

OVERVIEW OF THE COMMUNICATION STRUCTURE OF THE HIT ACCELERATOR CONTROL SYSTEM

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Abstract

The HIT ACS is a modular, PC and front-end controller (with FPGAs) based accelerator control system developed by the company Eckelmann AG, Wiesbaden, Germany in cooperation with GSI and HIT. It consists of a database and several central applications running on Windows 2k3 server machines as well as a dozen control room client PCs for the GUIs, and a few hundred front-end device controlling units (DCUs). Due to strict timing requirements in the ms and partly μ s range, communications during an acceleration cycle are done in real-time via RTB (Real Time Bus) and real-time shared memory components on the main control server. We show the overall structure of the ACS network and outline the relation of the component devices and the Ethernet and RTB communications between them.

HIT ACCELERATOR FACILITY

The Heidelberg Ion Therapy Centre (HIT) is a dedicated hadron accelerator facility for radio-therapeutical treatment of tumour patients [1, 2]. The characteristic energy loss profile of hadron beams in irradiated materials lends itself to very precise radiation therapy with fewer side effects. The DNA destructive maximum of the particle occurs at the Bragg peak immediately before it comes to rest and very little energy is lost in the entry channel. The achieved energy range of 88-430 MeV/u for carbon ions and 48-221 MeV/u for protons is sufficient to reach a penetration depth of 20-300 mm in water.

The facility is currently in the last phase of commissioning and the accelerator control system is nearly finished. Only certain functions from risk assessment and GUI revisions still need to be implemented [3]. The two horizontally fixed treatment places as well as the experimental area can be served with proton and carbon beams with qualified beam parameters (MEFI), other ions like helium and oxygen have been tested. The beam parameter ranges are shown in table 1.

Table 1: Beam Parameters

| Parameter | Steps | Protons | Carbon |
|--------------|---------|----------------------------------------|-------------------------------------|
| Energy | 255 | 48-221 MeV/u | 88-430 MeV/u |
| Focus | 4(6) | 8 – 20 mm | 4 – 12 mm |
| Intensity | 10 (15) | $4 \cdot 10^8$ - $1 \cdot 10^{10}$ 1/s | $1 \cdot 10^7$ - $4 \cdot 10^8$ 1/s |
| Gantry Angle | 365 | 365 | 365 |

The values in brackets are options, which will be realized after the linac upgrade program [4].

The gantry commissioning will restart at Q4/2008 and the first patient treatments are expected early in 2009 [5].

ACCELERATOR CONTROL SYSTEM (ACS)

The ACS is a modular software and hardware system which is responsible for the control of over two hundred devices used in generating and steering the ion beam in the HIT accelerator facility. The hardware components are ca. 250 Device Control Units (DCU), based on a design by Eckelmann AG, three MS Windows 2003 Server™ PCs, four MS Windows XP™ Gateway PCs and 13 MS Windows XP™ control room clients. DCUs consist basically of a network enabled embedded controller with real-time capabilities and differentiated random access and flash memory to store all device parameters for different combinations of ion type, energy, focus and intensity (MEFI – see table 1). The communication structure of the ACS is separated into two strands. All devices of the ACS communicate via Ethernet and TCP/IP or UDP on a local private subnet designated “DV3”. The devices taking part in beam generation also communicate via RTB.

PCs and the DV3 subnet

The DV3 subnet is almost completely separated from the office and clinic net, let alone the internet. The only connections are discrete routes from the main control server to the therapy control system (TCS) subnet and remote access via three dedicated Linux remote gateways.

The PCs shown in figure 1 on the following page comprise the main server and client components of the ACS. The heart of the system is the main control PC. It runs the main control application (MCA), which communicates with all devices and is responsible for the following functions:

- **Device status checks** – all devices send their status in regular intervals, additionally every participating device is checked before each cycle.
- **Data downloads to devices** – all beam control data is sent to the devices via the MCA
- **commands to devices** – all commands (e.g. reset, on, off, change mode...) to DCUs are sent via the MCA
- **System and device mode handling** – the system mode of the complete accelerator (e.g. Therapy or Experiment) and the devices (e.g. Experiment, QA, Therapy ...) is controlled by the MCA
- **Procedure and sequence control** – all procedures and sequences are controlled by the MCA

