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Message Scheduling for the FlexRay protocol

The Static Segment

Presented By

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Presented By
Najeeb
2013 – 5 – 9

Outline

- Introduction
- Notation And Performance Metrics
- Frame Packing Of Periodic Signals
- Message Schedule For The SS
- Application To Benchmark Examples
- Conclusion

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  - Signals have to be packed into equal-size messages to obey the restrictions of the FlexRay protocol, while using as little bandwidth as possible
  - A message schedule has to be determined such that the periodic messages are transmitted with minimum jitter
- We will discuss the problem of constructing feasible and efficient message schedules with low jitter, starting from the signal data to be transmitted.

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- Signal Framing

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  - The obtained messages are scheduled with minimum jitter in the FlexRay SS while using a minimum number of FIDs

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- FlexRay Software Architecture

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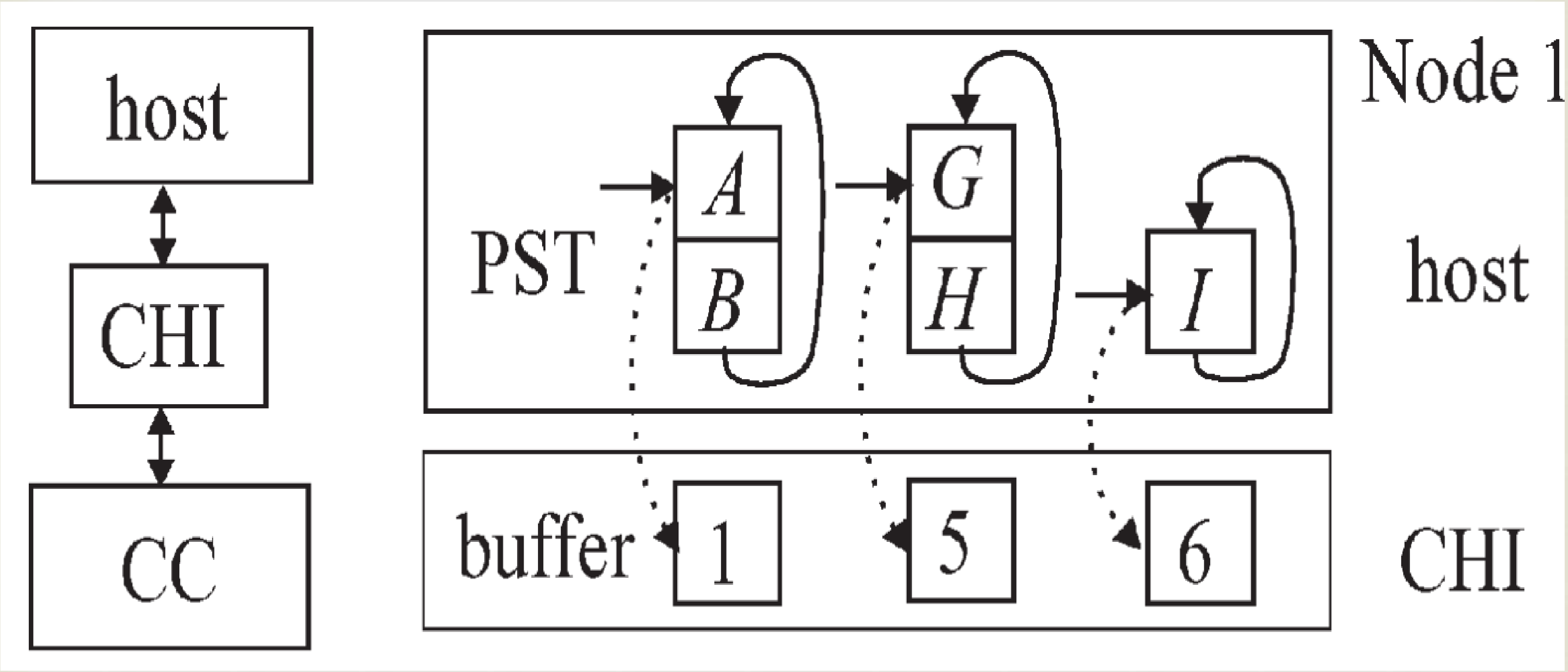

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$pm_m^n := ps_s^n$ denotes the *period*, $dm_m^n := ds_s^n$ denotes the *deadline*, and $bm_m^n := \sum_{S_s^n \in pack^n(M_m^n)} bs_s^n$ is the *number of* data *bits* of M_m^n.

