STEADY-STATE DATA ACQUISITION METHODS FOR LHD DIAGNOSTICS

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Abstract

The LHD experiment has gone through 5 campaign periods over the past 4 years, during which the diagnostics data continues to grow and the primary 28 measurements produce about 620 MB/shot in 150 shot/day 3-minute cycles. In 2002, 30-minute long-pulse experiments will be carried out in LHD, where real-time operations are indispensable for plasma measurements and data acquisition. The new scheme for utilizing conventional CAMAC digitizers in long-pulse experiments has been discussed and examined. As a result, in LHD, CAMACs will shift into $120 \sim 180$ s cyclic operation, synchronized by the diagnostic timing system. The new CompactPCI-based digitizer frontend has performed about 84 MB/s continuous acquisition in benchmarks, and has been formulated with the conventional CAMAC system to make concurrent acquisitions.

Key words: LHD, CAMAC, digitizer frontend, real-time data acquisition, CompactPCI

1 Introduction

In the case of recent quasi-steady-state fusion devices, non-stop real-time operation becomes indispensable to the data acquisition system [1–4], which was not significant in conventional short-pulse experiments. The newest non-tokamak fusion devices applying superconducting magnets, such as LHD and Wenderstein 7-X, usually plan to hold a quasi-steady-state experiment with over one thousand seconds plasma duration. For instance, the LHD experiment plans to extend discharges up to 10000 seconds plasma duration in the future [5]. In those circumstances, the data

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acquisition system also has to run in real-time so that it can display the transient behaviors in accordance with the ongoing plasma discharge. The recent growth in data streaming and broadband technology has enabled non-stop high-bandwidth data production, and continuous transfer/store within some definite delay.

Conventional data acquisition systems are often known as “batch-processing systems”, and usually apply the CAMAC digitizers in short-pulse discharge experiments. Although the CAMAC standard has been used as a substantial digitizer system in a conventional plasma experiment, it is not functional for real time data transfer and even its maximum bandwidth of 3 MB/s is quite insufficient now.

The CompactPCI standard has an affinity with the PCI bus so it will also be quite applicable for the PC-cluster or PC-based distributed system, especially in construction of a new data acquisition system [6]. Its complementarities with the conventional CAMAC based system have been successfully verified in LHD [7].

1.1 Status of LHD Data Acquisition

The LHD project has a diagnostic strategy to install in total about 30 kinds of plasma measurement devices. The total number of CAMAC modules and channels used in the LHD diagnostics are about 300 and 2000, respectively.

It is understood that in order to avoid data transfer bottlenecks, the corresponding number of data acquisition computers should also be installed and connected in parallel for every piece of diagnostic equipment. The LHD data acquisition system, i.e. the LABCOM system, has wholly adopted the massively parallel processing (MPP) structure, which is based on 30 sets of PC/Windows NT servers [8]. Recently, their acquired data went up to 620 MB/shot in the usual 150 shot/day operation. Figure 1 shows the data growth curve which tells the shot-by-shot total size of the raw data acquired by CAMACs. It gives an extrapolation that within a following few campaigns it could easily reach 1 GB/shot, which is the original specification designed for this system.

As there is about 300 meters distance from the digitizer room to the acquisition server computers, many pairs of SCSI-1 optical extenders have been applied to remotely manage the CAMAC crate controllers (CC) and digitizers. For this PC-SCSI-CAMAC linkage, we apply the home-made CAMAC handling drivers and system libraries on 30 acquisition servers. The typical throughput for the block data transfer is about 700kB/s $\sim$ 1 MB/s between CC and typical ADC [9]. The C++ code optimization by the multi-threading method and changing from the obsolete “O2” object-oriented database to “ObjectStore” provided by eXcelon Corp. have also improved the total processing ratefrom the previous 380 kB/s to 480 kB/s. As ObjectStore shows the ideal 400 – 500 kB/s database writing rate on PentiumPro 200 MHz dual-cpu machine [10], the throughput optimization gives an excellent attainment. The code reform also refined the acquisition reliability constantly over 99.9 %.

