DISTRIBUTED CONTROL SYSTEMS WITH VIRTUAL ENGINEERING STATIONS AND CONTROLLERS AS INTEGRATED NETWORK NODES WITH SINGLE PROTOCOL

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INTRODUCTION

Effective Data Acquisition and Control automation are constructed often from ordinary **PC-based desktop** systems. Advanced microelectronics opens new possibilities in developing of PC-based **non-desktop compact Modular systems** with Distributed systems architectures. Three levels of distributed Data processing according to proposed model [1]) should be built with compact PC MB interconnected by tradition LAN or System Area Networks (SAN). Interconnections of distributed nodes should be based on tradition Ethernet 10/100/1000 Switches or parallel-pipeline Scalable Interconnections for high-speed data processing Data Centers and distributed RT-systems. The basic system architecture levels include 3 types of nodes - Control Terminals (CT), Engineering Stations (ES) and Data Center (DC) connected by LAN or SAN. First two levels of integrated nodes are Virtual Engineering Stations (VES) and a lot of Virtual Control Terminal (VCT) as terminal RT-system nodes both with compact construction and modular architecture with active or passive backplane Bus. Conceptual approach to VCT and VES architecture integrated by LAN and SAN switches are proposed and discussed below for Control Systems.

1.MODULAR COMPACT VCT AND VES-NODE SYSTEMS WITH PASSIVE AND ACTIVE BUS

Modern CT-nodes should be based on modern processor MB or PC-compatible microcomputers and LAN.

Early microcomputers were based on the IBM PC (ISA bus) plug-in module, others were implemented as standalone (non-backplane) systems on a single board, and others are based on backplane (VME/VXI) and Single Board Computers (SBC). Integrated circuit had advanced functions that previously have occupied entire boards could be limited by single large-scale integration chips, which became a single-chip computer or DSP. PC/104 and PC/104-Plus modules tend to be made from standard PC desktop and laptop components, supported by embedded Linux. PC/104-Plus adds the PCI bus, using a board-to-board bus (120-pin). Modular Microcomputer consisted of a lot of boards (plugged into a backplane) including CPU, memory, disk controllers, and serial/parallel ports. Backplane-based single-board computers were used for data acquisition, process control, and different R&D projects, but were generally too bulky to be used as the intelligence embedded in devices. One of the best cost/performance RT-systems construction is Industry Computer System Main Board (MB) or modern compact PC MB and cPCI/PXI, connected by LAN or SAN with different topology according to the application. There was growing interest in IBM PC compatibility in **embedded** and **non-desktop** systems: PC chipset and peripherals compatibility could produce lower cost, simpler, and easier to support; PC

compatibility gives advantage of the PC's OS (Windows, Linux), language, and tools. With new interfaces (USB, FireWire, Bluetooth), architectures (MIPS, PowerPC, ARM), and OS (QNX, RT-Linux, RTEMS), the embedded SBC platforms are better for embedded modular RT-Systems for Control applications. Compact PCI-based Modular Computer Systems with active backplane and advanced modular systems cPCI/PXI with passive backplane should be used effectively for advanced Control and DAQ system nodes.

Field-buses usually have a modular approach in hardware and software to achieve different applications in economic ways. Most of today's computers have tradition network (Ethernet 10/100, FireWire, USB) as standard connectivity. Field-bus concept should include transparency to all of them. Serial buses (USB, FireWire) used for medium and high-speed I/O connectivity. New generation Distributed systems should be based on active or passive bus with single LAN interface for all levels including fieldbuses.

1. The first version of **Modular PC-compatible MB with active backplane** bus and two slots for multi-channel Measurement and Control (MAC) modules with embedded DSP are constructed on the base of Industrial Computer Systems (ICS) as the first version of RT-system for Control applications interconnected by LAN. Compact Modular RT-Systems on the base of small ICS MB with 2-4 slots proposed as **System Control Terminal** (SCT) station with embedded DSP and Microprocessor. Virtual Engineering Stations (VES) are interconnected by Ethernet 10/100/1000 (TCP/IP) in Distributed networks.

Each VES is based on Windows (or/and Linux) platform with LabView and each VCS is based on RT-LabView (or RT-Linux), oriented on DAQ, Monitoring and Control. One of two PCI-slots is used for DSP–based MAC-module, other slot used for MAC extension or second Ethernet. Proposed Virtual Control Terminal (VCT) node with active bus is based on **compact MB** with **only two slots** for DSP-based Measurement and Control (MAC) modules. Developed **Object Signal Interface** (OSI) device is connected to MAC in compact PC MB is constructed as a Front-end modular Electronics in RT-system. Second version of SCT is constructed as compact Embedded MB with and DSP-based MAC-modules inside OSI. RT-system as VCS-node includes Object oriented Signal (analog and digital modular electronics), Conditioning Interface (OSI) Device, MAC-modules with 16 channels and compact PC MB. Each developed VCS contains Front-end Electronics (fields specific 16 analog and 32-64 digital channels with ADSP218x) and compact single-board Control SBC (PC-compatible MB with 2 PCI slots for MAC) or embedded processor node with 4 PCI slots and connected to LAN (or SAN). The third level of architecture is DC (Data Base and servers). The same network Interconnects used by all virtual nodes.

