REAL-TIME MEASUREMENT AND CONTROL AT JET - STATUS 2007

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Abstract

The Joint European Tokamak (JET) is a large machine for experiments on fusion plasmas. Many of the experiments use real-time measurements and controls to establish and/or maintain specific plasma conditions. Each Instrument (Diagnostic or Heating/Fuelling/Magnet) is connected to a network. The number of systems has now grown to over thirty, and new systems are being planned for the future. Since some of the systems are used to control critical parameters of the JET plasma, we are improving the availability, reliability and maintainability of the facility. We must ensure that systems check their message structures against a central Data Dictionary, at build-time and run-time and secondly that the systems check their input data streams are alive before, during and after a JET pulse. Finally, we are developing high-level control configuration tools. From all of these, we identify some general principles which are applicable to the next generation machines.

INTRODUCTION

The EURATOM/UKAEA Fusion Association is a world leader in the development and operation of automation and control systems for large experimental machines such as JET and MAST [1]. The **Real-Time Measurement and Control (RTMC)** Facility at JET [2, 3] is the infrastructure for integrated plasma control combining (see Fig. 1):-

- **Measurements** e.g. Electron Density, Electron Temperature, Ion Temperature,
- **Analysis** e.g. Plasma Shape, Confinement
- **Actuators** e.g. Gas Introduction, Neutral Beam Injection heating
- *run-time*-configurable **Controllers** built with a high-level but text-based process-block language.

RTMC is now **frequently** used in Experiments:-

(i) to provide repeatable plasma scenarios, e.g. plasma pressure (β_n), special gas (^{3}He),
(ii) to study event-driven dynamic processes, e.g. MagnetoHydroDynamics (MHD),
(iii) to optimise session productivity, e.g. using dynamic limits to avoid disruptions which might otherwise damage the plasma conditions or even the the machine,
(iv) to study Plasma Control techniques themselves, e.g. current drive for steady-state operation,
(v) to provide JET machine protections e.g. plasma-facing vessel component heat-load limits.

RTMC SYSTEMS

Real-Time Data Producers & Consumers

The Producers and Consumers of Real-Time Data abide by the following policies.

- They send sets of **calibrated physics** signals (not raw instrument data) in output datagrams over the Real-Time Data Network (RTDN), autonomously, at their natural sample rate.
- They send/receive on **Permanent Virtual Circuits** (PVC's) which are established by the RTDN Administrator. The systems do not establish their own connections.
- They do not know who produces inputs or consumes outputs. This permits new consumers to be added to the network without disturbing existing connections.
- They check that the input datagrams are being received, and do a "Blind-Stop" if they are not.
- They can be built on Windows NT4, Windows 2000, Linux, Solaris and VxWorks (PowerPC). Generally the end-end transmission time is ~ 120 µs +/- 10 µs, which is well within our fastest cycle-time ~ 2 ms.

Real-Time Data Network

The Real-Time Data is transferred between producers and consumers with the ATM AAL5 protocol, which allows timely transfer of datagrams. Its small cell size allows small datagrams to intermingle with large, and not get held-up. The System to Switch link is 155 Mbps Multi-mode fibre-optic. The Switches are 2.5 Gbps fabrics. Up to now we have used Marconi/Fore LE155 workgroup switches.

RTMC ISSUES & UPGRADES

Generally, the experience has been very good. The ATM network has been capable, reliable, and adaptable. For the **ITER-Like Antenna (ILA)** and **ITER-Like Wall (ILW)** Projects, there are demands for new connections but all the present ports are committed.

The network used small workgroup switches and there was a risk of psu failure, which would stop operations. The switches are now "enterprise grade" Marconi/Fore ASX1000 and ASX200 types with redundant power supplies, and fabric controllers. We have spare fabrics, and MMF modules sufficient for future expansion.

The configuration of the Virtual Circuits was done manually through a telnet session. The number of systems connected is now more than 30 with >50 PVCs. The PVC configuration is now automated, using Python scripts.

See the Appendix of M.L. Watkins et al., Fusion Energy 2006 (Proc. 21st Int. Conf. Chengdu, 2006) IAEA, (2006)