2 Steady-state Operation Schemes

Effective utilization of existing digitizer resources, such as CAMAC or VMEbus modules, becomes important in the long pulse experiment. In short duration, CAMAC modules still have enough capabilities to digitize any transient plasma phenomena, however, a quasi-steady-state plasma experiment of about 30 minutes duration is scheduled for LHD 2002 campaign. Therefore, real-time operation has been similarly required for the data acquisition system with other equipment.

2.1 CAMAC Cyclic Operation

Because the CAMAC digitizers cannot run nonstop ADC conversion due to specification restrictions, it will be indispensable to adopt the new real-time digitizer systems. However, the effective utilization of the existing digitizer resources is still very important, especially for large-scale experimental devices or projects. Thus we discussed the following operation methods for the LHD data acquisition CAMAC digitizers:

(1) 1-way coarse sampling over a whole long pulse.
(2) Event-driven trigger system [11].
(3) 2-way alternating operation [12].
(4) Iterative operation every 2 or 3 minutes.

Only (3) is exactly correspondent to the continuous, i.e. real-time data acquisition operation. Considering the reality of splitting about 2,000 measurement signals in LHD, however, it will be quite natural to make (4) the ordinary choice where finely sampling digitizers will run cyclically, as if there were some short-pulse images (typ. 3 min.) in a long-pulse duration. (1) and (2) can be selectable in accordance with each diagnostics requirement.

As the LHD central control system will provide only one shot sequence even in steady-state experiments, cyclic sub-structured ones have to be made locally in combination with the diagnostics master PLC and timing system (DTS). See Fig. 2. The locally generated sub-shot sequences will be distributed to the client devices superimposed on the original long shot sequence. Therefore, the end acquisition system could also run in the long-pulse experiments without changing any operational behaviors. As for the data retrieval clients' synchronization, mixed sequence (S1–S10 and s3–s9) messages are distributed by IP multicast packets.

To complement the intermittent operation of the CAMAC digitizers in long-pulse experiments, R&D for the wide-bandwidth real-time digitizer frontend (DFE) system has proceeded simultaneously. It also aims to realize a thorough solution for the steady-state operation of the massively sized data acquisition system. For that purpose, the CompactPCI standard can smoothly replace the CAMAC digitizers because of its popularity and low price by PCI compliance. In this study, simultaneous R&D and verification have been continued in order to satisfy the DFE matters for the fusion plasma diagnostics [7]:

(1) Sampling rate: 0.5$\sim$1 MS/s·ch, resolution: 12$\sim$16 bit.
(2) Over 100 channel containable in one DFE.
(3) Nonstop AD conversion and over 100 MB/s data transfer.
(4) Over 500 meters optical expansion between DFE and PC.
(5) Affinity with PC technology.

In the modern PC environment the PCI bus becomes the de facto standard. As the CompactPCI is the field-bus subspecies of the PCI bus, its affinity with the PC and PCI bus is quite advantageous in terms of cost, production, and distribution. So in this study, the brand new DFE system based on the CompactPCI standard has been designed and tested to realize the ultra-fast (Gbps) non-stop data acquisition, whose schematic view can be seen in Fig. 3. In 2001 – 2002, the CompactPCI evaluation equipment with the following specifications has been examined under the cooperation of the National Instruments Corp.

- 4-ch. max. 10 MS/s transient recorder ADC w/ 64MB buf. · · · 7.
- 3-U 8-slots PXI chassis (32-bit 33 MHz, PCI rev.2.1) · · · 1.
- MXI-3 1.25Gbps CompactPCI–PCI optical link interface · · · 1.

In a performance verification using this prototype system, we could successfully confirm the nonstop data transfer rate of 84MB/s from ADC modules to the host computer's main memory. Such wide-band streaming transfer of the massively sized physics data has revealed its instrumental reality in this LHD examination. We will continue R&D toward the faster ADC module based on the wider PCI bus rev. 2.2 and PCI-X. The cost reduction will also become more important for accelerating the CAMAC replacement by CompactPCI modules. In comparison with other data link technologies [13,14], the cost performance will be the key issue to make them fit for practical use in LHD and other fusion devices.