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- The signals in S_{pj} have to be transmitted in at most R_{pj} different messages
- Define a binary variable $X_{pj,i,k}$, where $X_{pj,i,k}=1$ means that the signal $S_{pj,i}$ is packed into the message $M_{pj,k}$ and otherwise, $X_{pj,i,k}=0$.

Contd…

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$$0 \le x^n_{p_j,i,k} \le 1, \quad \text{for } i,k = 1,\ldots,R^n_{p_j}$$

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$$bm^n_{p_j,k} = \sum_{i=1}^{R^n_{p_j}} x^n_{p_j,i,k} \cdot bs^n_{p_j,i}$$

Contd…

Signal Set for Two FlexRay Nodes

signal	$S^1_{3,1}$	$S^1_{3,2}$	$S^1_{3,3}$	$S^1_{3,4}$	$S^1_{3,5}$	$S^2_{2,1}$	$S^2_{2,2}$	$S^2_{2,3}$
data (bit)	65	50	30	40	35	20	25	10
signal	$S^2_{2,4}$	$S^2_{2,5}$	$S^2_{2,6}$	$S^2_{1,1}$	$S^2_{1,2}$	$S^2_{1,3}$	$S^2_{1,4}$	$S^2_{1,5}$
data (bit)	25	45	30	30	30	15	50	25

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$$T_{\mathrm{STS}} = k_{\mathrm{STS}} \cdot T_{\mathrm{MT}}$$

$$T_{\mathrm{STS}}^{2} \leq T_{\mathrm{STS}} \leq T_{\mathrm{STS}}^{127}$$

$$20 \text{ bits} \cdot \lceil bm_{p_j,k}^{n}/16 \rceil \tau_{\mathrm{bit}} \leq y_{p_j,k}^{n} \cdot (T_{\mathrm{STS}} - O_{\mathrm{F}} \cdot \tau_{\mathrm{bit}})$$

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$$0 \leq y_{p_j,k}^{n} \leq 1.$$

- The new binary variable $y_{pj,k}$ is 1 if at least one signal is packed into the message $M_{pj,k}$.

Example

SIGNAL SET FOR TWO FLEXRAY NODES

signal	$S^1_{3,1}$	$S^1_{3,2}$	$S^1_{3,3}$	$S^1_{3,4}$	$S^1_{3,5}$	$S^2_{2,1}$	$S^2_{2,2}$	$S^2_{2,3}$
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For example, we choose $\tau_{\text{bit}} = 0.1\ \mu$s/bit and $T_{\text{MT}} = 3\ \mu$s. In addition, assume that $O_{\text{F}} = 90$ bits. Considering node 1 as described above, it holds that $bm^1_{3,1} = 65$ bits $> 0 \Rightarrow y^1_{3,1} = 1$ and $bm^1_{3,2} = 155$ bits $> 0 \Rightarrow y^1_{3,2} = 1$. Hence, with (14) and (16), $T_{\text{STS}} = k_{\text{STS}} \cdot 3\ \mu s \geq 20.0\ \mu s + 9.0\ \mu s \Rightarrow k_{\text{STS}} \geq 10$. The remaining variables $bm^1_{3,k}$ and $y^1_{3,k}$ are 0.

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$$\min_{X} \sum_{n=1}^{N} \sum_{p_j \in \mathcal{P}^n} \sum_{k=1}^{R_{p_j}^n} \frac{y_{p_j,k}^n \cdot T_{\mathrm{STS}}}{p_j \cdot T_{\mathrm{c}}}$$

Optimization Contd…

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$$pack^n\left(M^n_{p_j,k}\right) = \left\{S^n_{p_j,i} \in \mathcal{S}^n_{p_j} \,|\, x^n_{p_j,i,k} = 1\right\}$$

Message Schedule For The SS

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- If all messages in M^n have to be scheduled without jitter, then $N_{SP}=lcm(pm_1,\ldots,pm_{Gn})$ has to be chosen.

