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Ricerca Formazione Innovazione

Using Ethernet for real-time communication in a Nuclear Fusion Experiment

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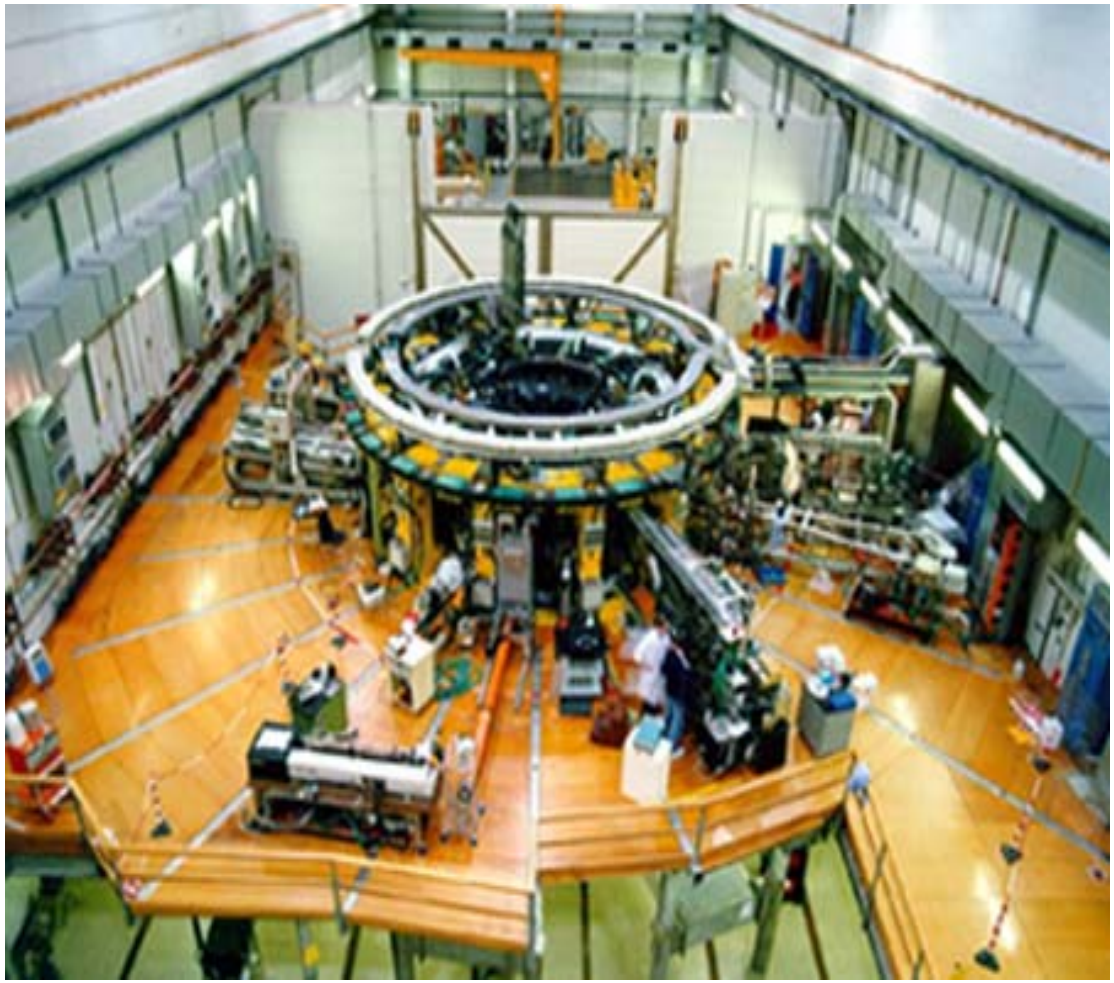
The RFX-Mod experiment

- The RFX-Mod experiment resumed operation in Dec. 2004
- It explores a magnetic confinement which is alternative to the Tokamak configuration
- Major/minor radius of the torus: 2 / 0.5 m
- Plasma discharge: up to 2 MA / 400 ms
- Makes an extensive usage of digital control systems



