Communication systems for vehicle electronics

Presentation overview

- ***Background***

  automotive electronics, an application area for time triggered communication.

- ***Time triggered protocols***

  TTCAN, based on popular "Controller Area Network" (CAN) protocol.

  TTP/C, Operational in civil aircrafts.

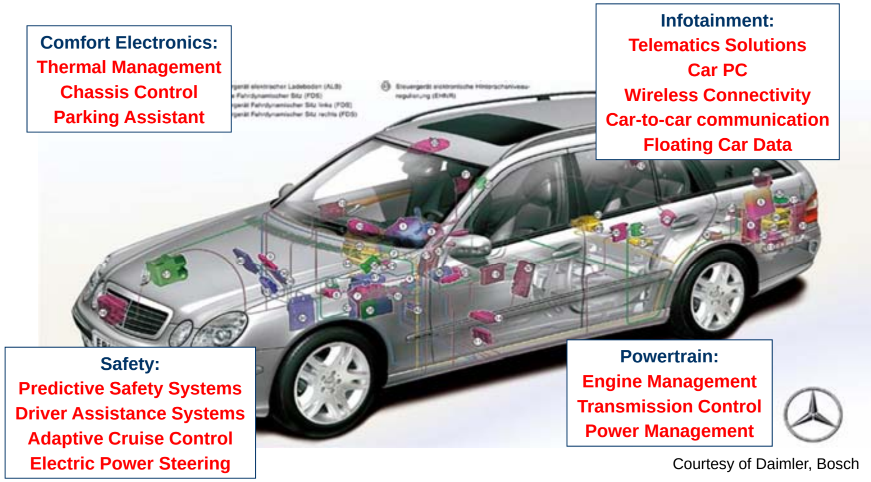
  FlexRay, based on BMW's "ByteFlight".

  TTEthernet, based on classical Ethernet.

- ***Hybrid scheduling***

  combining static scheduling with fixed priority scheduling analysis.

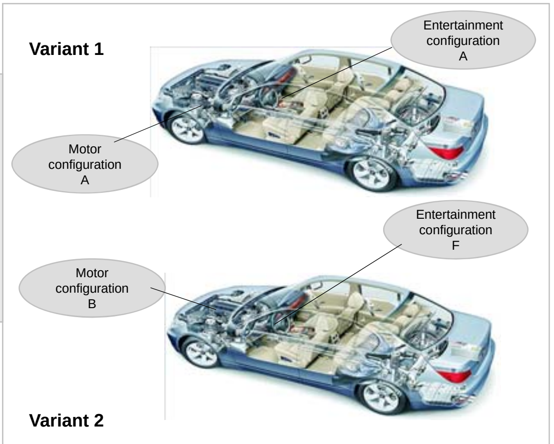
A premium passenger car is controlled and managed by 80+ Embedded Systems