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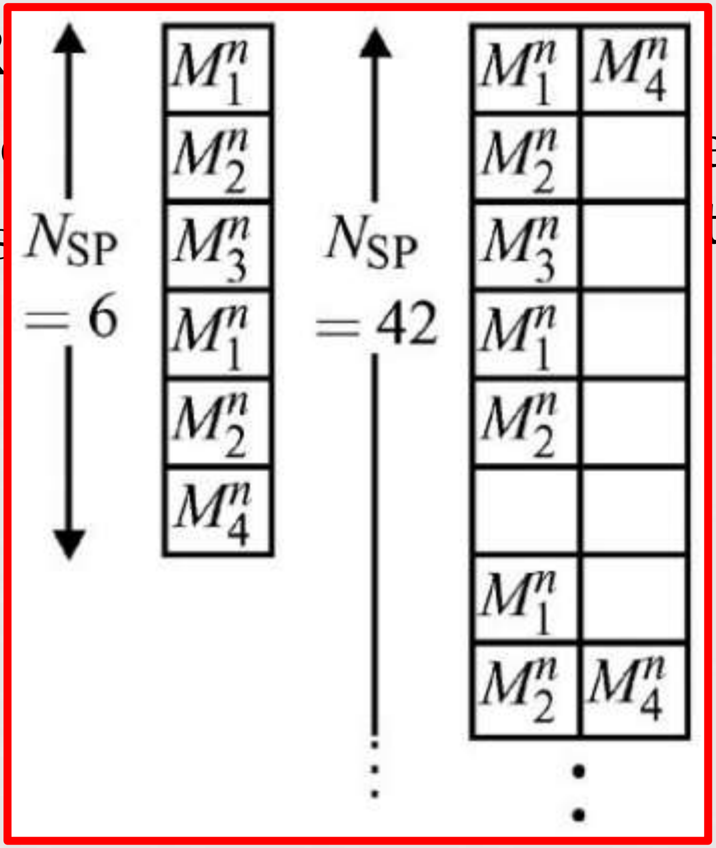

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- X-Group
  - Let $x, y \in N_0$ be nonnegative integers and $0 \leq y \leq x - 1$. Then, the STSs in the FCs $y + i \,.\, x$, $i \in N_0$, for an FID form an x-group for that FID.

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Proposition 5.1 (Coprime Message Periods): Let M_m^n and M_l^n be messages with coprime periods, i.e., $\gcd(pm_m^n, pm_l^n) = 1$. Then, M_m^n and M_l^n cannot be scheduled with the same FID without jitter.

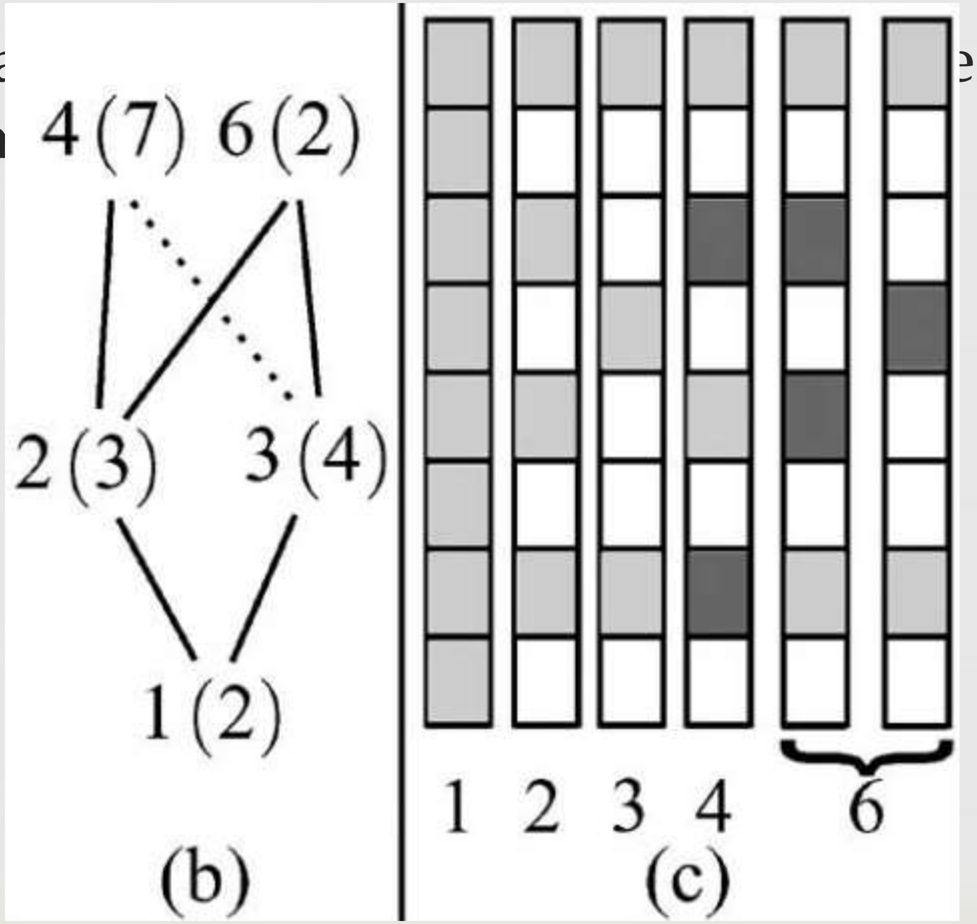
Message Schedule Without Jitter

- Ordering of Messages
  - We define a partial order, i.e., a reflexive anti-symmetric transitive order relation "|" on the set of messages M such that for M_m, $M_l \in M$,$M_m | M_l$ if pm_m divides pm_l. E.g.

