Evaluation of numerical bus systems used in rocket engine test facilities

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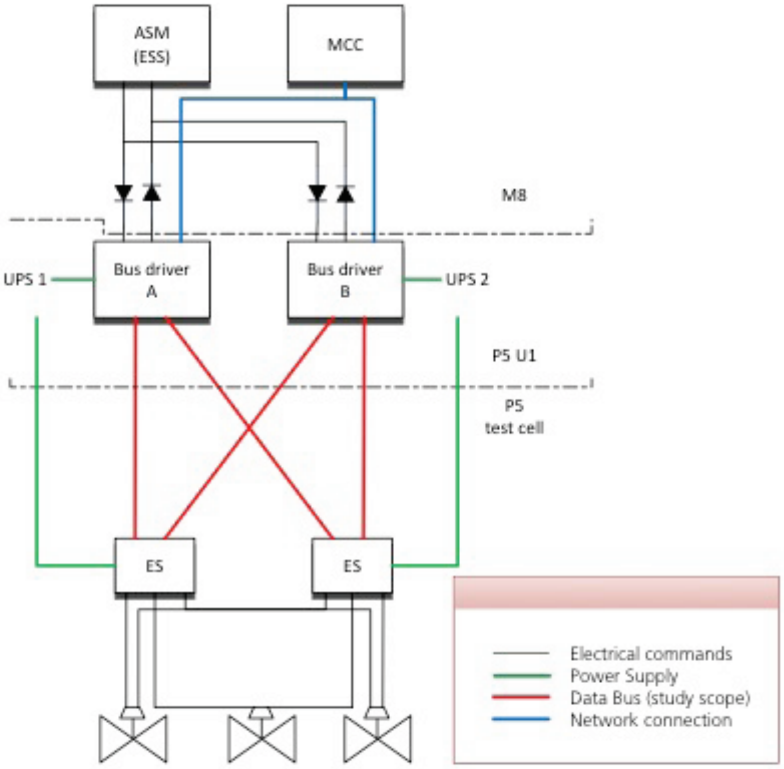
Numerical bus systems for avionic systems

- Aircraft Data Network (ADN): Ethernet derivative for Commercial Aircraft
- **Avionics Full-Duplex Switched Ethernet (AFDX)**: Specific implementation of ARINC 664 (ADN) for Commercial Aircraft
- ARINC 629: Commercial Aircraft (Boeing 777)
- **IEEE 1394b**: Military Aircraft
- **MIL-STD-1553**: Military Aircraft
- MIL-STD-1760: Military Aircraft
- MIL-STD-1773: Military Aircraft
- **TTP** - Time-Triggered Protocol: Boeing 787 Dreamliner, Airbus A380, Fly-By-Wire Actuation Platforms from Parker Aerospace
- **TTEthernet** - Time-Triggered Ethernet: NASA Orion Spacecraft

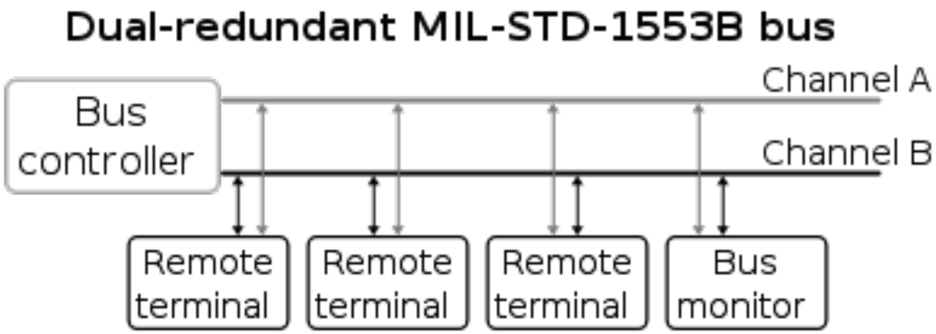
Test bench set-up

Basic requirements:

- Reliability
- Command source MCC and ASM
- Timing requirements (10 ms)
- End-to-end latency 1 ms
- Bus length >50m
- Throughput: > 200 kbit/s



Bus systems:
MIL-STD-1553 (reference)