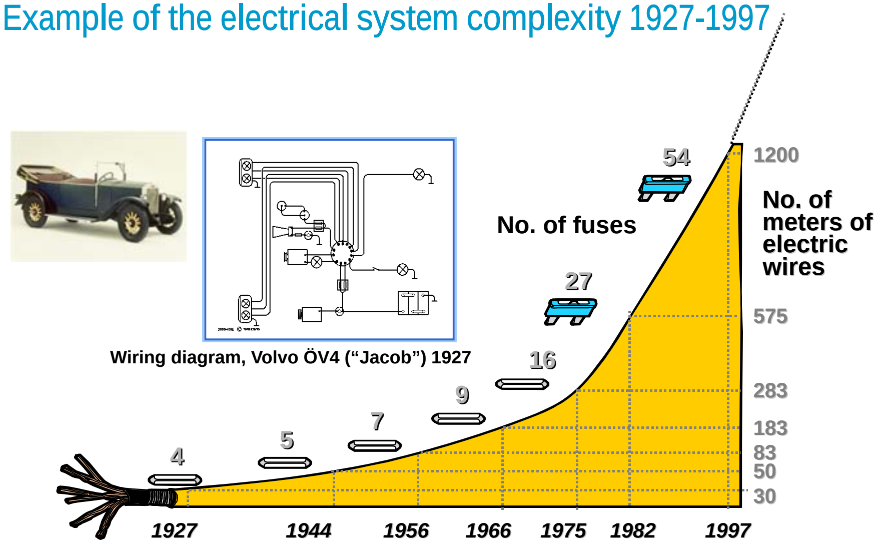
Courtesy of Daimler, Bosch

Virtual differentiation between variants

- **All variants of a specific model are physically identical and differ only in their individual software configuration**
- **The various included physical components can be activated or deactivated by the software**



Example of the electrical system complexity 1927-1997



Wiring diagram, Volvo ÖV4 ("Jacob") 1927

The evolution of functional requirements on the electrical system

Power production and distribution
Simple components

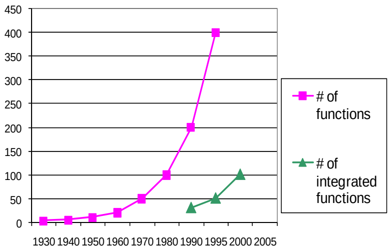
Architecture
Optimisation on many levels
Standardised interfaces

More complex functions
stand-alone systems
ABS, Airbag

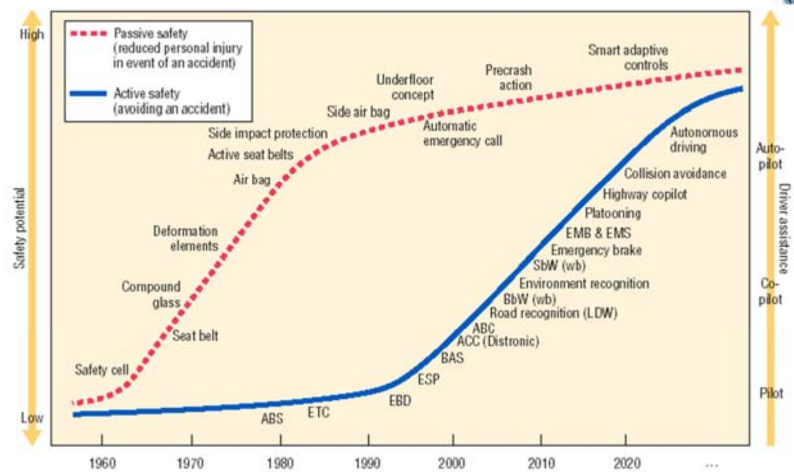
Integration of systems
Optimisation of information
Common data busses

