Time triggered real time communication

Presentation overview

- ***Background***

  automotive electronics, an application area for time triggered communication.

- ***Time triggered protocols***

  TTPC, first commercial implementation. Originally from TU Vienna. Operational in civil aircrafts.

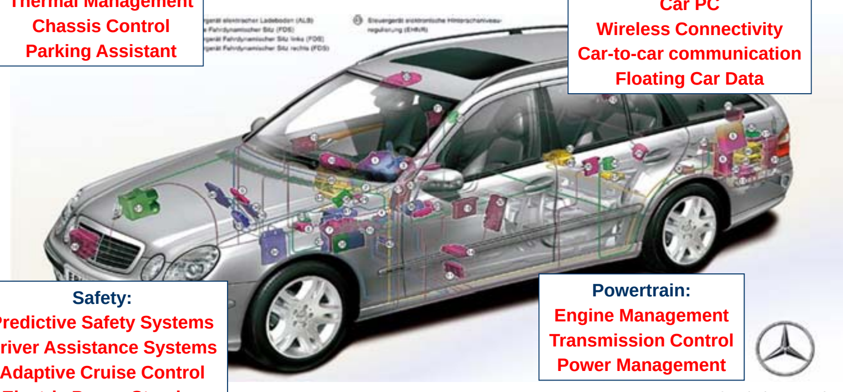
  TTCAN, based on *Controller Area Network* (CAN) which is widely used in today's vehicular electronic systems.

  FlexRay, based on BMW's "ByteFlight". Anticipated in next generation automotive electronic systems.

- ***Hybrid scheduling***

  combining static scheduling with fixed priority scheduling analysis.

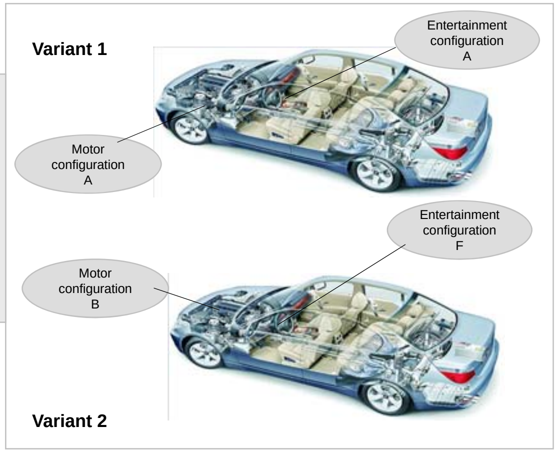
A premium passenger car is controlled and managed by 80+ Embedded Systems