In order to realize the 100 MB/s data streaming toward the analysis or display client computers, it is indispensable that Gigabit (Gbps) network connections are available between the data acquisition server and the retrieving client. In Jan. 2002, the LHD site successfully introduced a backbone node of 10 Gbps SuperSINET. It is the Japanese inter-university network upgraded from the previous ATM-based SINET by using DWDM technology. The backbone node consists of two kinds of gigabit ports: One is the 10 Gbps IP-based internet, and the others are some point-to-point 1 Gbps Ethernet links. As a result, we have enough network environment to realize 1 Gbps data streaming toward remote collaboration laboratories, such as Nagoya Univ., Kyoto Univ., and Univ. of Tokyo.

We also examined writing the data stream into the hard-disk array to demonstrate the real-time data storage. Figure 4 shows the resulting performance. It was given by the set of Promise FASTTRAK TX2000 (a popular ATA-RAID controller) and four 5400 rpm ATA133 disks (Maxtor 4G160J8), and they organize a RAID0 striping volume. In larger I/O size regimes, the read/write rates steadily show over 95/85 MB/s, respectively. So we can conclude that such PC parts perform high rates enough for even our CompactPCI prototype's streaming data of 84 MB/s.

3 Summary

In this study, the 3 minutes cyclic operation scheme of the CAMAC-based data acquisition system has been developed and demonstrated successfully toward the LHD long-pulse experiment in 2001. In order to generate and distribute the sub-structured control sequences within a longer one, additional VME timing modules and wired-logic handling PLCs have been installed. Sub-sequences will be practically recognized as a series of short-pulse operations so that all the acquisition instruments will run synchronously on them.

In addition to the effective utilization of the existing digitizer resources, our prototype investigation to demonstrate a new real-time digitizer system, which is based on the CompactPCI standard, has proved its ultra-high bandwidth of 84 MB/s continuous data streaming from the digitizer front-end to the hard-disk striping array. As the next step, we plan to establish the expected 100 MB/s capability by applying the higher revisions of PCI bus, simultaneously with the study for cost reduction.