1970 1980 1990 2000 2010

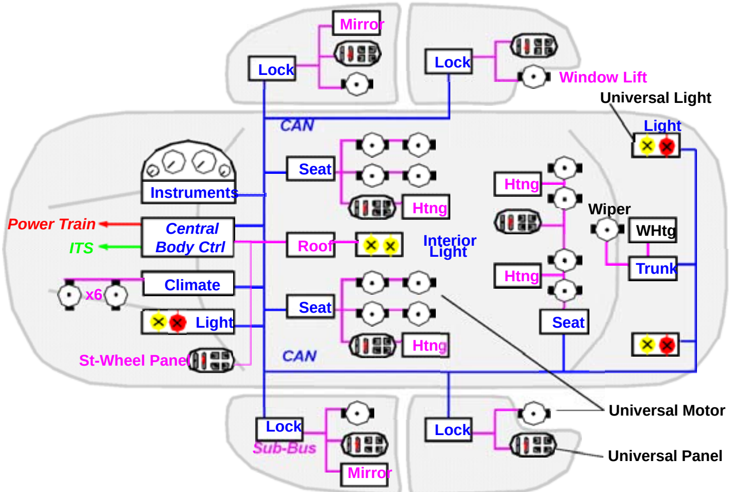
Features



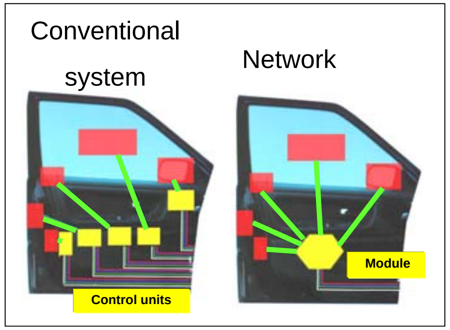
Automotive electronics roadmap

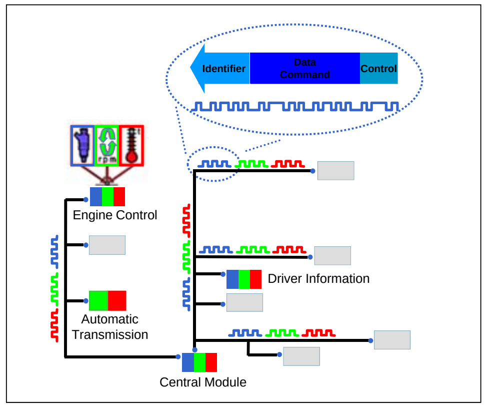


Example of the electrical system…

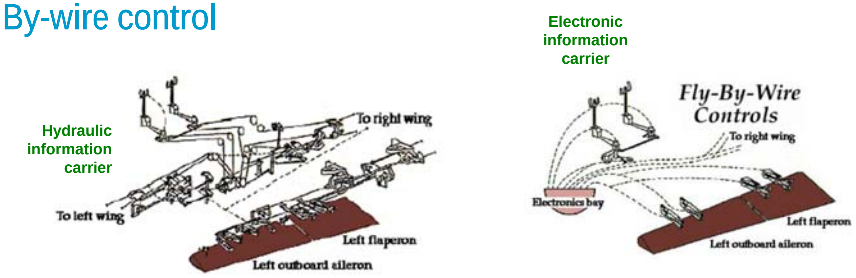


Multiplex Networks





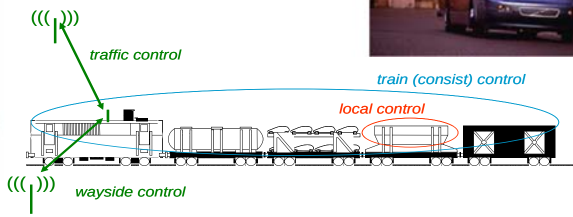
By-wire control



The F-8 Digital Fly-By-Wire (DFBW) flight research project validated the principal concepts of all-electric flight control systems now used on nearly all modern high-performance aircraft and on military and civilian transports. The first flight of the 13-year project was on May 25, 1972.

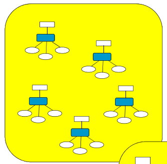
Courtesy of Dryden Flight Research Center

Electronics in distributed control

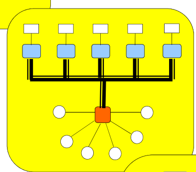


Control system implementation strategies

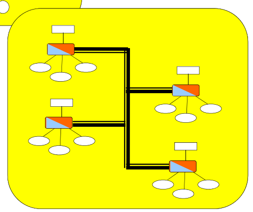
Local control
- Local information processing
- Independent control objects



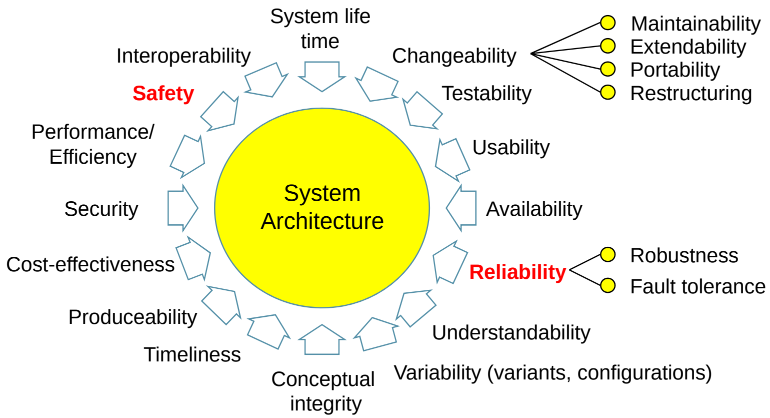
Centralized global control
- Local and central information processing
- Interconnected control objects