- establishes requirements for digital, command-response, time division multiplexing data bus.
- Main elements are:
  - Bus Controller (BC)
  - Remote Terminal (RT)
  - Bus Monitor (BM)
- Operation is asynchronous, which mean every terminal (BC, RT and BM) uses independent clock source

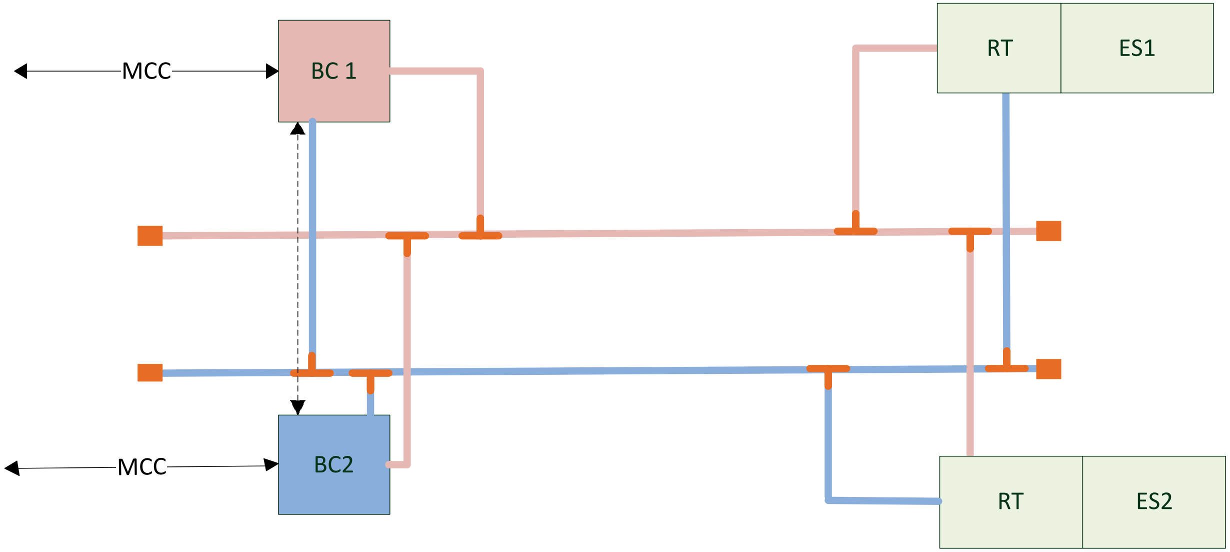
Bus systems:
MIL-STD-1553 (reference)

- Characteristics:

Characteristics	Description
Cable	Twisted pair (12 twists per meter), shielded
Capacitance wire-to-wire	100pF/m
Cable attenuation	5 dB/100m
Cable termination resistors	$(Z_0 \pm 2\%)\ \Omega$
Transformer coupled stubs (preferred)	Up to 6 m length, galvanic isolated
Direct coupled stubs	Up to 30 cm length

Bus systems:
Hyper-1553

- Possible successor of the 1553 using the same physical layer
- Data rate exceeded up to 200 Mbit/s throughput
- Not available on market yet