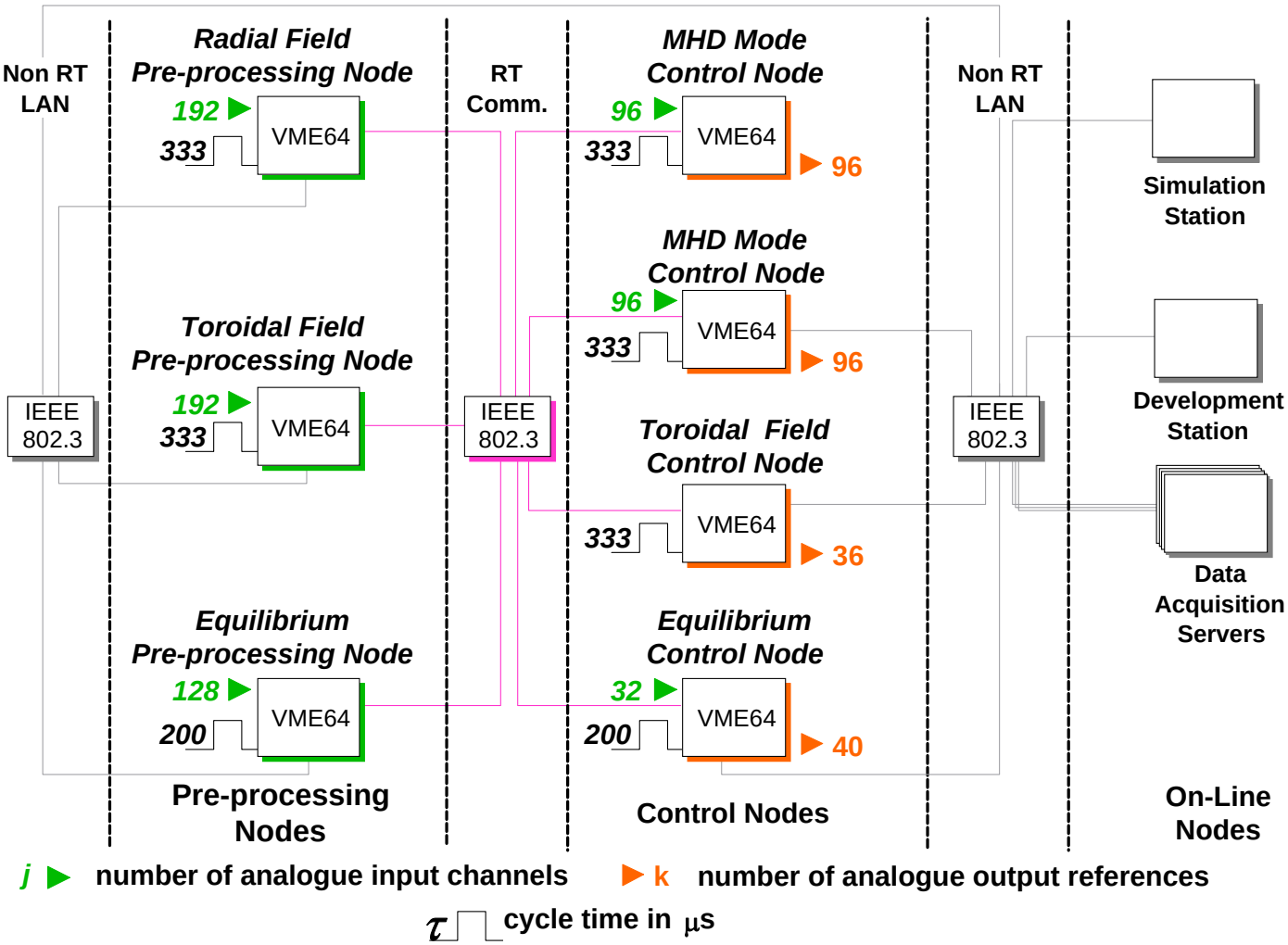
Common requirements in real-time control for fusion devices

- Synchronous High Speed Feedback Control
  - ✓ Plasma control
- Distributed architecture
- Experimental applications
  - ✓ Prototypes
- Rich set of input/output analogue channels
  - ✓ Up to some hundreds of sensors
  - ✓ Tens of actuators (mainly power amplifiers)
- Control cycle time from 1 ms to 300 μs

Control System Overview

- The real-time control system of RFX-mod is composed of 7 nodes (VME racks)
- Each node hosts a a CPU board and a number of ADC and DAC boards
- The nodes either
  - Acquire data and perform local pre-elaboration to produce a set of parameters
  - Compute some kind of control algorithm, based on the parameters possibly computed by other nodes, and produce a set of reference signals.
- A real-time communication network is therefore required to exchange the computed parameters among nodes.