Distributed global control
- Local and distributed information processing
- Interconnected control objects



Non-functional requirements



Tradeoffs from Safety/Reliability requirements

The extremes from reliability requirements leads to safety requirements.

Safety requirements implies redundancy, (Fail-Operational, Fail-Safe, etc).

Safety requirements also demands predictability, we has to show, a priori, that the system will fulfill it's mission in every surrounding at every time.

- ***In a distributed environment, only time triggered protocols with redundant buses can provide this safety.*** *Contemporary TTP's are:*

TTCAN, based on *Controller Area Network* (CAN) which is widely used in today's vehicular electronic systems.

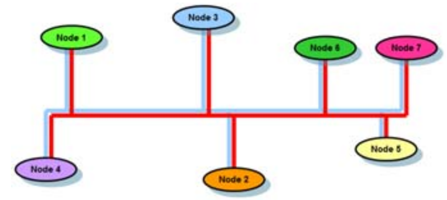
TTP/C, Originally from TU Vienna. Operational in civil aircrafts.

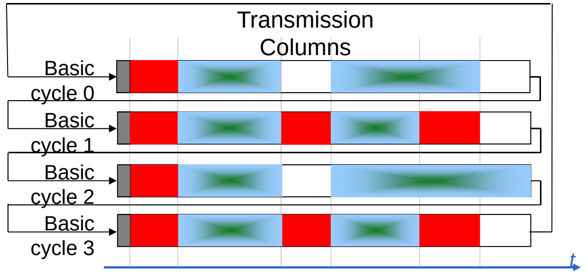
FlexRay, based on BMW's "ByteFlight". Operational in contemporary automotive electronic systems.

TimeTriggered Ethernet. TTEthernet expands classical Ethernet with services to meet time-critical, deterministic or safety-relevant conditions.

Time Triggered CAN

- Based on the CAN protocol
- Bus topology
- Media: twisted pair
- 1Mbit/s





"Exclusive" – guaranteed service

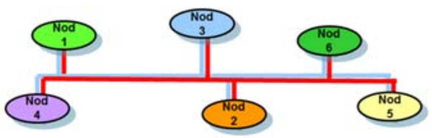
"Arbitration" – guaranteed service (high ID), best effort (low ID)

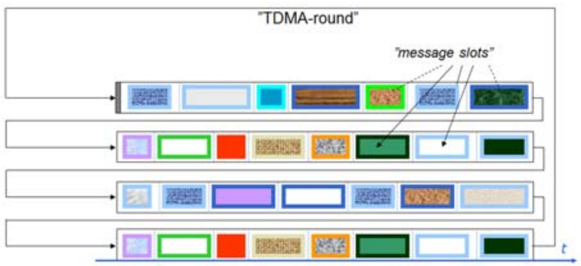
"Reserved" – for future expansion...

Time is global and measured in *network time units* (NTU's)

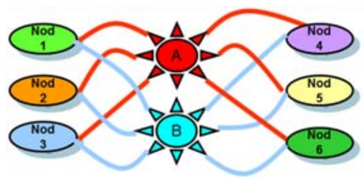
Time Triggered Protocol /Communication

- Double channels (one redundant). Bus topology or "star" (optical)
- Media: twisted pair, fibre
- 10 Mbit/s for each channel





A network is built on either twin buses or twin stars.