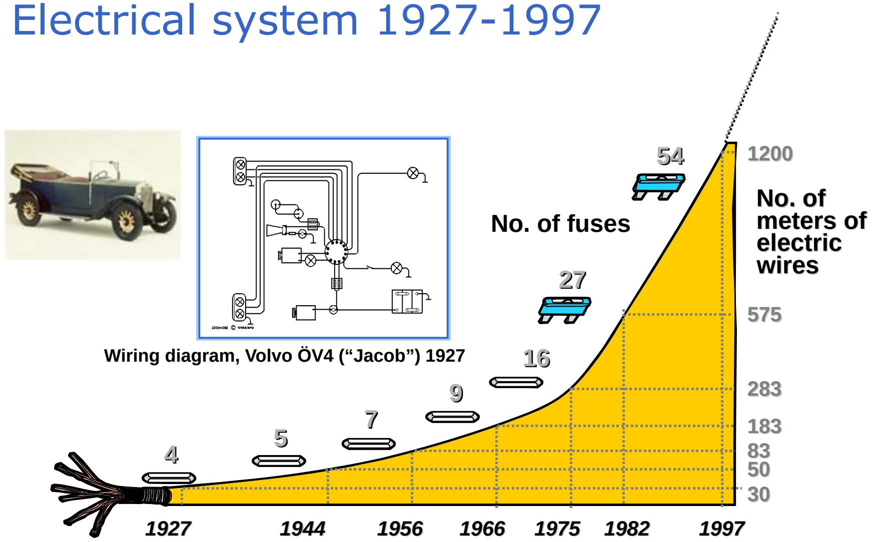
Courtesy of Daimler, Bosch

Virtual differentiation between variants

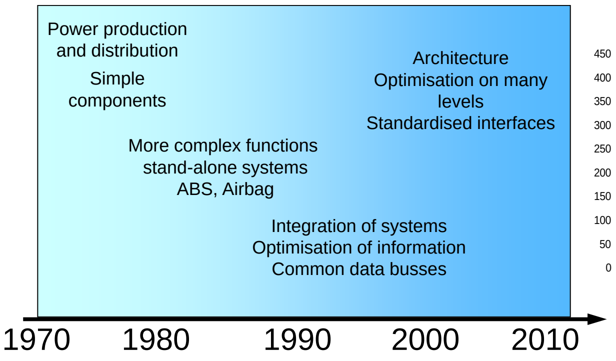
- **All variants of a specific model are physically identical and differ only in their individual software configuration**
- **The various included physical components can be activated or deactivated by the software**