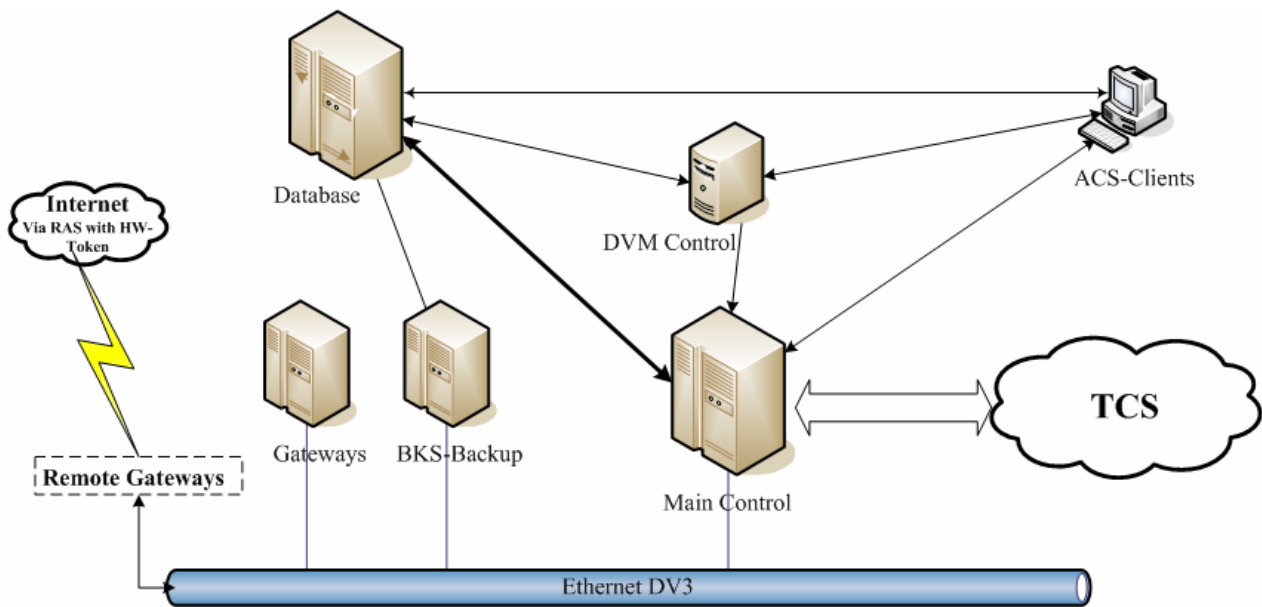


Figure 1: ACS PCs in DV3

It also runs the beam control application in real time shared memory which controls the beam cycle execution via the timing master (DCU-Z). The data controls which process beam diagnostic data and send it to client applications and the database also run on this PC, as is the TCS communication application which communicates with the therapy control system and interprets TCS commands.

The Database PC runs an Oracle database which contains all ACS data. Log entries and all measured snapshot data from devices and beam diagnostics as well as processing data from monitored systems (like vacuum pressures and ion source data) are likewise stored in the database for one month and then dumped to the backup server where they can be re-imported into the database as needed.

The DVM Control PC runs the DVM control application which calculates the download data sets for all devices from physical parameters based on a theoretical model set by beam physics experts in a beam optics/beam line GUI.

The Gateway PCs use specialized hardware and OPC software to connect to beam diagnostics devices and other special devices like e.g. the ion source microwave amplifier, RF devices or the personnel safety system (PSS) [6].

The Backup PC contains a second Oracle database and runs the dbservice application which controls all house-keeping tasks for the main ACS database and can be used in an emergency to replace the database server. Additionally it runs the DHCP and DNS server software for the DV3 subnet. All devices are registered as reserved DHCP leases with no freely available IP ranges.

The ACS client PCs in the control room run all the necessary GUIs to monitor and control the accelerator.

The DV3 subnet runs on a Gigabit infrastructure comprised of four stacked Cisco Catalyst c3750G switches for all critical components and several Cisco Catalyst 2948G switches for auxiliary devices and the client PCs. The subnet mask is 255.255.252.0 and the subnet can address

up to 1022 hosts. It is further divided into logical subnets for clients, server, accelerator devices, maintenance PCs etc.