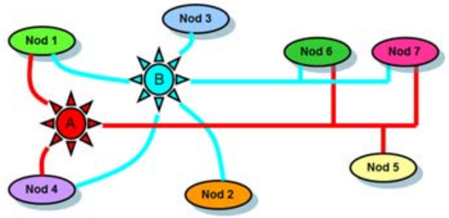


All communication is statically scheduled

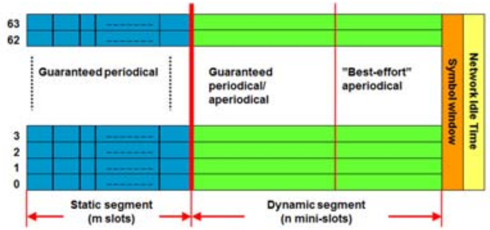
Guaranteed service, Non periodical messages has to been fitted into static slots by the application

Flexray

- Double channels, bus or star (even mixed).
- Media: twisted pair, fibre
- 10 Mbit/s for each channel



Redundant channel can be used for an alternative schedule



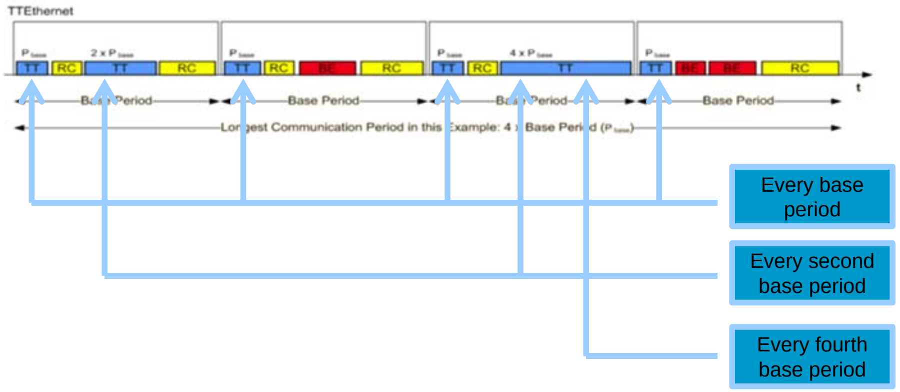
"Static segment" (TTCAN "Exclusive") – guaranteed service

"Dynamic segment" (TTCAN "Arbitration") – guaranteed service (high ID), "best effort" (low ID)

Max 64 nodes on a Flexray network.

Time Triggered Ethernet

- Classic Ethernet bus topology
- 1 Gbit for each channel



Compare with TTCAN "basic cycles"

Comparisons

All protocols targets real time applications.
TTCAN and Flexay combines time AND event triggered paradigms well.

All protocols are suitable for scheduling tools.
TTP/C has commercial production tools. Tools for TTCAN and Flexray are anticipated.

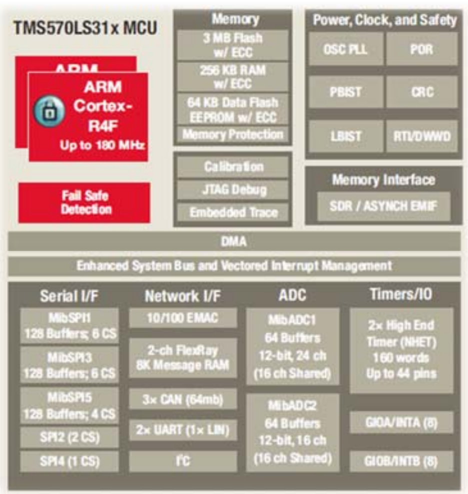
CAN, many years experiences, a lot of existing applications.
Implies migration of existing CAN applications into TTCAN.

TTP/C considered as complex.
Poor support for asynchronous events. High complexity, lacks second (or multiple) sources.

Flexray is the latest initiative.
New hardware, promoted in for example "AUTOSAR".

TTEthernet.
Proven technology with lots of existing hardware,

What to choose?