2. The advanced compact modular systems with passive bus should be based on single Euro-card (3U- format) as international standard (IEEE 1101.1). The VMEbus follow this standard allows 16-bit data transfers on the 3U-form factor (full data bus bandwidth is supported only on 6U). Compared to VME (3U) cPCI (3U) is more effective systems on price/performance and there are difficulties on implementing PC functions in the VME architecture. 3U cPCI's bus performance is superior to 3U VME. The cPCI/PXI bus supports full 32-bit or 64-bit data transfers in both single- and double-wide boards. Compared to competing embedded PC board formats and offers next several advantages. The cPCI/PXI enables greater system flexibility extending the PCI slot limit from 4 (max 8 modules). The cPCI was designed for industrial environments (like VME) and PXI – for Instrumentation Systems (like VXI). The 3U cPCI passive backplane is expandable and small. The backplane approach makes maintenance and upgrading of 3U cPCI modules much simpler. The cPCI/PXI (3U) boards support I/O required for Industry Automation, which requires distributed I/O. CPCI supports the Fieldbuses for DAQ and Control, monitor, and report on processes. CPCI Systems supports advanced networking functions on cPCI single-board computers (Ethernet 10/100, USB, FireWire and Field buses). Modularity provides access to the widest range of applications and gives flexibility of cPCI/PXI-based SBC support.

3. Embedded Modular System should be construct with PCI or cPCI/PXI (3U) Hardware with 4 slots. The last has advantages: 1) Small form factor (220-pin, 2mm connector) represents good platform against shock and vibration for Control applications. 2) Building complete PC module (with graphics, Fast Ethernet, IEEE 1394, USB, Field-buses, flash memory, and 128 Mbytes of SDRAM) on the compact flexible 3U-platforms. 3) Reducing power consumption is an important step toward low cost, and the move to smaller processing geometries has been a reduction in power levels. Research shows that control devices implemented with 3U cPCI typically consume less than ~20W. 4) In addition to an 8-slot cPCI backplane with 64-bit bus gives economic backplanes (passive and active) with using of equipment racks and enclosures with EMI shields.

Different RT OS should be used (RT-LabView, RT-Linux, RTEMS, QNX)) for DAQ and Control Applications. Modern embedded-computer solutions have a need for Windows-based software to achieve better human-machine interfacing, networking and file management. So, on second level data processing in VES should be used good interface, but on the first level in VCS better to use deterministic hard real-time software for the control applications (RT-Linux, RTEMS, QNX, OS-9, VxWork). Linux support for PC-compatible embedded SBCs tends to be provided using the chips in normal manner, including some specific functions like: Display controller modes, LCD panel control signals, PCMCIA, onboard solid-state disks, Nonstandard functions (watchdog timer). The same software developed for all versions. Developed version of the System Model is based on LabView with Windows (or Linux) as basic System Software platforms. Modular Application Software for measurement, signal processing and Data processing are developing on this platform. Virtual Instrumentations and standard Application Software are based on basic OS Windows (Linux) and should work on VES connected to a number of distributed CS with RT-LabView (or RT-Linux) connected by Ethernet10/100. Each VES should have access to DC on Multi-server level.

2. SAN-BASED ARCHITECTURE FOR DISTRIBUTED SYSTEMS

One of the best System Area Network (SAN) is Scalable Coherent Interconnections (SCI) developed for Advanced Multiprocessor Architectures, because of bus limits for a number of parallel processors in Distributed Data Processing systems. Multiprocessor SAN-architecture is described as high-performance RT-system or (DC) which should be a Data Processing Cluster. SAN interconnections are discussed as advanced modular Architecture for high performance DC. The same approach is effective for DAQ-systems with parallel-pipeline Data-flow processing in real time. SCI-interconnection aims on scalable multiprocessor Clusters and high-performance multiprocessor modular RT-systems. Real-time Multiprocessor Core and OS for Distributed Multiprocessor systems, which can be used effectively for DC and for DAQ as RT-systems are proposed for different applications in Experimental area and Engineering.

1.Distributed Parallel Data Processing Model used as Symmetrical Multiprocessing (SMP), Massively-Parallel Processing (MMP), Cluster Systems (RMC and NUMA). A RMC (Reflecting Memory Cluster) is a clustered system with a memory replication or memory transfer mechanism between nodes and traffic interconnect. The first developer of SCI-based high-performance modular multiprocessor system with hardware coherency was Sequent. Advanced Integrated RT-systems with Effective SAN Architecture on the base of standard Compact-PC modules (PC-board) and Link-modules (Dolphin's) for effective cost/performance systems according to multilevel Physical Model are proposed for High-performance DAQ, Control and Distributed Data Processing in Experimental Physics Research. High modular structure of Distributed Integrated System should support effective Interaction of distributed processor and memory with help of Link-modules to the System Area Network (SAN) for high-performance DC.