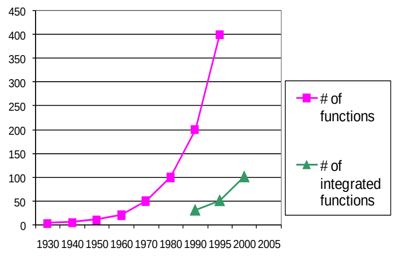
Electrical system 1927-1997



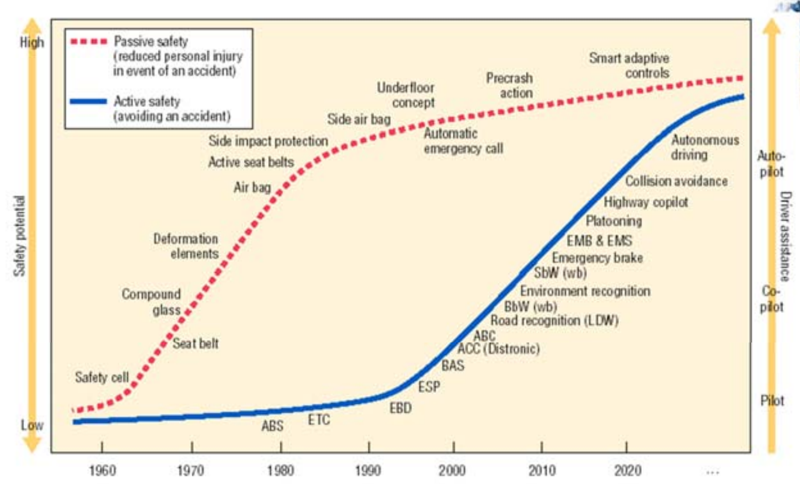
The evolution of the electrical system



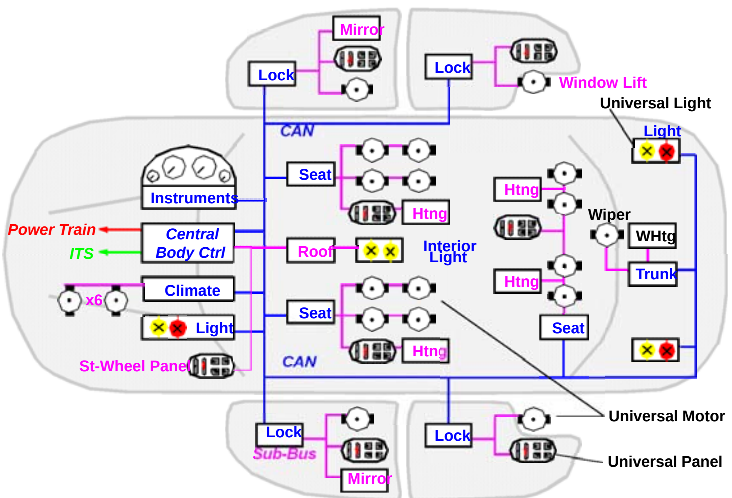
Features



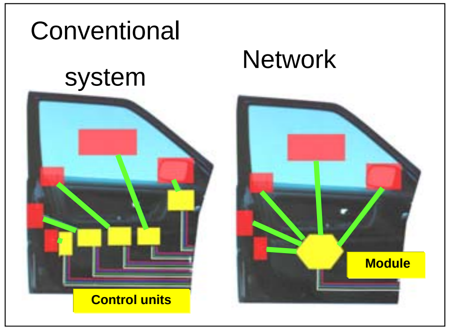
Automotive electronics roadmap

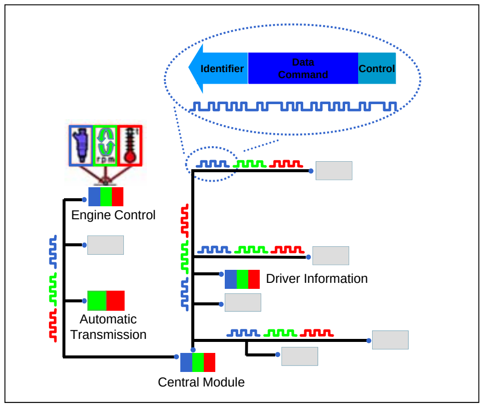


An electrical system…

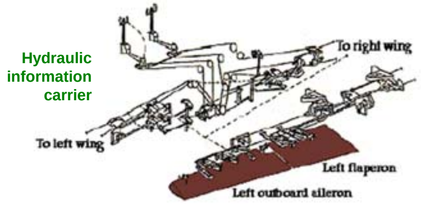


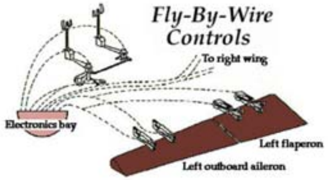
Multiplex Networks





By-wire control

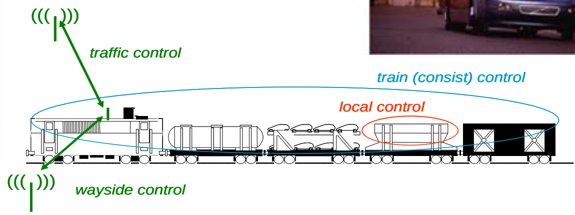




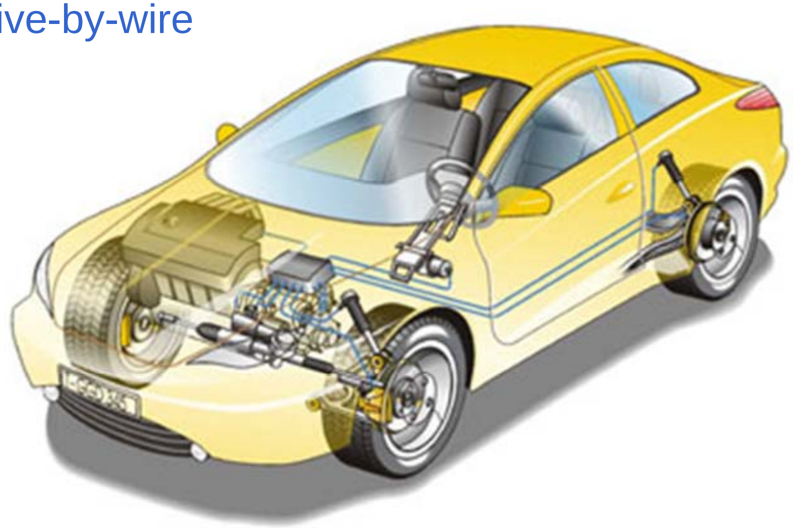
The F-8 Digital Fly-By-Wire (DFBW) flight research project validated the principal concepts of all-electric flight control systems now used on nearly all modern high-performance aircraft and on military and civilian transports. The first flight of the 13-year project was on May 25, 1972.