Key features

- ARM Cortex-R4F core floating-point support
- Up to 180 MHz
- Lockstep safety features built-in simplify SIL-3/ASIL D applications
- Up to 3-MB Flash/256-KB RAM with ECC
- Memory protection units in CPU and DMA
- Multiple communication peripherals:
  - Ethernet, FlexRay, CAN, LIN, SPI
- Flexible timer module with up to 44 channels
- 12-bit analog/digital converter
- External memory interface

Targeted transportation applications

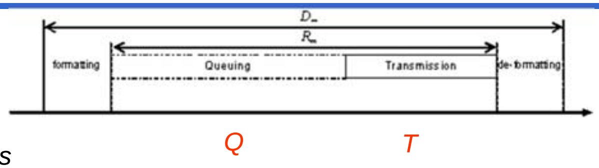
- Braking systems (ABS and ESC)
- Electric power steering (EPS)
- HEV/EV inverter systems
- Aerospace
- Railway control, communications and signaling
- Off-road vehicles

Combining time triggering with events: Example of Hybrid scheduling for *TTCAN*

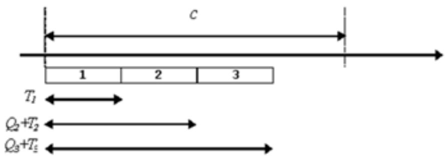
Messages are sorted into three different categories:

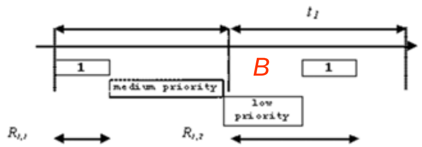
- Hard real-time, for minimal jitter with guaranteed response time.
- Firm real-time, for guaranteed response time, but can tolerate jitter.
- Soft real-time, for "best effort" messages.

TTCAN detailed study



Response time analysis

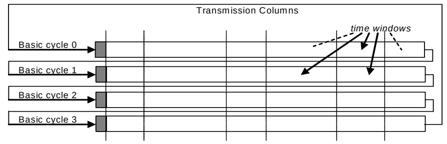




$$Q_i = \sum_{\forall j: P_j < P_i} \left\lceil \frac{Q_i}{t_j} \right\rceil T_j$$

$$R_i = B_i + T_i + Q_i$$

Time triggered messages M^h



After structuring:

M : $\{M^h, M^f, M^s\}$, assume that at least M^h is defined. We now construct a matrix cycle. Due to protocol constraints, the schedule has to fulfil:

$$\mathbf{LCM}(M^h_p) = x\,2^n$$

where:

- LCM is *least common multiple* period for the M^h message set;
- x is the preferred length of a basic cycle within LCM;
- n is the number of *basic cycles*.

Hardware constraints:

Hwc1: $1 \le x \le 2^y$, has to be consistent with a hardware register, y bits

Hwc2: $0 \le n \le k$, always a power of 2, constraint in hardware.

Hwc3: # of triggers $\le Tr$, columns in the matrix cycle. Limited by the number of available trigger registers.

Multiple solutions satisfies the equation...

Choose a strategy:

Strategy 1:

Minimize number of *basic cycles*, requires a longer *basic cycle*, and more *triggers*.

Strategy 2:

Minimize length of *basic cycles*, increase probability of finding a feasible schedule for large message

Persuing the strategies...

Construct a schedule for the following set:

$\boldsymbol{M^h}$ = ($M1$, $M2$, $M3$) with the following attributes (NTU):

$M1_p$ = 1000, $M1_e$ = 168

$M2_p$ = 2000, $M2_e$ = 184

$M3_p$ = 3000, $M3_e$ = 216

It's obvious that:

LCM($M1$, $M2$, $M3$) = 6000.

and:

$$6000 = x\,2^n$$

Strategy 1

Minimizing number of basic cycles yields: $2^n = 1$, so $n = 0$ and $x = 6000$.
Hwc1 and Hwc2 are fulfilled.
Total numbers of *triggers* for *N* messages in one *basic cycle* is:

$$\sum_{i=1}^{N} \frac{LCM(\boldsymbol{M})}{M^i}$$

in this case:

$$\#\text{ of } triggers = \frac{6000}{1000} + \frac{6000}{2000} + \frac{6000}{3000} = 11$$

So, strategy 1, leads to a solution with:

- 1 *basic cycle* and 11 triggers.
- MAtrix cycle length is 6000 NTU.