Message Schedule Without Jitter Optimization

- We display the partial order of messages for an example message set.

Message Schedule Without Jitter Optimization

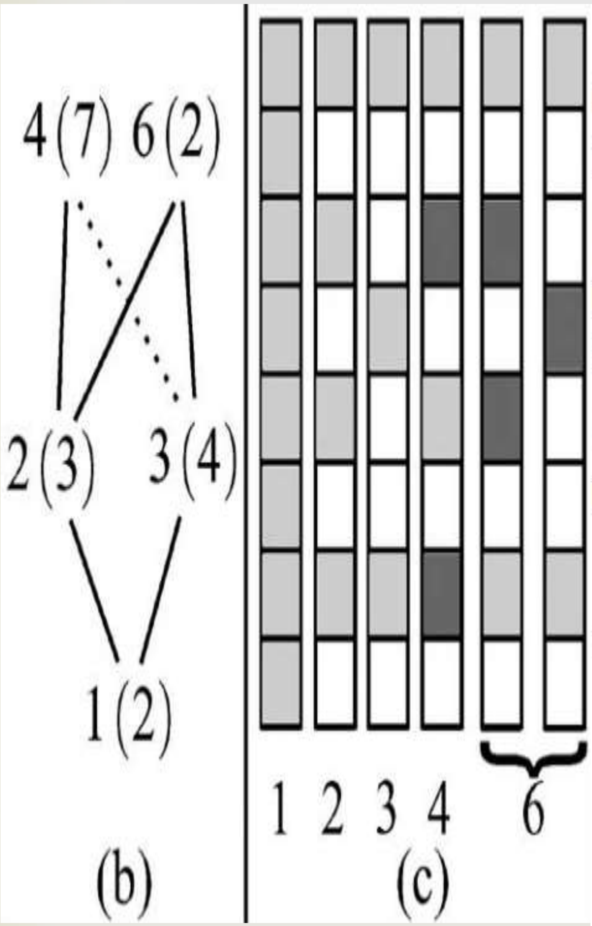
- We displa  es for an example m

Message Schedule Without Jitter Optimization

- To achieve an efficient message schedule, the number of allocated FIDs $n_{FID}(n)$ has to be minimized for each node $n \in N$.

- At least one FID has to be allocated for each co-prime period and can be filled with messages whose periods are divided by the respective co-prime period

Message Schedule Without Jitter Optimization



Referring to Fig and the coprime period 2, the $n_{(2)} = 3$ messages with period 2 are placed in three 2-groups, the $n_{(2,2)} = 7$ messages with period 4 are placed in $\lceil 7/2 \rceil = 4$ 2-groups, and the two messages with period 6 are placed in $\lceil n_{(2,3)}/3 \rceil$ 2-groups. Together, these messages occupy $3 + \lceil 7/2 \rceil + \lceil n_{(2,3)}/3 \rceil$ 2-groups, which amounts to $\lceil (3/2) + (1/2)(\lceil 7/2 \rceil + \lceil n_{(2,3)}/3 \rceil) \rceil$ FIDs. Hence, the messages with periods 1, 2, 3, 4, and 6 occupy

$$n_{\mathrm{FID}}(n) = n_{(1)} + \left\lceil \frac{3}{2} + \frac{1}{2} \left(\left\lceil \frac{7}{2} \right\rceil + \left\lceil \frac{n_{(2,3)}}{3} \right\rceil \right) \right\rceil + \left\lceil \frac{4}{3} + \frac{1}{3} \left\lceil \frac{n_{(3,2)}}{2} \right\rceil \right\rceil .$$

Message Schedule Without Jitter Optimization

- Defining X as the vector of all unknown variables, the optimization problem for our example is

$$\min_{X} n_{\mathrm{FID}}(n)$$

- Subject to the constraint that $n_{(2,3)} + n_{(3,2)} = 2$.