DCUs and Real Time Bus

The Device Control Units (DCU) are multi-purpose devices that are used throughout the installation to control all different devices. They are connected to backplanes which tell the DCU what kind of device it controls and set its IP-Address. All types of DCU have their basic hardware in common – a PowerPC CPU with 64 MB RAM, 32 MB flash memory and an FPGA which controls the data bus connected to the device. All setup data is downloaded via Ethernet to the RAM memory and can be copied to the flash memory on command. All data sets are verified by live md5-checksums which are calculated on the DCU and compared to checksums stored in the database. The flash memory contains all validated control data for therapy or QA modes while the control data for experimental modes is stored in volatile RAM memory which can be changed on the fly by the appropriate GUI. Changing of the flash memory requires higher user privileges and sets a QA-flag.

The DCU-types vary according to the kind of device they are connected to. The types called “DCU-P” are linked to pulsed devices which set up to 2 discrete values per cycle. The types designated “DCU-R” are linked to ramped devices which set a continuous ramp of values over the entire cycle. The “DCU-SD” types are beam diagnostic DCUs which supply trigger signals for beam measuring. The types called “DCU-RB” are enhanced to work within ns timings and are used for the bumper magnets in the multi-turn synchrotron injection. The “DCU-T” types set a gate during the cycle and are used for choppers and RF devices. The types named “DCU-LWL” and “DCU-TS” are equipped with an extra fibre optic add-on card to connect to the medical interlock units of the TCS. The former are connected to the scanner mag-

nets and have additional firmware functions to also switch control between ACS and TCS.

In addition to an Ethernet connection, all DCUs are connected to an RTB strand (see figure 2). This strand is comprised of a terminated bus system of CAT5+ cables running from the timing master DCU in the server room to every DCU in the facility. Each RTB signal is a differential signal using its own wire pair.

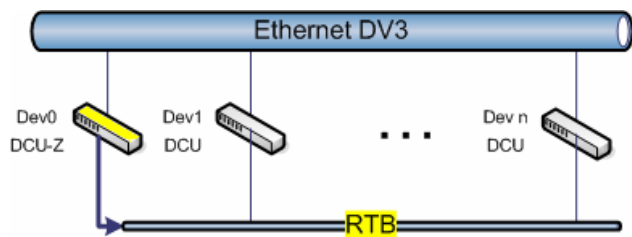
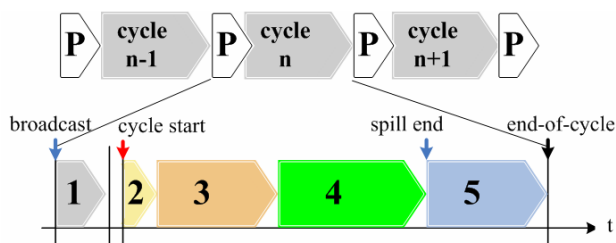


Figure 2: DCUs connect to DV3 and RTB

The timing master (DCU-Z) sends synchronisation and trigger signals via RTB to all devices in real time to control the acceleration cycle. Each sub-cycle phase is triggered by these signals and the RTB allows for microsecond precision in the device control units. The signal delay used in the preparation phase is measured with integrated delay circuits for every DCU inside the accelerator facility and stored in the database. The setup delay is calculated in some units according to a polynomial equation used to approximate the real switching delay which has been measured for all devices.

ACCELERATION CYCLE

An acceleration cycle begins with a broadcast packet sent from main control to all devices announcing the start of a new cycle. All devices answer this broadcast with their status and calculated preparation delay, which is a combination of signal delay and setup time.



- 1 preparation phase
- 2 injection phase
- 3 acceleration phase
- 4 extraction phase
- 5 reset phase

Figure 3: Overview of acceleration cycle

As soon as all required devices have answered, the timing master sends the signal “start cycle” and all devices prepare for the cycle. After the preparation delay the injection and acceleration phases begin. As soon as the devices are on the extraction plateau, the “spill start” signal begins the extraction phase which is ended by the “spill end” signal. In the reset phase the synchrotron dipoles run a conditioning ramp and the beam control application ends the cycle with the “end-of-cycle” signal. Now all snapshot and logging data is written to the database and the accelerator is ready to start the next acceleration cycle.

CONCLUSIONS

The communication and network structure of the HIT accelerator facility is based on mature and well understood technology and delivers high performance communications for all network traffic. Measurements of peak load on the switches never exceeded 10 percent of available resources. The RTB system is stable and provides μ s accuracy in triggering and cycle control. The ACS itself is in the last stages of testing. Some additional features required by risk management are still awaiting implementation but the main structure of the ACS has been tested and pronounced ready for patient treatment.

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