Courtesy of Dryden Flight Research Center

Electronics in distributed control



Drive-by-wire

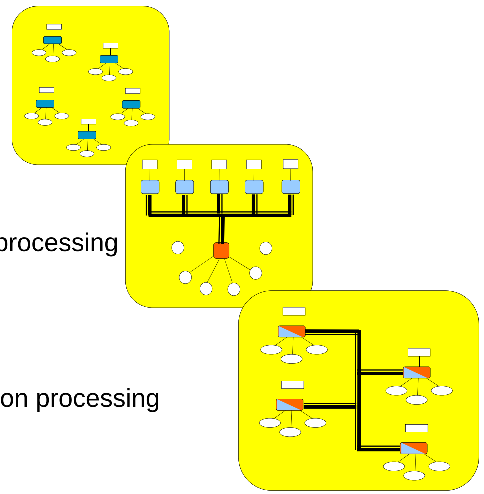


Control system implementation strategies

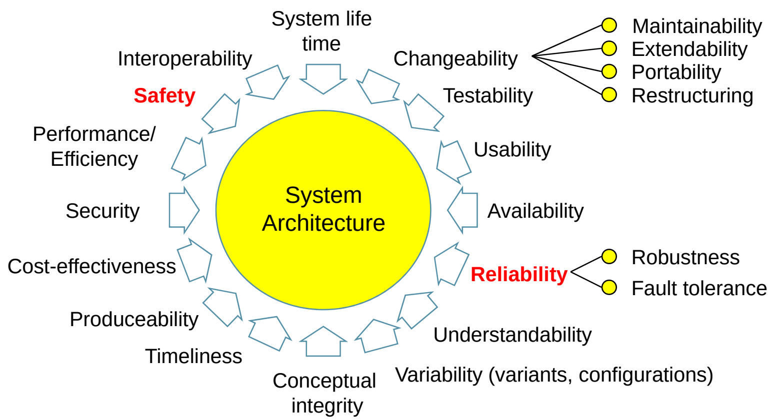
Local control
- Local information processing
- Independent control objects

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 and redundant buses can provide this safety.*** *Contemporary TTP's are:*

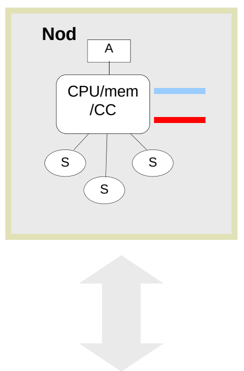
TTP/C, first commercial implementation. Originally from TU Vienna. Operational in civil aircrafts.

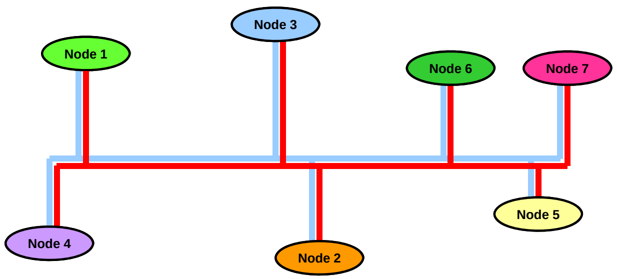
TTCAN, based on *Controller Area Network* (CAN) which is widely used in today's vehicular electronic systems.