Basic Cycle Triggers																	
0	168	352		1000		2000	2168		3000		3352		4000	4168		5000	
M_1	M_2	M_3		M_1		M_1	M_2		M_1		M_3		M_1	M_2		M_1	

Strategy 2

n = 0:
6000 = x 2^0 ⇒ x = 6000
(same as strategy 1)

n = 1:
6000 = x 2^1 ⇒ x = 3000

n = 2:
6000 = x 2^2 ⇒ x = 1500

n = 3:
6000 = x 2^3 ⇒ x = 750

***n* = 4:**
6000 = x 2^4 ⇒ x = 375

n = 5:
6000 = x 2^5 ⇒ x = 187.5

Basic cycle								*Trigger Information*
1 (at 0)	0	168	352	-	-	-	-	
2 (at 375)	-	-	-	-	-	-	-	
3 (at 750)	-	-	-	-	-1000	-	-	
4 (at 1125)	-	-	-	-	-	-	-	
5 (at 1500)	-	-	-	-	-	-	-	
6 (at 1875)	-	-	2000	2168	-	-	-	
7 (at 2250)	-	-	-	-	-	-	-	
8 (at 2625)	-	-	-	-	-	-	-	
9 (at 3000)	3000	-	-	-	-	3352	-	
10 (at 3375)	-	-	-	-	-	-	-	
11 (at 3750)	-	-	-	-	-	-	4000	
12 (at 4125)	4125	4168	-	-	-	-	-	
13 (at 4500)	-	-	-	-	-	-	-	
14 (at 4875)	-	-	-	-	-	-	5000	
15 (at 5250)	-	-	-	-	-	-	-	
16 (at 5625)	-	-	-	-	-	-	-	Minimum *Triggers*
1	M_1	M_2	M_3					3
2								0
3					M_1			1
4								0
5								0
6			M_1	M_2				2
7								0
8								0
9	M_1					M_3		2
10								0
11							M_1 ?	1
12	? M_1	M_2						2
13								0
14							M_1	1
15								0
16								0

Strategy 2

Avoid this conflict with the requirement that:
a basic cycle shall be *at least as long as* the shortest period in the message set.

Applying this restriction we get:
n = 2, (x = 1500)
which yields a feasible schedule:

Basic cycle									*Trigger Information*
	1	0	168	352	-	-	-	1000	
	2	-	-	-	2000	2168	-	-	
	3	3000	-	3352	-	-	4000	4168	
	4	-	-	-	5000	-	-	-	Minimum *Triggers*
1		M_1	M_2	M_3				M_1	4
2					M_1	M_2			2
3		M_1		M_3			M_1	M_2	4
4					M_1				1

Verifying the events... (M^f)

Basic Cycle	Grey slots are supposed to be allocated for M^h								
	NTU-slots (Columns)								
1		q_0							
2		q_1					q_2		
3		q_3		q_4			q_5		
.....		...			...		...		...
2^n		q_{N-3}					q_{N-2}		q_{N-1}

```
for each message m in M^f :
  for message m = 1 up to last_m
    for virtual message VM_i = 1 up to last_VM
      if( Q_m + T_m ) falls within ( VM_i,start , VM_i,completion )
        Q_m = VM_i,completion
      else
```

$$Q_m = \sum_{\forall j: P_m < P_j}^{1} \left\lceil \frac{Q_m}{t_j} \right\rceil T_j$$

```
      endif
    end
  end
end
```

Conclusions

- Applicable real time communication protocols for safety-critical applications has to provide strictly periodical (minimal jitter), periodical (jitter is negligible) and a-periodic communication to fully support control applications.
- Scheduling periodical and a-periodical events requires a combined approach, *hybrid scheduling*.
- Hybrid scheduling is sparsely found in today's literature...

Thank you for your attention.