Message Schedule Without Jitter Optimization

- Generalizing the previous example we have the following optimization equations.

$$\min_{X} n_{(1)} + \sum_{f_1 \in F^n(1)} \left\lceil \frac{n_{(f_1)}}{f_1} + \frac{1}{f_1} \sum_{f_2 \in F^n(f_1)} \left\lceil \frac{n_{(f_1,f_2)}}{f_2} + \frac{1}{f_2} \sum \cdots \right.\right.$$

$$\left.\left. + \frac{1}{f_{K-1}} \sum_{f_K \in F^n(f_1 \cdots f_{K-1})} \left\lceil \frac{n_{(f_1,\ldots,f_K)}}{f_K} \right\rceil \cdots \right\rceil \right\rceil$$

subject to the constraint

$$\forall p_j \in \mathcal{P}^n : \sum_{c_{p_j} \in \mathcal{C}_{p_j}} n_{c_{p_j}} = N_{p_j}^n .$$

Message Schedule With Jitter Optimization

- We discuss the configuration in Fig (b), where jitter is allowed for a number of$N_{4,jitter}$ messages with period 4.
- Such a message can be placed into any free x-group with $x<4$
- We define the variable $n_{(3),4}$ that represents the number of messages with period 4 that are scheduled with the SC (3)

Message Schedule With Jitter Optimization

- It must still hold that the number of messages scheduled with period 4 is equal toN_4

$$\sum_{c_4 \in \mathcal{C}_4} n_{c_4} + n_{(3),4} = N_4^n.$$

- With the additional constraint that

$$n_{(3),4} \leq N_{4,\text{jitter}}^n.$$

Message Schedule With Jitter Optimization

- The overall jitter for messages scheduled with jitter is given by

$$J_4^n = n_{(3),4} \cdot 3T_\mathrm{c}.$$

- The new optimization equations are given by

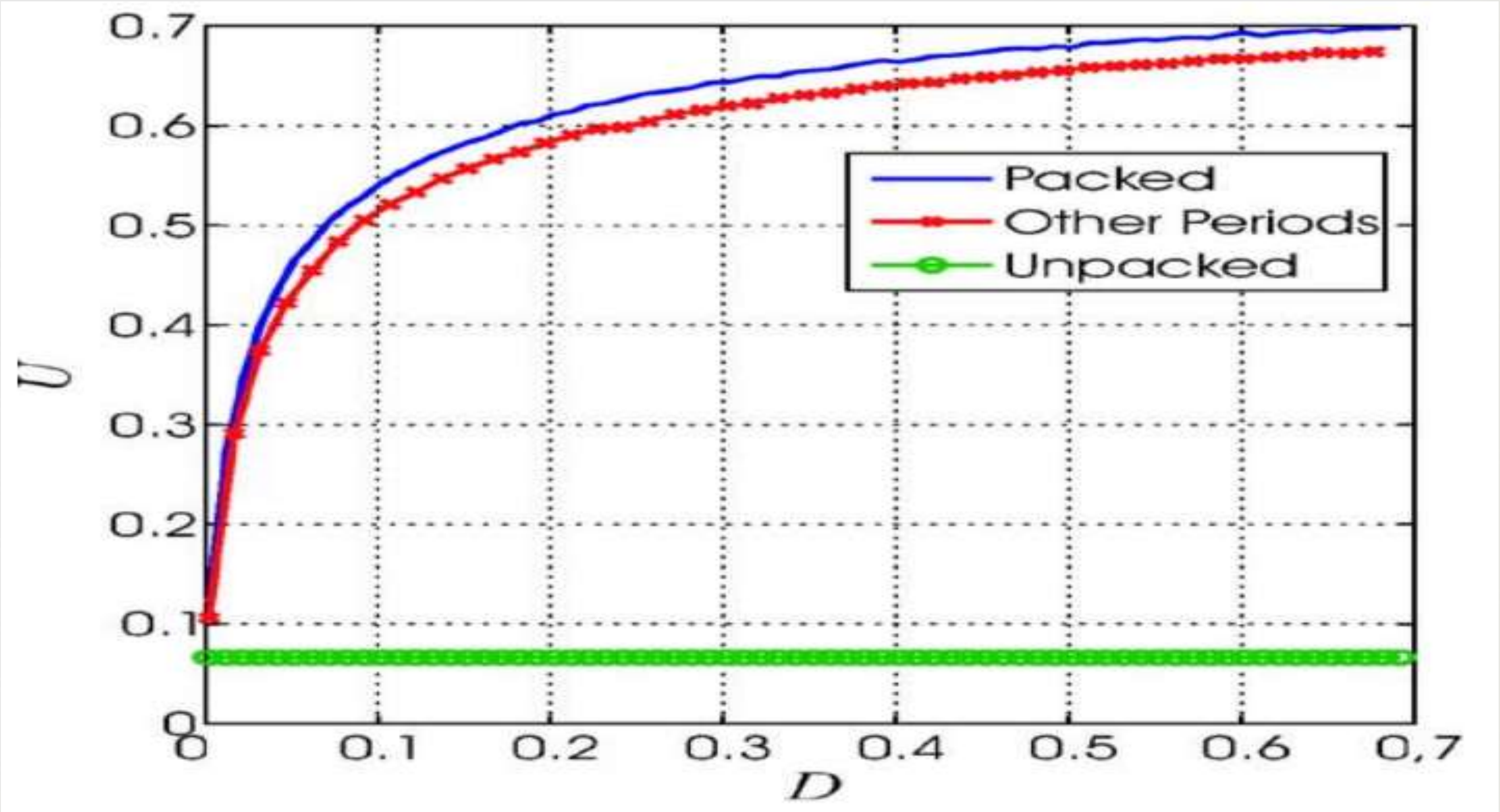
$$\min_X n_{(1)} + \left\lceil \frac{n_{(2)}}{2} + \frac{1}{2}\left(\left\lceil \frac{n_{(2,2)}}{2} \right\rceil + \left\lceil \frac{n_{(2,3)}}{3} \right\rceil\right) \right\rceil + \left\lceil \frac{n_{(3)} + n_{(3),4}}{3} + \frac{1}{3}\left\lceil \frac{n_{(3,2)}}{2} \right\rceil \right\rceil + \frac{\rho}{T_\mathrm{c} \cdot N_\mathrm{SP}^n} \cdot J_4^n$$