2. Real-time systems can be described on Nuclear, Atomic and Molecular levels with weak and astrong interactions between nodes. **Nuclear structure includes** a set of Core processors, memory, I/O controllers and interconnections. New single-chip Microcomputer has short links, better access and data transfer time than out of chip memory on the same board. **Atomic structure includes** compact boards and includes special-purpose or general-purpose processors. The simplest effective RT-system for DAQ and Control can be based on a standard PC MB with 1, 2 (Dual) or 3 (Quad) microprocessors on the board. Number of processor modules on the same bus is limited. Symmetrical Multiprocessing (SMP) is basic Software Model for Multiprocessors. **Molecular structure** depends of SAN-topology in which multiprocessor nodes are interconnected ("Big Bus" Model) into a large (Kilo-Processor) systems.

Interconnection in Distributed System is based on Link-, Bridge- and Switch-Modules (L-Modules, B-Modules and S-Modules). Tradition communications are based on bus, limiting a number of processor. The cost of communication speed decreases faster than the cost of pins and board space. Practical solution is based on using of packet-based signaling over many independent point-to-point links. But it introduced a new problem - to maintain cache-coherence in the shared-memory system model. **Weak interactions** between processor modules are based on message passing (Ethernet). Intermediate interaction is based on external memory devices (disks, tapes) used in Clusters. **Strong interactions** of Processor Cores are based on Direct Access into distributed memory and realized on SCI, which also supports a weak interactions of processor modules. Strong SCI-interactions includes small packet transactions (split packets with echo). Packet Formats include *writexx*, *readxx, movexx and locksb* commands, where *xx* –represent one of the allowed data block length (number of data bytes, on the right after the packet header).

Distributed-memory Model of SAN-architecture can support parallel-pipeline data processing (computing) in a single address space as SMP-model. 64-bits address supports 256 Tbytes in each node. **Scalability** is problem of performance increasing in Multiprocessor RT-Systems (interconnected to Kilo-Processor systems). **Cache coherency** supports data availability for all processor in distributed parallel data processing RT-system, which includes many processors, attempting to modify a single datum or holding their own copies of it in their cache at the same time. Coherency, implemented by software or hardware, is request to prevent multiple processors from trying to modify the same data at the same time. Hardware coherency supports high-performance, but Software coherency provides good performance at low price.

Topology of modular RT-Systems should be based on required set of selected Modules to develop the system optimal to the decided problem. The system in for DAQ and Control Fields should have a topology according to the structure of large equipment.

New 64 bit microprocessors are good for *advanced SAN-based systems* because System Cluster shares a 64-bit SCI-address, where the high order 16 bits are used to rout packets to the appropriate node. System topology can be based on a simple ringlet, multi-ringlet, bridges or powerful switches for Parallel-pipeline strong interactions between processors. SCI is based on point-to point connections and supports transactions all processor modules at the same time. Commercial Dolphin's L-modules provide 800 Mbytes/s bi-directional SCI link for moving large volumes of Distributed data with small application-to-application latency (2.3 micro sec) and reduces the overhead of inter node control messages for the best scalability for multi-node applications. Distributed High-performance nodes should be based on Weak and Strong links. Weak connections are for installation, maintenance and remote access and Strong connections for Dataflow processing in real time.

3. SUMMARY

1.Compact PC-compatible modular RT-system architecture for Control applications should be used Effectively as Virtual Control System Terminal (VCT) node with 2 PCI slots for MAC modules, connected to Signal conditioning device, and integrated by single LAN-interface including for fieldbus.

- Compact Virtual Engineering Stations connected by LAN-switch with distributed VCST should be effective as User interface to Distributed RT-systems for Data Collection, Diagnostics and Analysis in DAQ and Control applications.
- Advanced effective VCT should be based on embedded cPCI/PXI modular systems or PCI with 4 slots for Mac-modules and OSI in single device as node with LAN-interface.
- Basic OS for distributed modular RT-system are based on Windows and Linux platforms with LabView.

2. Embedded modular RT-systems have advantages:
- increasing embedded intelligence, many require user-friendly graphical & speech interfaces;
- growing need for electronic devices to be interconnected (TCP/IP, PPP, HTTP, FTP);
- USB is replacing all serial, parallel, and PS/2 ports, FireWire (IEEE-1394) is beginning to use;
- modern processors (highly integrated ARM, MIPS, PowerPC, and x86 based application-oriented system-on-chip) are being developed;
- standard LAN (Ethernet10/100/1000) is became everywhere, including fieldbus;
- QNX or RT-Linux or RT-LabView are using in modular RT- systems, offering a low cost, open source solution with support for open standards, networking, communications and Internet.

3. Scalable multiprocessor system architecture is proposed for high-performance systems for DAQ and Effective DC cluster for parallel-pipeline data-flow processing and analysis in real-time.

- Based on proposed Joint General Model the Distributed Scalable Modular RT-System integrates DAQ, Trigger and Control Systems and based on LAN (Ethernet) and SAN (SCI) interconnections.
- Distributed SAN-based Architecture on the base of 32- and new 64–bit multiprocessors and LAN is good approach for high-performance systems in nearest future.

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