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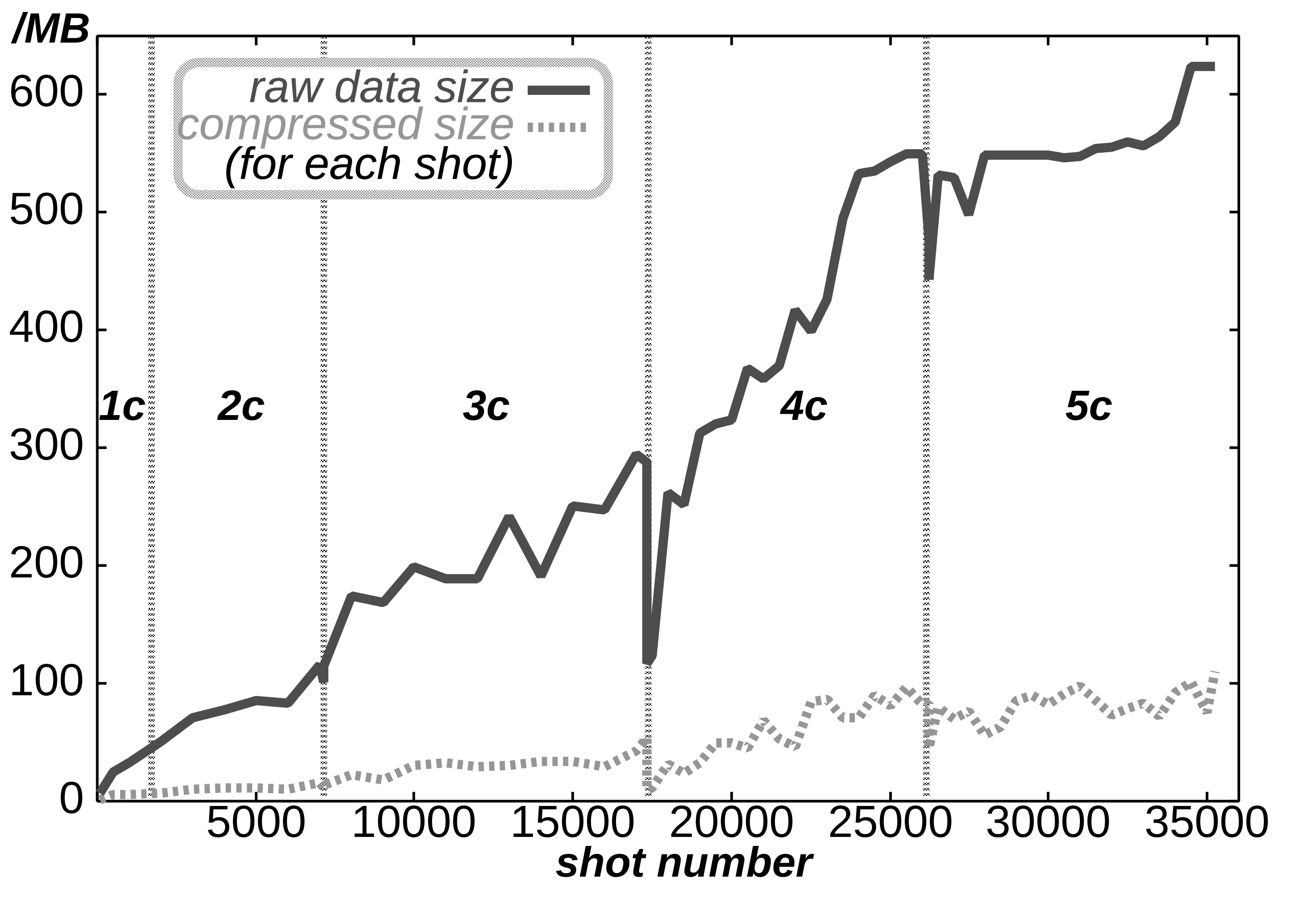
Fig. 1. Growth of shot-by-shot data size acquired by LABCOM system: Though the raw data size had kept growing almost as double as the previous one until the 4-th experimental campaigns, the growth rate slowed down in the 5-th one.