- Where the last term reflects the number of FIDs that can be completely filled with the accumulated jitter

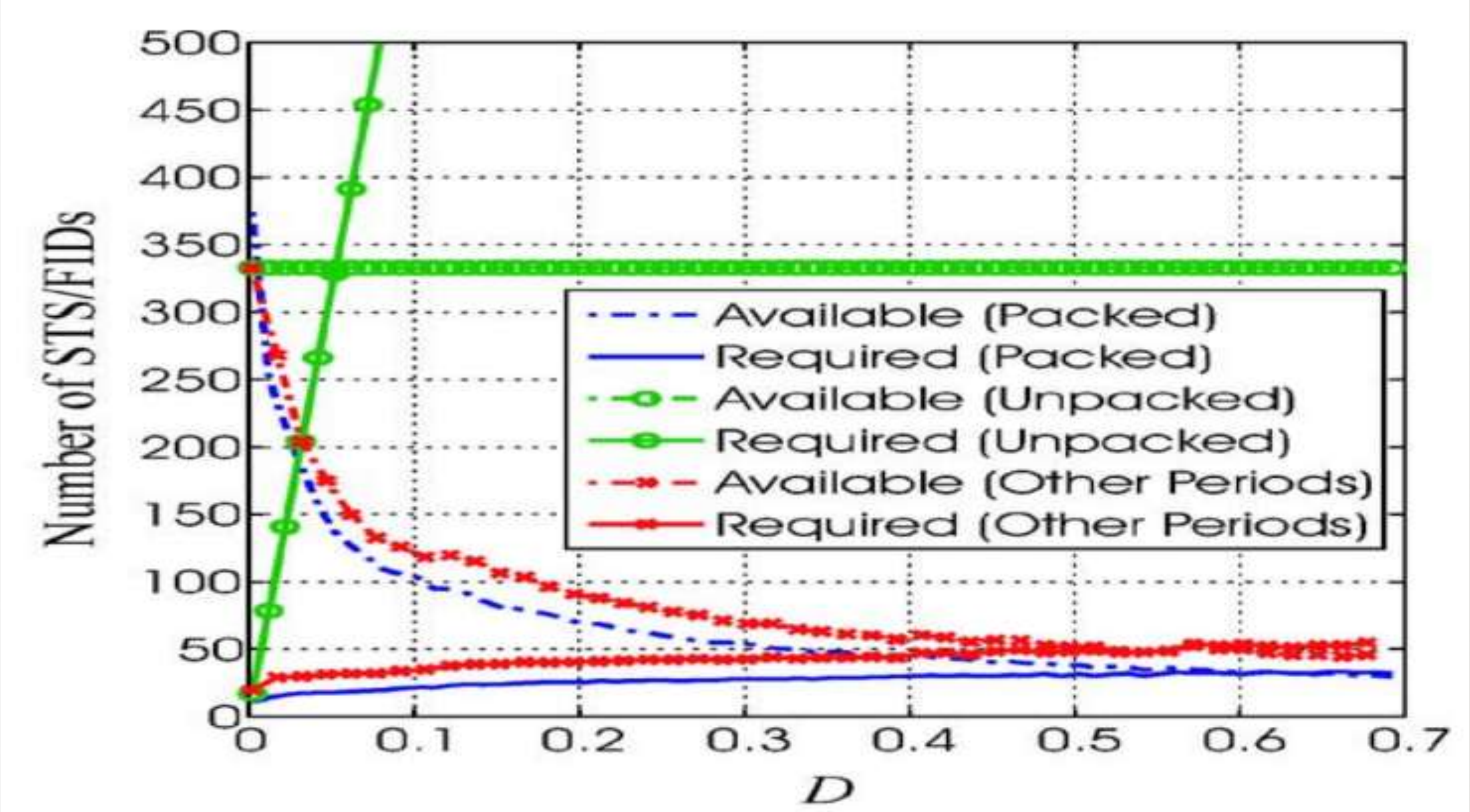
Application To Benchmark Examples

- Society of Automotive Engineers (SAE) benchmark signal set was used to analyze general characteristics of FlexRay scheduling
- The SAE set comprises 22 signals whose periods are integer multiples of 5 ms, and that are exchanged among six nodes

