame; FES is the end sequence of the frame, followed by the CRC, consisting of a low level and a high level; after the end of the frame sequence will follow a dynamic drag sequence, which is DTS, DTS is determined by the length The low level and the high level of one bit. The dynamic slot length  $L_{DS}(m_j)$  is as shown in Equation 2.

$$L_{DS}(m_j) = 1 + \text{ceil}((L_{F_{DS}}(m_j) + 1) \times t_{bit}) (t_{MT} \times (1 - CDM) \times t_{MS})^{-1} + DSIP \quad (2)$$

where  $L_{DS}$  is the dynamic slot length in MT;  $\text{ceil}$  is the upper rounding function;  $t_{bit}$  is the time per transmission; MinPD is the minimum propagation delay; MaxPD is the maximum propagation delay;  $t_{MT}$  is the duration of each macro beat; CDM is the maximum clock deviation.

## 2.2. The Worst-Case Response Time

The worst-case response time is the length of time from the generation of the message to the completion of the transmission. It consists of three parts  $\sigma_m$ ,  $C_m$  and  $\text{delay}(m)$ , as shown in equation 3.

$$\text{WCRT}(m) = \sigma_m + C_m + \text{delay}(m) \quad (3)$$

where  $\sigma_m$  is the delay caused by the message missing its corresponding time slot, as shown in Equation 4:

$$\sigma_m = L_{DS} - (a_{ID}(m) - 1)t_{MS} \quad (4)$$

$C_m$  is divided into two parts, one part is due to the high priority message, the transmission time is not successfully sent in this cycle, or the time slot has been successfully transmitted in the previous cycle. The other part is the delay caused by the successful transmission of higher priority messages.

$\text{delay}(m)$  is the delay of the message in the first cycle. That is, during the period of message transmission, the delay from the beginning of the period to the transmission of this message and the time required to transmit the message, as shown in Equation 5:

$$\text{delay}(m) = T_{ss} + w^f(m) + L_{DS}(m) \times t_{MS} \quad (5)$$

$w^f(m)$  is the time delay before the message is sent in the dynamic segment of the current period.

## 2.3. Network Utilization Parameters

FlexRay Network utilization  $U_{DS}$  refers to the percentage of bandwidth required to transmit messages to

the total bandwidth, as shown in Equation 6. Because of the aperiodic character of dynamic segment, the network utilization of a communication cycle does not represent the whole, and each communication cycle has its own network utilization.

$$U_{DS} = \frac{\sum_{j=1}^n l_{DS}(m_j)}{L_{DS} \times N} \quad (6)$$

### 3. Dynamic Segment Message Scheduling Scheme

#### 3.1. Composite Deadline Message Scheduling Method

Properly setting the FlexRay dynamic segment length optimizes the performance of the car bus network, enabling the network to better meet real-time standards. In a dynamic segment with a fixed length, the frame ID is used to determine the order of message transmission. Whether the frame ID is arranged properly or not directly affects the bandwidth utilization.

The earliest deadline first algorithm (EDF) is a preemptive scheduling algorithm that uses only the deadline to determine the priority of the transmission, for the shorter deadline, the higher priority. However, this traditional method is very limited. Once the number of messages transmitted in the dynamic segment increases, this method cannot meet the message scheduling requirements well. The composite earliest deadline first algorithm (CEDF) proposed in this paper set the ratio of the message deadline to the message length to  $\beta$ . For the smaller ratio, the higher priority, and the more efficient dynamic segment scheduling.

In order to make the experiment more efficient, the feasibility of the experiment is verified by Matlab simulation, and the most suitable dynamic segment length is obtained. First calculate the upper and lower limits of the dynamic segment length, set to  $[L_{DS}^L, L_{DS}^H]$ . Where the maximum value of the sum of the frame ID value and the message length is taken as the minimum dynamic segment length, the maximum length of the dynamic segment is the sum of all message lengths. Based on the lower limit of the dynamic segment length, the dynamic segment length is increased one by one in units of minislot length. According to the worst response time, it is judged whether the transmission condition is satisfied, and all the data is smoothly transmitted. Finally, the network utilization in each case is calculated by calculation, and a line chart is formed in comparison with the conventional method. According to the above flow, Fig. 3 is drawn.

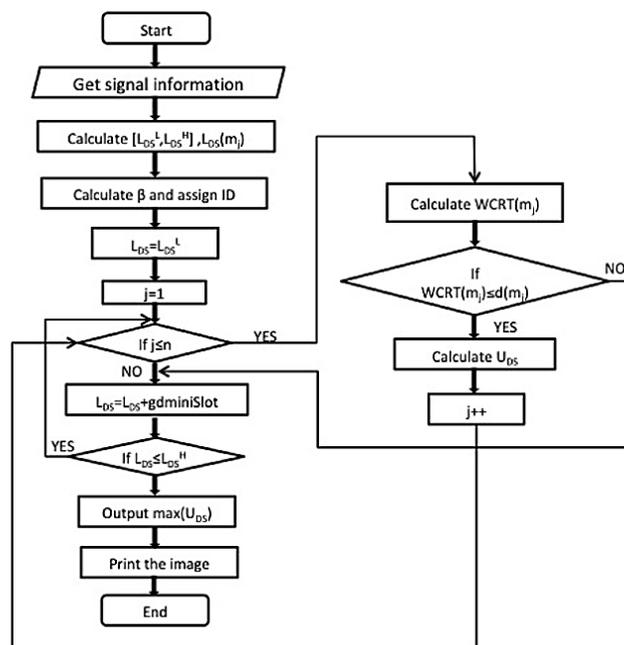


Fig. 3. Message scheduling flowchart.