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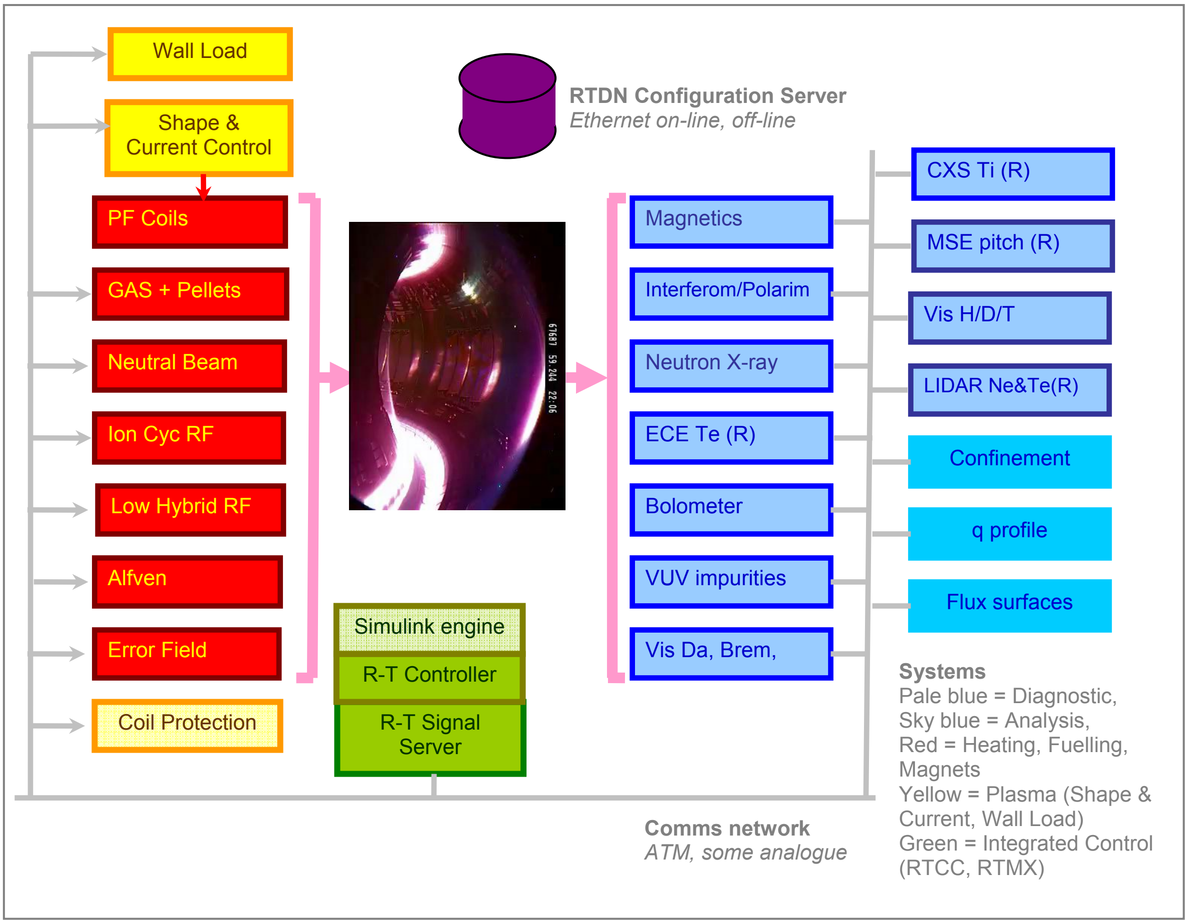

Figure 1: The Real=Time Data Network 2007.

Over the years, it has been difficult to ensure the datagram structures are consistent and correct across the several different developers and platforms, and this has lead to incorrect data being sent on rare occasions.

The Datagram Definitions are now being held on web-server. Fig. 2 shows a datagram configuration file for a Bolometer, specifying the type, position and size of the data fields :-

PradTot, the Total radiated power,

PboloV[32], the Vertical camera array power,

PboloH[24], the Vertical camera array power,

... and is sent every 5 ms from the beginning of the plasma.

At run-time, during the initialisation phase of a JET pulse, the systems compare the current definitions with the definitions they were built with and only go “Ready” if they agree. The systems will also check that the inputs data streams are active. At build-time, the make-scripts will get the definitions from the server and incorporate these into data-structures in the code. The Administrators maintain the configuration files, version-controlled, on the web-server.

With these measures, we can be confident that JET will run with correct data streams!

```
KB5Datagram =
  {
  Name = "KB5 Bolometer"
  Version = " $log$ "
  Class = "RTDatagramDefinition"
  VCI = 458
  DataServer = "db"
  DataPath = "/jpf/"
  TimeNode = "b5r-time"
  Datagram =
    {
    PradTot =
      {
      Type = float
      Units = "W"
      SignalNode = "b5r-Ptot"
      }
    PboloV[32] =
      {
      Type = float
      Units = "W /strad /m2"
      SignalNode = "b5r-PboloV:%02d"
      SignalNodeBaseIndex = 1
      }
    PboloH[24] =
      {
      Type = float
      Units = "W /strad /m2"
      SignalNode = "b5r-PboloH:%02d"
      SignalNodeBaseIndex = 1
      }
    }
  }
```

Figure 2: Example Datagram Configuration.