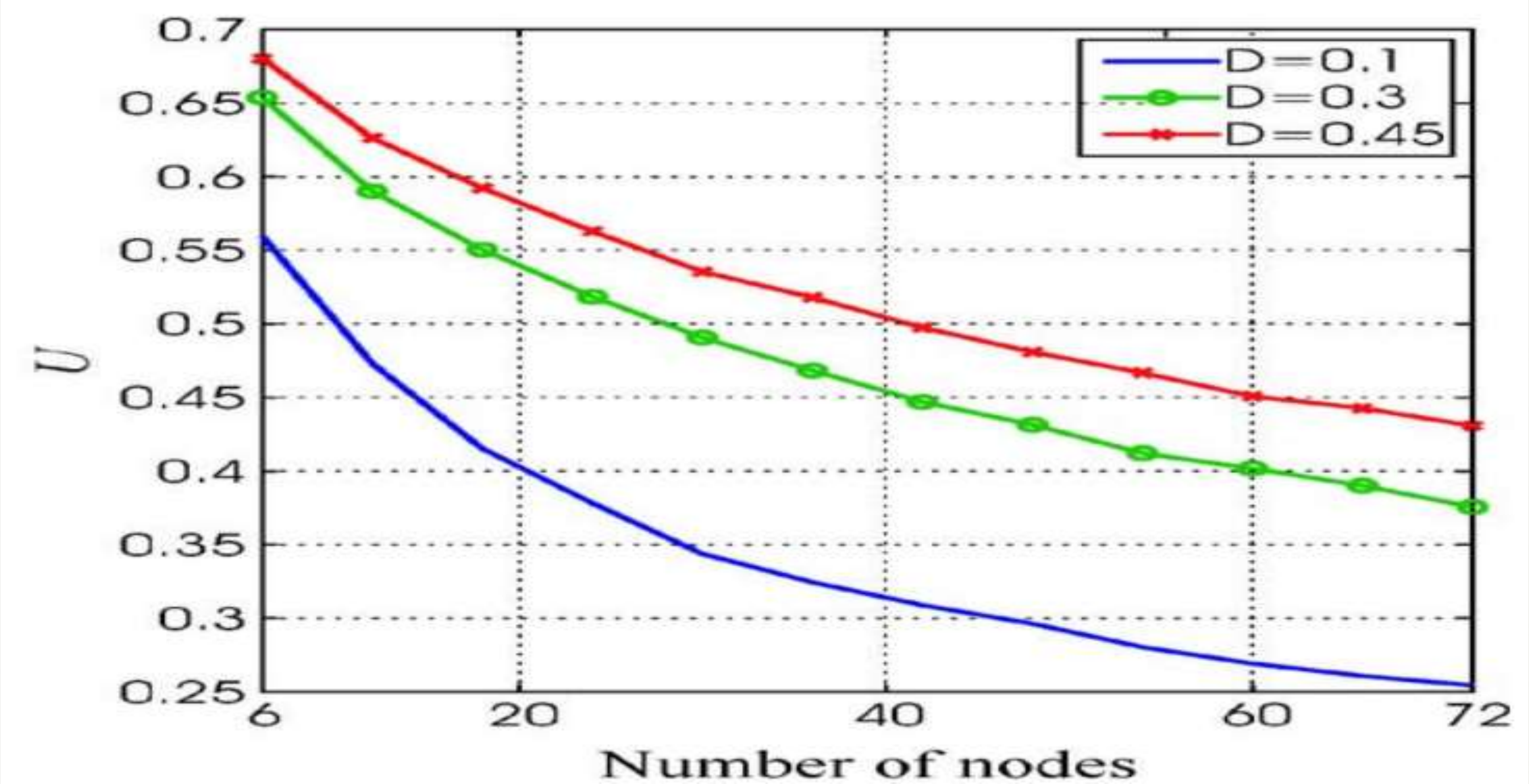
Utilization with respect to Demand



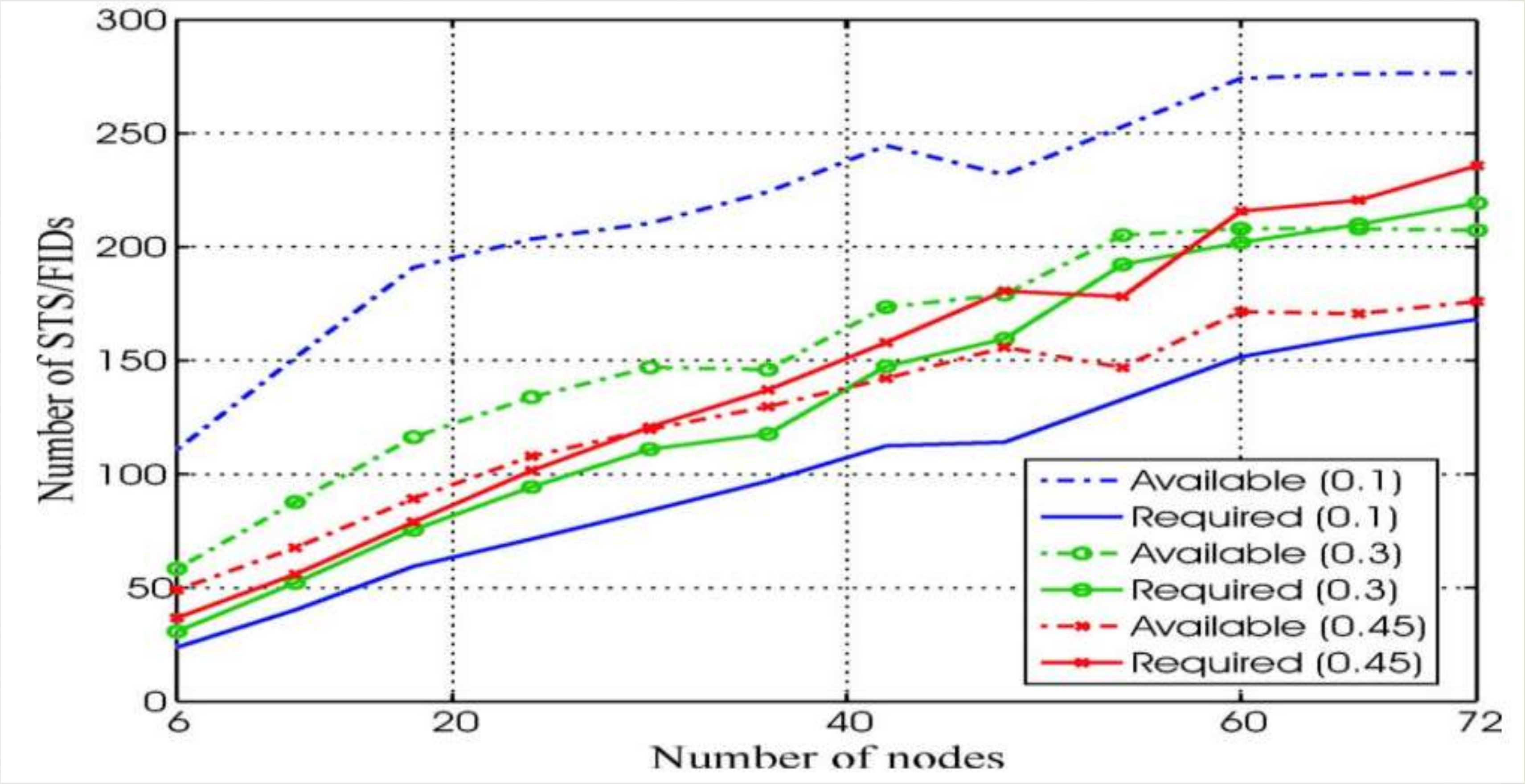
Required FIDs versus available STS with respect to D



Utilization for Different Numbers of Nodes



Required FIDs versus available STSs for different numbers of nodes



Conclusion

- It can be concluded that
  - Frame packing is essential to achieve a satisfactory utilization
  - Fewer signal data can be scheduled on a FlexRay bus with a larger number of nodes