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

TTCAN

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





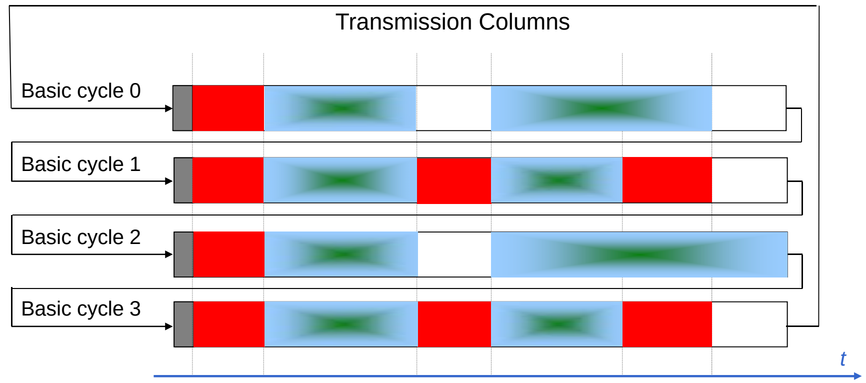
A second controller is required to implement the redundant bus

TTCAN

"Exclusive" – guaranteed service

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

"Reserved" – for future expansion...

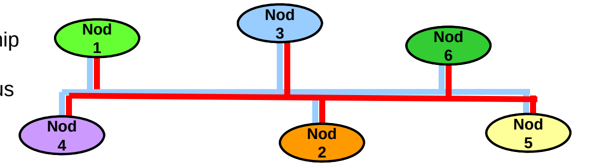


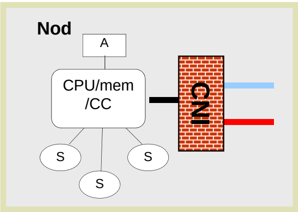
Time is global and measured in *network time units* (NTU's)

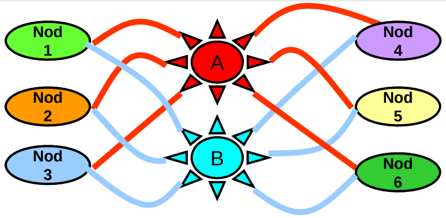
TTP/C

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

CNI works as a “firewall”
Status, global time, membership
Control, clock interrupt
Watchdog, checking consensus
Data the actual message



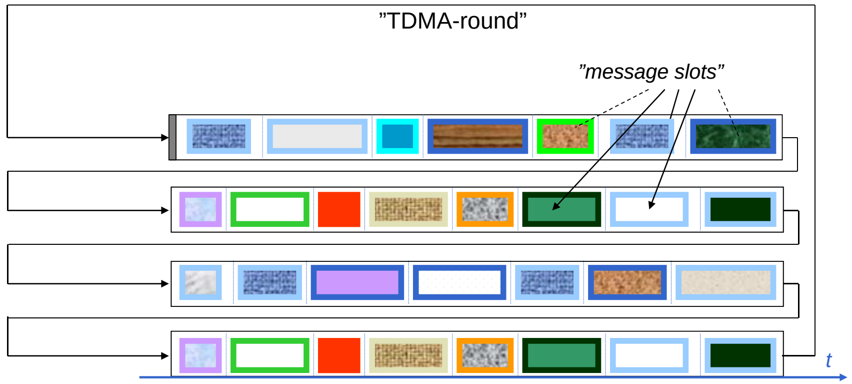




A network is built on either twin buses or twin stars.

TTP/C

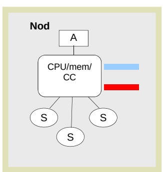
All communication is statically scheduled
Guaranteed service