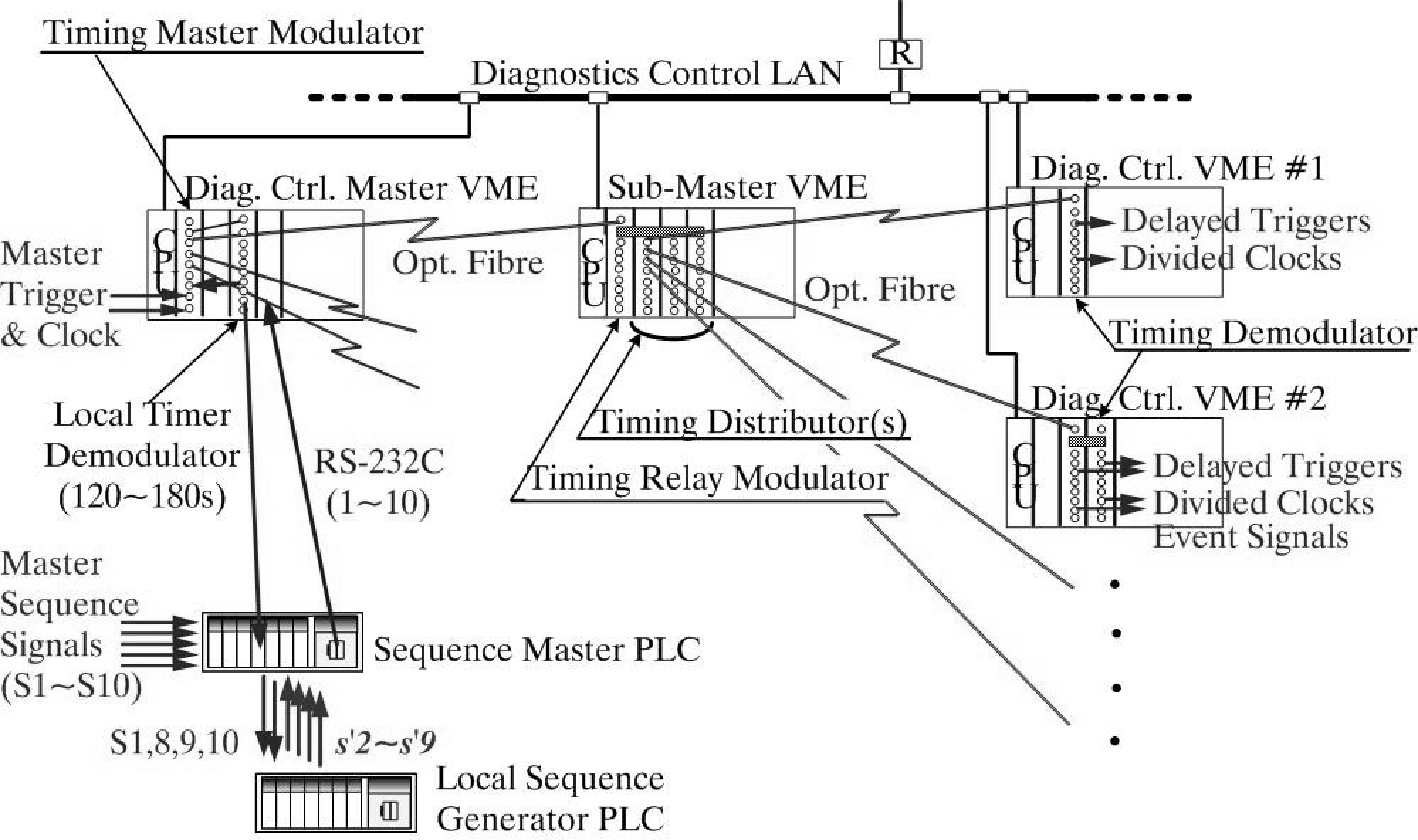
Fig. 2. Sub-sequence generation and distribution circuit: A set of DTS and PLC are used for the local sub-sequence timer.