FURTHER WORK

The Microsoft Windows Operating System (OS) has been used up to now for real-time physics analysis. However, the real-time latency has suffered as the OS has developed from NT to XP, so we will port the analysis systems from Windows to Linux, and take the opportunity to consider RT-Linux as well.

ATM was first chosen when Ethernet was only 10 Mbps on a shared cable. Now gigabit Ethernet switched networks are readily available, so we will evaluate the use of UDP and multicast, and other high-level data streaming and sharing protocols.

The Real-Time Signal Server (RTSS) was developed as part of a monolithic product some 15 years ago, and includes a key Machine Protection function, the Plasma Density Validation. We plan to move this to a separate system, to maintain the integrity of the Density Control System, and to allow RTSS to change more frequently as the new systems are added.

The Real-Time Central Controller language has limited functionality (e.g. SISO). To cater for more complex controls required for JET Scientific programme (e.g. MIMO), we plan to (i) integrate a Matlab/Simulink run-time engine so that Simulink process and controller models can be used directly, and (ii) evaluate Scilab/SciCos which is another well-established, but open-source, graphical process block design tool (Fig. 3).

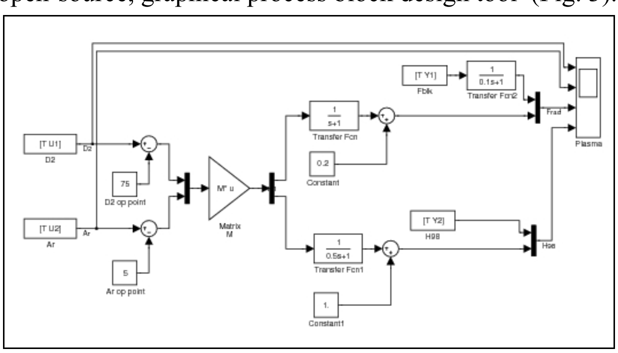

Figure 3: Example of a Process Block Language.

In 2008 JET will commission the ITER-Like Antenna (ILA) and in 2009, JET will replace the carbon tiles with the ITER-Like Wall (ILW) using more delicate Be/W tiles. For both, the RTDN will be expanded to cover, in real-time,
(i) Be/W tile temperature,
(ii) Tile thermal and Plasma-Wall models and
(iii) configurable, extensible logic for Inter-Plant Control & Protection.

This latter will use "plug-in" code modules, supervised by work-flow engines running schedules on appropriate time-scales (~ms for plasma control) (see Fig. 4). The interlinking logic will be captured in workflow, while the active control will reside in dedicated controllers as now (e.g. PPCC), but modularised even further. Thus if a plasma-wall fault occurs, the protection logic will switch to a "safer" scenario. This idea is also related to ITER CODAC concepts.

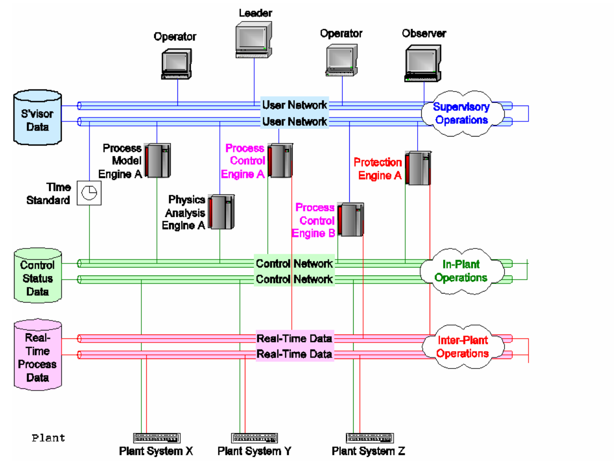

Figure 4: Configurable, Extensible Real-Time Data Network.

CONCLUSIONS

For Real-Time Data Transfers between major tokamak plant systems, the network can be based on commercial-off-the-shelf standard network components. Large tokamaks inevitably develop, so the infrastructure has to be designed to be configurable and extensible at ***run-time***. The configuration changes must be traceable and machine-readable, so that not only the real-time process data but also the operational schedules (work-flows) can be monitored and analysed.

The network switches must have high **reliability, availability and maintainability** as well as adequate capability (throughput and delay) and capacity (connections)

For **operational integrity**, the Systems must comply with a **Data Protocol**, particularly (i) using a published data configuration, and (ii) checking for input arrival.

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REFERENCES

[1] A.Murari et al., "Development of real-time diagnostics and feedback algorithms for JET in view of the next step", Plasma Phys. Control. Fusion 47 No 3 (March 2005) 395-407.
[2] R.Felton et al., "Real-time measurement and control at JET experiment control", Fusion Engineering and Design, Volume 74, Issues 1-4, November 2005, Pages 561-566.
[3] R.Felton et al., "Real-Time Measurement and Control at JET – 2005", ICALPECS 2005, Geneva.