RFX-mod Real Time Control System Layout



Real-time communication requirements

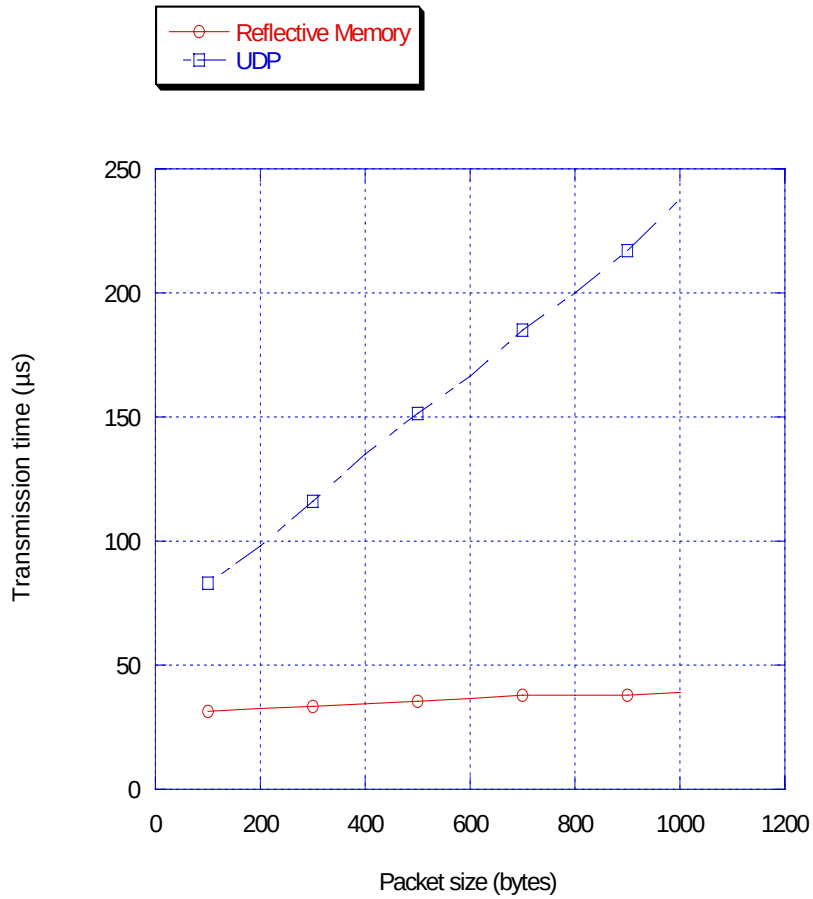
- Network communication is likely to represent the bottleneck in a distributed real-time system.
- Reliability is not always mandatory
  - ✓ Reliability required for: Configuration, Alarm Handling
- In a control loop occasional loss of a data packet can be tolerated.
- A reliable communication channel would detect the loss of a packet via some sort of time-stamping mechanism, and would require the re-transmission of the packet.
- In a control loop this would create a useless out-of-date packet, referring to an old sample.

Ethernet vs Reflective memory

- Reflective memories represent the traditional solution in digital control systems for nuclear fusion .
  - ✓ Reflective memories provide a shared memory space and handle data update propagation via a fibre optic channel using a proprietary protocol
  - ✓ Reflective memory boards are offered by several companies, but nevertheless they represent custom solutions.
- The performance of 100 Mbit/s Ethernet proved enough for the requirements of the RFX-mod digital control.
  - ✓ Although the performance of reflective memories is better than 100 Mbit/s Ethernet, there is a much wider user community for Ethernet than for reflective memories.
  - ✓ and consequently the performance of Ethernet is expected to keep pace with the technology evolution.
  - ✓ A migration to 1 Gbit/s Ethernet is foreseen for more demanding applications.

Ethernet vs. Reflective memory: Performance

- The Figure shows the communication time for a range of packet sizes between two communicating units connected to a 100 Mbit/s Ethernet switch in an isolated network.
- The times include the driver and the IP stack overhead.
- In the same figure it is also shown the transmission time for a reflective memory (VMIC VMIPMC-5565) using a 2 Gbit/s fibre optic channel.
- The difference in performance increases with the packet size because of the different communication speed (100 Mbits/s versus 2 Gbit/s).
- However, for small packet sizes the ratio between the transmission times is much lower than the theoretical value of 20.



Reliability in UDP communication

- The use of UDP for real time communication may raise two concerns: reliability and jitter in transmission time.
- The packet loss rate proved negligible in an isolated network.
  - In this case, in fact, packets are sent **synchronously** and there is therefore a finite (and low) limit in the maximum number of packets concurrently sent, excluding the small number of packets (such as ARP messages) exchanged for the network management.
- A time-stamping mechanism is implemented to detect packet loss or duplication
  - Duplicated packets are discarded, and no action is taken when the loss of a packet is detected

Jitter

- Jitter in transmission has been measured with a time resolution of 240 ns.
  - The measured standard deviations in round trip times (where the receiver acknowledges the sender with a packet of the same size) are 0.46 µs and 0.64 µs for packet sizes of 100 and 1000 bytes
- In practice no jitter greater than 15µs has been measured for the used packet sizes (< 1000 bytes) and this represents a quite acceptable value at the system cycle times (> 50 µs) of practical interest.

Conclusions

- Real time communication is essential for the control of modern fusion devices
- The major design choice in RFX-mod has been the usage of ethernet, in spite of the traditional solution based on reflective memory.
- Provided the initial requirements are satisfied, ethernet is preferable for several reasons
  - Ethernet standard is ubiquitous in computer networking and all the commercial VME single board processors have one or even several Ethernet adapters. Therefore the risk of investing in a futureless technology is nonexistent.
  - Although the performance of reflective memories is better than 100 Mbit/s Ethernet there is a much wider user community for Ethernet than for reflective memories and consequently the performance of Ethernet is expected to keep pace with the technology evolution.