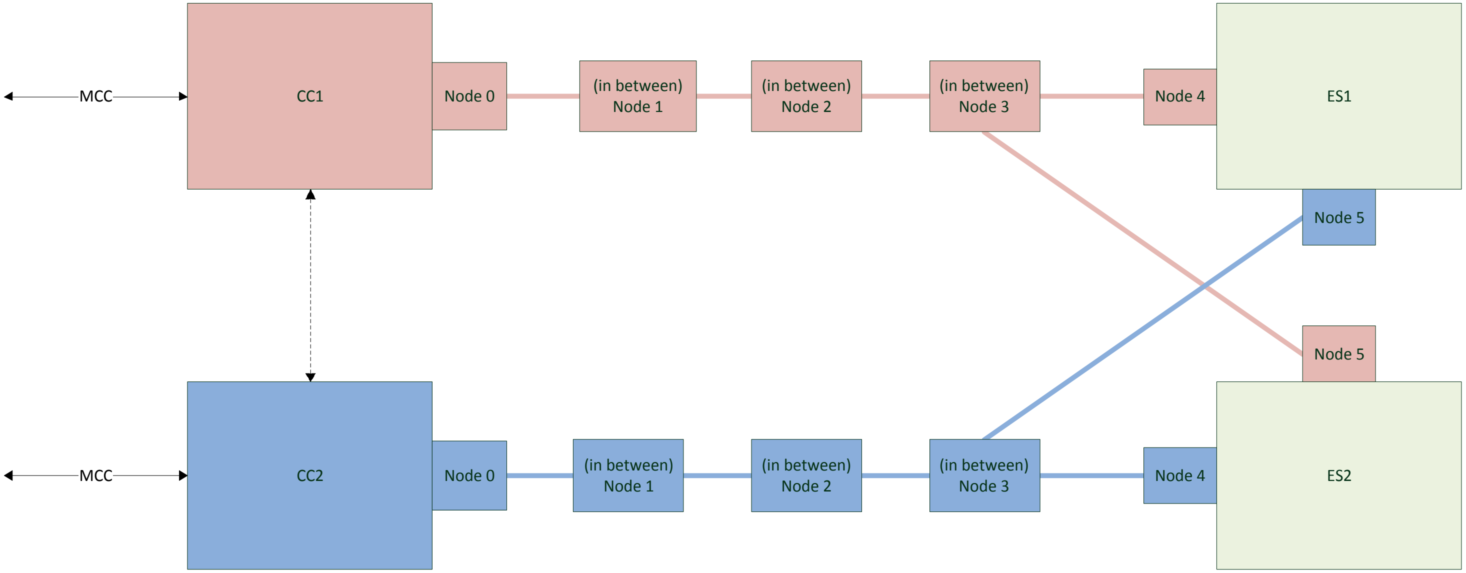
Bus systems:
FC-AE-1553

- Using Fiber optics as physical transport layer
- Throughput exceeded up to 10 Gbit/s
- Upper layer protocol identical to MIL-STD-1553

Advantages	Disadvantages
High throughput	Media change between optical and electrical systems
Reduced EMI/EMC concerns	Higher bit error rate in radiative enviroments
Less weight	In practical use problems with mechanical load on interfaces
Long data bus (>100 m) possible	
Low latency (µs range)	

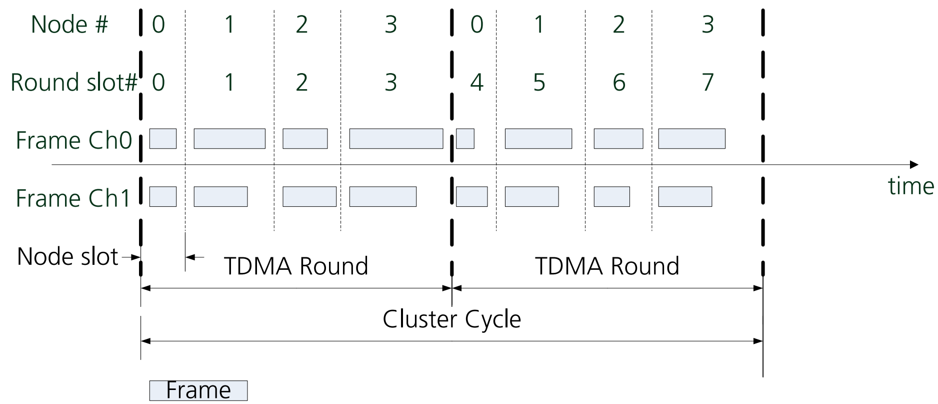
Bus systems:
AS5643 (based on IEEE 1394)

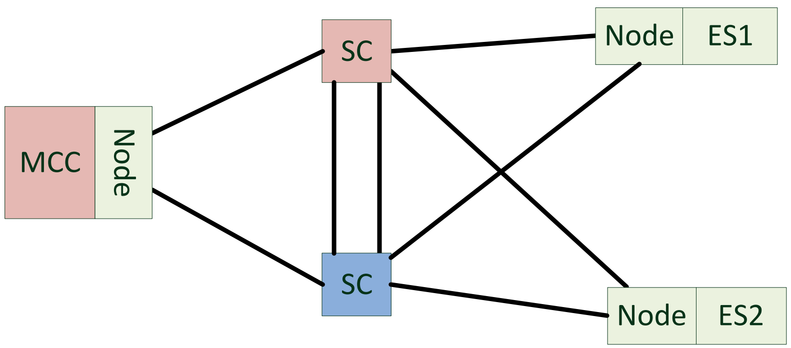
- Deterministic and high throughput (up to 3.2 Gbit/s) network (based on Firewire)
- Latency < 3μs, maximum length: 72m
- Doesn‘t allow hot swap in the moment !