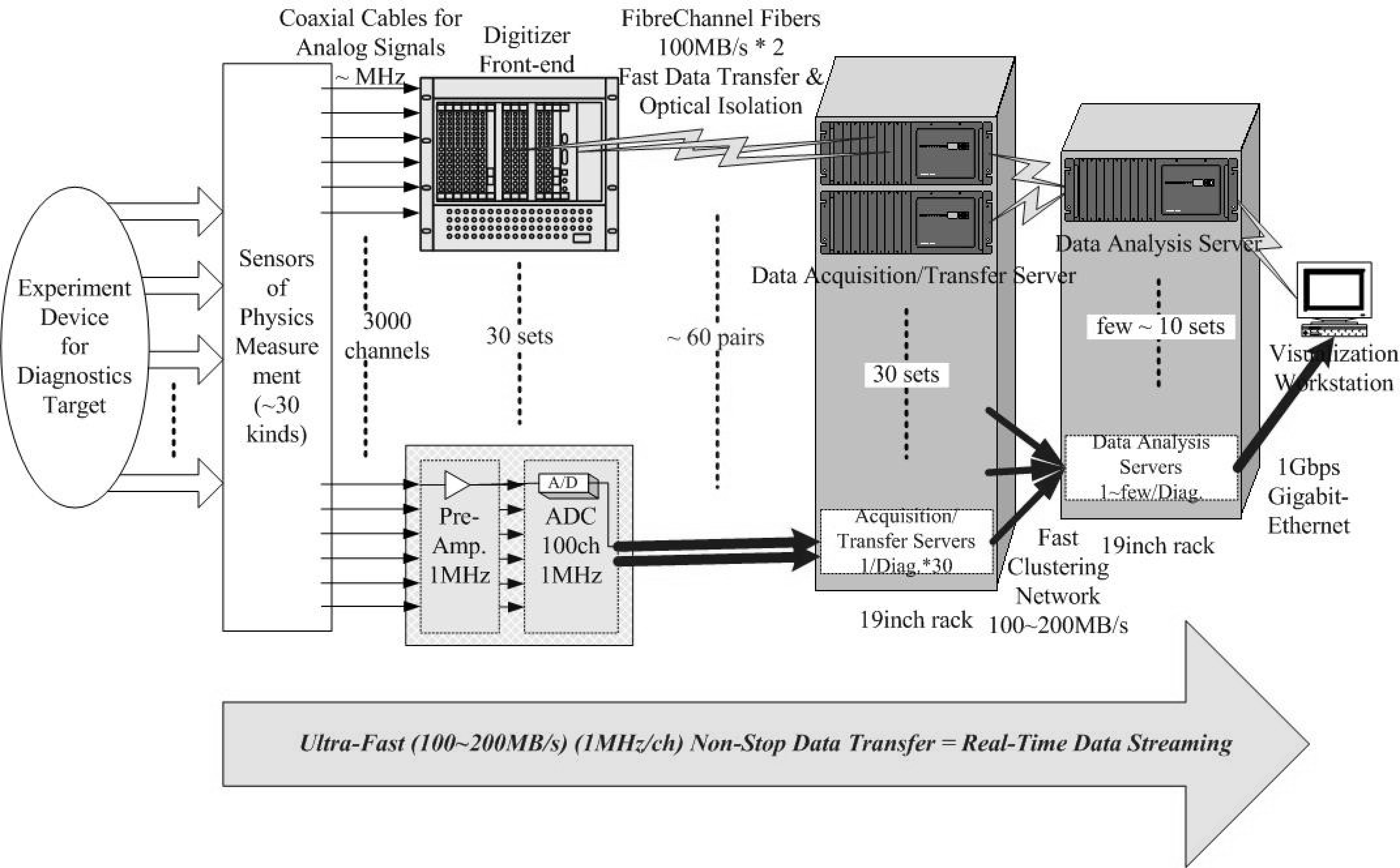
Fig. 3. Schematic view of new streaming digitizer system: Fine and real-time data sampling will be enabled. It applies the CompactPCI DFE and PC clustering computers.

Fig. 4. Data I/O rate in ATA-RAID system: Four ATA133 disks form a FAT32 filesystem in RAID0 striping volume. The striping block and file allocation sizes are both 64 kB.