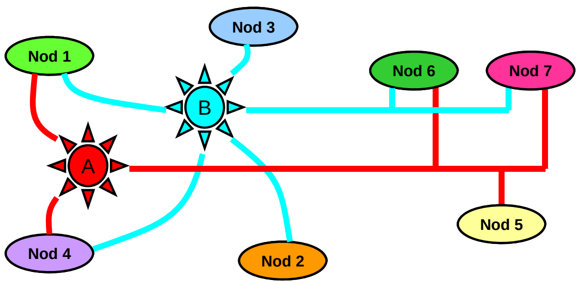


Non periodical messages has to been fitted into static slots by the application

Flexray

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



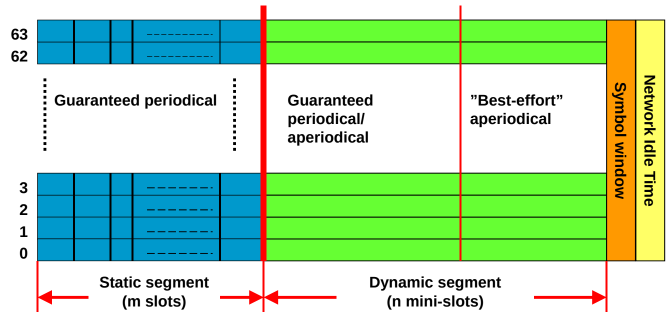


Redundant channel can be used for an alternative schedule

Flexray

”Static segment” (compare TTCAN ”Exclusive”)
– guaranteed service

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



Max 64 nodes on a Flexray network.

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.

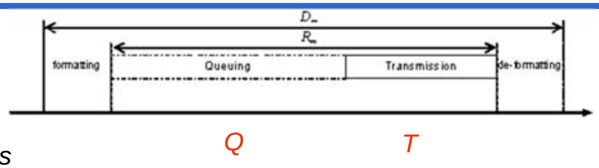
Flexray is the latest initiative.
Supported by most automotive suppliers.

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

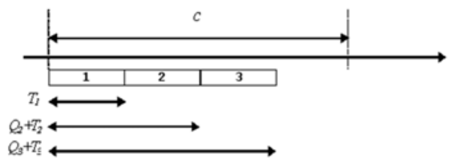
Messages are sorted into three different categories:

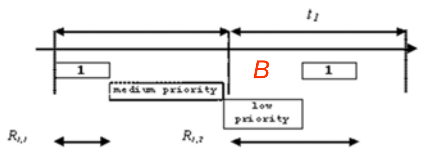
- Hard real-time, for minimal jitter with guaranteed response time.
- Firm real-time, for guaranteed response time, but can tolerate jitter.
- Soft real-time, for "best effort" messages.

TTCAN detailed study



Response time analysis

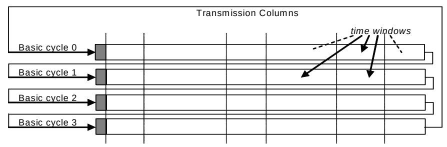




$$Q_i = \sum_{\forall j: P_j < P_i} \left\lceil \frac{Q_i}{t_j} \right\rceil T_j$$

$$\boxed{R_i = B_i + T_i + Q_i}$$

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:

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

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 $\Rightarrow$ *x = 6000*
(same as strategy 1)

n = 1:
6000 = x 2^1 $\Rightarrow$ *x = 3000*

n = 2:
6000 = x 2^2 $\Rightarrow$ *x = 1500*

n = 3:
6000 = x 2^3 $\Rightarrow$ *x = 750*

n = 4:
6000 = x $\boldsymbol{2^4}$ $\Rightarrow$ ***x = 375***

n = 5:
6000 = x 2^5 $\Rightarrow$ *x = 187.5*

Basic cycle									*Trigger* Information / Minimum *Triggers*
	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)	-	-	-	-	-	-	-	
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	1 2 3 4	0 - 3000 -	168 - - -	352 - 3352 -	- 2000 - 5000	- 2168 - -	- - 4000 -	1000 - 4168 -		*Trigger* Information / 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 future safety-critical applications has to provide strictly periodical (minimal jitter), periodical (jitter is negliable) and a-periodic communication to fully support control applications.
- Scheduling periodical and a-periodical events requires a new approach, *hybrid scheduling*.
- Hybrid scheduling is sparsely found in today's literature...

Time triggered real time communication

Thank you for your attention.