Bus systems: TTP (Time Triggered Protocol)

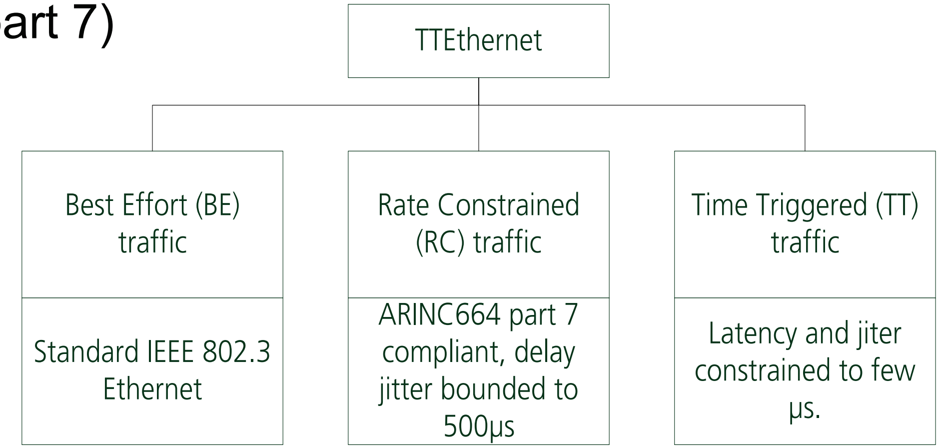
- Doesn‘t specify a physical layer: Concept of Time-Triggered Protocol as successor of MIL-STD-1553 in late 1990s.
- Global time base, concept includes a bus guardian for failure detection
- Single failure tollerant, throughput up to 5 Mbit/s
- But: not scalable (max. 64 nodes)





Bus systems:
TTEthernet (Time Triggered Ethernet)

- Established since TTP does not work on Gbit-Ethernet networks with more than 5MBit/s
- Selected as the bus system for Orion space craft
- Compliant to DO-254 (hardware) and DO-178 (software)
- Three parts of communication:
    - BE traffic (IEEE 802.3) → standard Ethernet → not real time!
    - RC traffic (ARINC 664 part 7) → identical to AFDX
    - TT-traffic → using an global time base for hard real time applications
- Used in Airbus A380
- Depending on implementation 1 or 2 failure tollerance



Conclusion

- Rocket engine tests can always lead to catastropic failures. Such failures has to be reduced by design (especcially by MCC design) as „very unlikely“ → A maximum failure rate of 10^{-6} per year is defined as “very unlikely”
- In Aircrafts it is assumed, that a complete failure of avionics leads every time to catastropic events but such events has to be excluded with a maximum failure rate of 10^{-9} per flight-hour

→Use of Avionic systems in test benches meets the needed safety requirements.

- For launchvehicle borne environment where there can be additional mechanical, EMI and radiation hazards, an additional safety assessment needs to be made.
- TTP and TTEthernet have the advantage of being "replica deterministic".

Conclusion

- AS 5643 and FC-AE-1553 have both excellent throughput and latency parameter, but TTP and TTEthernet are step forward in terms of reliability and fault-tolerance, due to the membership service, the fault-tolerance hypothesis and the compliance with the DO-178 and DO-254.
- Assuming reliability and safety are priority:
    - TTP with MIL-1553 physical layer (SAE AS 6003/1) and
    - TTEthernet (SAE AS6802)
- Are both assumed to be appropriate choices of replacement for MIL-STD-1553
- Final choice choice has to include launcher and test bench systems and has to be based on RAMS(S) analysis.