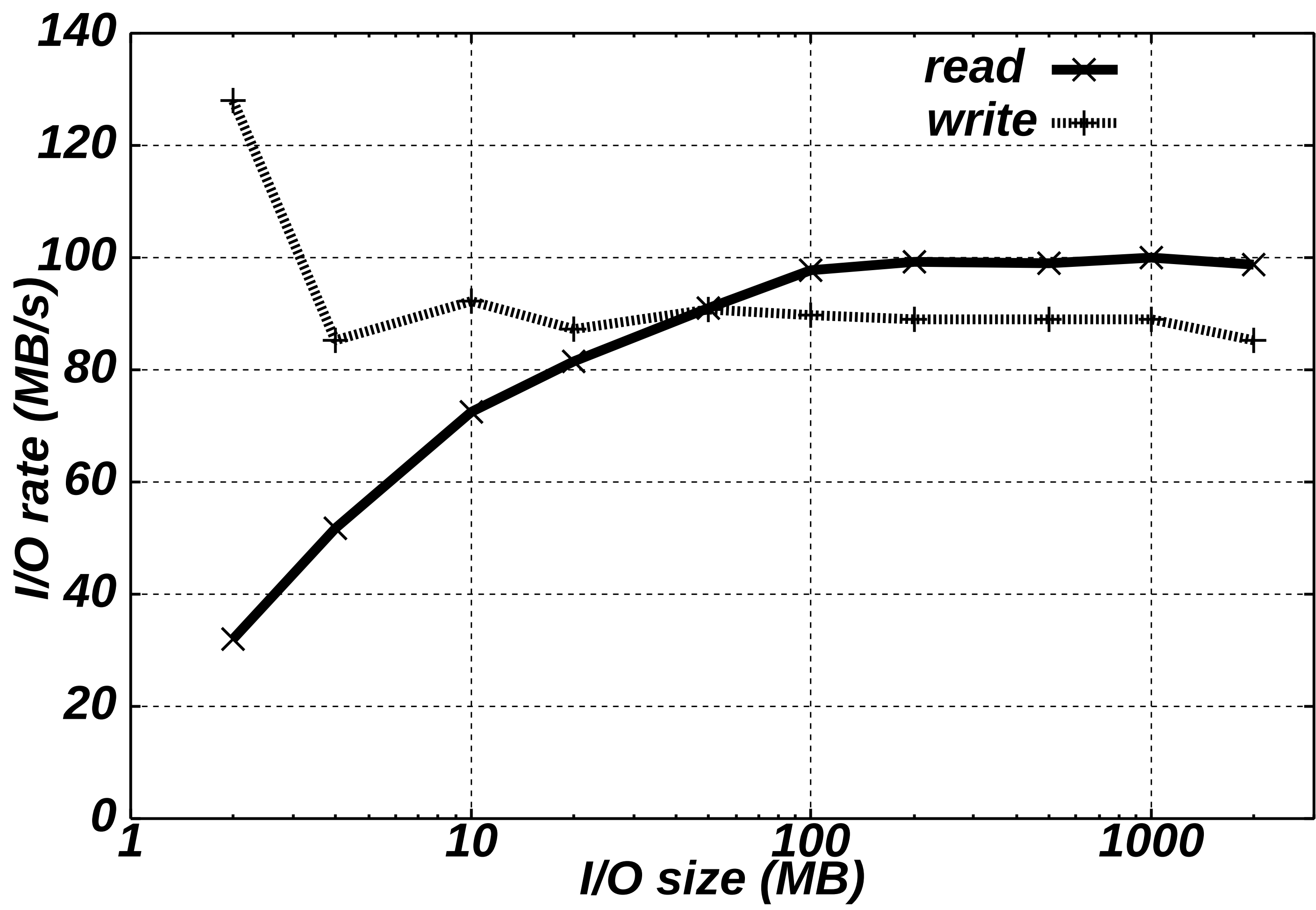


/MB
raw data size
compressed size
(for each shot)
1c
2c
3c
4c
5c
0
100
200
300
400
500
600
5000
10000
15000
20000
25000
30000
35000
shot number


Timing Master Modulator
Diagnostics Control LAN
R
Diag. Ctrl. Master VME
CPU
Master Trigger & Clock
Opt. Fibre
Sub-Master VME
CPU
Opt. Fibre
Diag. Ctrl. VME #1
CPU
Delayed Triggers
Divided Clocks
Timing Demodulator
Diag. Ctrl. VME #2
CPU
Delayed Triggers
Divided Clocks
Event Signals
Local Timer Demodulator (120~180s)
RS-232C (1~10)
Timing Distributor(s)
Timing Relay Modulator
Master Sequence Signals (S1~S10)
Sequence Master PLC
S1,8,9,10
s'2~s'9
Local Sequence Generator PLC



Coaxial Cables for Analog Signals ~ MHz
Digitizer Front-end
FibreChannel Fibers 100MB/s * 2 Fast Data Transfer & Optical Isolation
Experiment Device for Diagnostics Target
Sensors of Physics Measure ment (~30 kinds)
3000 channels
30 sets
~ 60 pairs
Data Acquisition/Transfer Server
30 sets
Data Analysis Server
few ~ 10 sets
Visualization Workstation
Pre- Amp. 1MHz
A/D
ADC 100ch 1MHz
Acquisition/ Transfer Servers 1/Diag.*30
Data Analysis Servers 1~few/Diag.
1Gbps Gigabit-Ethernet
Fast Clustering Network 100~200MB/s
19inch rack
19inch rack
Ultra-Fast (100~200MB/s) (1MHz/ch) Non-Stop Data Transfer = Real-Time Data Streaming



read
write
I/O rate (MB/s)
I/O size (MB)
0
20
40
60
80
100
120
140
1
10
100
1000