### 3.2. Scheduling Allocation

In the experiment, 20 dynamic frames are set. To ensure the data is comprehensive, the five message lengths and the deadline length are arranged intricately. According to the scheduling method of this paper, each message is assigned a priority, as shown in Table 1.

Table 1. Dynamic Message Sets

Dynamic Frame	Deadline(Ms)	Length(Byte)	ID	Dynamic Frame	Deadline(Ms)	Length(Byte)	ID
$m_1$	10	16	4	$m_{11}$	5	16	2
$m_2$	5	32	1	$m_{12}$	15	4	15
$m_3$	5	8	3	$m_{13}$	25	16	10
$m_4$	25	4	17	$m_{14}$	50	32	8
$m_5$	15	8	11	$m_{15}$	50	32	9
$m_6$	20	2	19	$m_{16}$	15	2	18
$m_7$	20	16	7	$m_{17}$	50	8	16
$m_8$	15	8	12	$m_{18}$	5	2	14
$m_9$	50	2	20	$m_{19}$	25	32	6
$m_{10}$	25	32	5	$m_{20}$	15	8	13

### 4. Simulation Result

This paper uses Network Designer. FlexRay to establish a database, the parameters are shown in Table 2. In addition, each message is sent to the transmitting node occupied by the dynamic segment, and the sending frame and the receiving frame of the signal are determined, and finally the message scheduling table is determined, as shown in Table 3. The file generated by the FIBEX is applied in the network topology.

Table 2. Network Simulation Parameter Table

Parameter	Value	Unit	Parameter	Value	Unit
$TSS$	9	Bits/frame	CID	11	Bits/frame
$FSS$	1	Bits/frame	APO	2	Bits/frame
$BSS$	2	Bits/byte	FES	2	Bits/frame
$DTS$	2	MT	DSIP	1	MS
$MinPD$	0.2	us	MaxPD	0.5	us
$T_{SW}$	0	MT	$T_{NIT}$	9	MT
$T_{SS}$	3564	MT	$T_{DS}$	360	MT
$t_{bit}$	0.1	us	$t_{MT}$	5	us
$t_{MS}$	4	MT	$T_C$	5	ms

Table 3. Dynamic Frame Schedule

Dynamic frame	signal	ECU	data length (Byte)	ID	Dynamic frame	signal	ECU	data length (Byte)	ID
$m_1$	$s_1$	1	16	68	$m_{11}$	$s_{11}$	3	16	66
$m_2$	$s_2$		32	65	$m_{12}$	$s_{12}$		4	79
$m_3$	$s_3$		8	67	$m_{13}$	$s_{13}$		16	74
$m_4$	$s_4$		4	81	$m_{14}$	$s_{14}$		32	72
$m_5$	$s_5$		8	75	$m_{15}$	$s_{15}$		32	73
$m_6$	$s_6$	2	2	83	$m_{16}$	$s_{16}$	4	2	82
$m_7$	$s_7$		16	71	$m_{17}$	$s_{17}$		8	80
$m_8$	$s_8$		8	76	$m_{18}$	$s_{18}$		2	78
$m_9$	$s_9$		2	84	$m_{19}$	$s_{19}$		32	70



In Fig. 6, the red dotted line is the network utilization analysis graph based on the EDF deadline algorithm, and the blue solid line is the network utilization analysis graph of the composite deadline algorithm proposed in this paper. In the case that the length and number of dynamic segment slots are the same, comparing the network utilization, it can be seen that the network utilization rate of the proposed method is consistently higher than the original deadline algorithm.

In Fig. 7, when the length of the corresponding minislot is set to  $4MT$ , the difference in network utilization finally obtained by the two methods can be seen that when the number of minislot is 90, the optimization degree is the highest and the network utilization rate is improved. 31.11%.

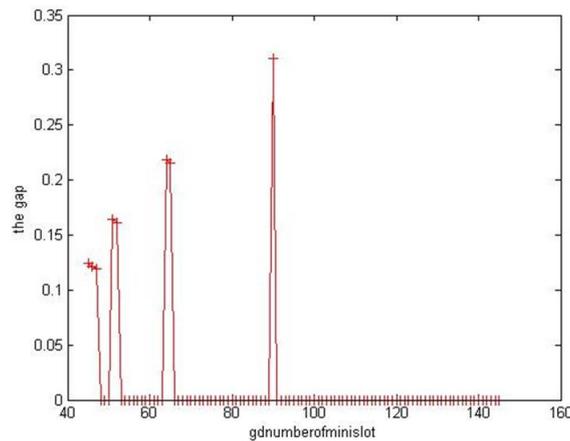


Fig. 7. Difference in network utilization when the length of the minislot is  $4MT$ .

## 5. Conclusion

In today's rapid development of automotive networks, FlexRay is an in-vehicle communication network that can help realize automotive intelligence. This paper proposes a new dynamic segment message scheduling optimization scheme for this network. The composite deadline algorithm is used to calculate the ratio of the message deadline to the message length as the basis for assigning priorities. According to the dynamic segment transmission characteristics, the dynamic message ID is allocated on the premise that the message can be scheduled. The simulation results of CANoe show that the composite deadline algorithm proposed in this paper improves the utilization rate of the FlexRay dynamic segment network by 31.11%.

## Conflict of Interest

The authors declare no conflict of interest.

## Author Contributions

Shi-Nan Wang: Methodology and writing of original draft; Yi-Nan Xu: Conceptualization and supervision.

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