# A Performance Requirements Analysis of the SSC Control System

S.M. Hunt, K. Low
SSC Laboratory *
2550 Beckleymeade Ave.
Dallas, Texas 75237

*Abstract*
This paper presents the results of analysis of the performance requirements of the Superconducting Super Collider Control System. We quantify the performance requirements of the system in terms of response time, throughput and reliability. We then examine the effect of distance and traffic patterns on control system performance and examine how these factors influence the implementation of the control network architecture and compare the proposed system against those criteria.

## I. INTRODUCTION

The Superconducting Super Collider Laboratory (SSCL) is a complex of accelerators being built in the area of Waxahachie, Texas. It will be fully operational at the end of the decade. The SSCL consists of six accelerators: a 1 Gev Linac, three booster synchrotrons (the 12 Gev low energy booster, a 200 Gev medium energy booster, a 2 Tev high energy booster) and two intersecting, contra-rotating 20 Tev synchrotrons that make up the Collider itself. The complex will occupy approximately 112 km of underground tunnels. There are estimated to be about 150,000 control points requiring remote control and interrogation in order to operate the accelerator and diagnose its condition.

## II. PERFORMANCE REQUIREMENTS

### A. Response time

The control system's response to operator requests should be such that response delays be unnoticeable to the operators. The minimum response time of the control system should be, in the absence of any other constraining factors, 20Hz.
In addition, it will be necessary to provide for higher rates, up to 1 Khz for some essential services like the quench protection monitors (QPM).

### B. Throughput

In the Collider tunnel there are 5 Superconducting dipole magnets per half-cell and 968 half-cells per ring. Every 450m is an equipment niche (alcove) which controls 5 half-cells (200 niches). The HEB has 280 half-cells controlled by 24 Niches. The MEB consists of 200 half-cells controlled from 8 surface buildings and the LEB has 108 half-cells controlled from 6 surface buildings. Throughput requirements vary widely [Table 1]. The Linac is not considered here. The environmental (ENV) figures include niche temperature, power, smoke alarms, oxygen and water. The value in the column marked Locations indicates the number of Niches or equipment buildings for a particular machine. The value in the column marked Bytes indicates the number of bytes of raw data being generated at that location for each time interval indicated in the column marked Rate, which is the number of time intervals per second. The value in the column marked Bandwidth is the total number of bytes per second generated for that equipment type and is the product of the Locations, Bytes and Rate values. For the LEB BPM data rates have been set in this table at one tenth of the raw rate in order to conserve bandwidth.

The total amount of data generated site-wide by the SSCL is in excess of 250 Mbytes per second (2 Giga bits per second)[1,2].

### C. Reliability

Total allowable unscheduled downtime for the control system is 30 hours in 4505 hours of operation per year. The control system will consist of 205 equipment locations consisting of 162 Collider niches, 24 HEB niches, 11 MEB buildings, 6 LEB buildings, the Linac and the control room complex. Each of these locations will have one communications element (Hub Gateway or multiplexor, depending on the communications architecture chosen) and up to 9 equipment crates.
If each of these 2050 elements (205 locations x 10 elements) is a "critical" system, then to achieve 30 hours of unscheduled downtime with a mean time to repair of 1.5 hours (20 incidents per year) each element would have to achieve a mean time between failure of 54 years [3]. It is therefore clear that other measures, such as the use of redundant systems, will be necessary in order to achieve the necessary reliability figures.

### D. Capacity

The installed system should have a capacity at least 50% greater than the requirements stated above. It should furthermore be capable of being expanded by 400% without incurring any additional civil engineering costs or replacement of existing components, only expansion costs.

## III. OPERATIONAL REQUIREMENTS

### A. Data Accessibility

---

*Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC02-89ER40486.

Table 1. Throughput and response time requirements

| System | Locations | Bytes | Rate | Bandwidth |
|---|---|---|---|---|
| LEB | | | | |
| BPM | 6 | 108 | 50,000 | 32,400,000 |
| RF | 1 | 2,125 | 20 | 42,500 |
| RAMPS | 6 | 432 | 720 | 1,866,240 |
| VACUUM | 6 | 288 | 20 | 34,560 |
| ENV | 6 | 22 | 20 | 2640 |
| MEB | | | | |
| BPM | 8 | 150 | 6,600 | 79,200,000 |
| RF | 1 | 2,125 | 20 | 42,500 |
| RAMPS | 8 | 600 | 720 | 3,456,000 |
| VACUUM | 8 | 400 | 20 | 64,000 |
| ENV | 8 | 22 | 20 | 3,520 |
| HEB | | | | |
| BPM | 24 | 70 | 24,000 | 40,320,000 |
| RF | 1 | 2,125 | 20 | 42,500 |
| QPM | 24 | 60 | 720 | 1,036,800 |
| CRYO | 24 | 326 | 20 | 156,480 |
| RAMPS | 24 | 280 | 720 | 4,838,400 |
| VACUUM | 24 | 187 | 20 | 89,760 |
| ENV | 24 | 22 | 20 | 10,560 |
| COLLIDER | | | | |
| BPM | 200 | 58 | 3000 | 34,800,000 |
| QPM | 200 | 60 | 720 | 8,640,000 |
| CRYO | 200 | 135 | 20 | 540,000 |
| RF | 1 | 1062 | 20 | 21,240 |
| RAMPS | 200 | 332 | 720 | 47,808,000 |
| VACUUM | 200 | 155 | 20 | 620,000 |
| ENV | 200 | 22 | 20 | 88,000 |
| TOTAL | | | | 256,123,700 |

Control loops will be implemented at the Local (Niche), Regional (Sector) and Global (Control room) levels[4]. However, in order to debug the systems it will be necessary to open some of the local and regional loops from the control room, and move some of the loops from local to regional to control room and vice versa. For instance a control room algorithm might be tested at the global level and then installed as a local loop for reasons of security, because it may need to continue to operate when the global system is in a maintenance mode.

This leads to a requirement that all raw data that might be needed at any level of the control system, even local loops, must be available in the control room. Furthermore this has the important advantage that application programs will have access to all of the data associated with the sensors that might otherwise be hidden. For example if a beam monitor system provided only the result of a calculation, for instance the beam tune, it would not be a simple matter to add another capability, for instance a calculation of the beam lifetime. More importantly new algorithms could not be tested without affecting the operation of existing systems. In addition, as new capabilities are added to systems, the control system should not limit the raw data that is acquired to some arbitrary fraction of the total. All data should be available at all levels.

### *B. Traffic Patterns*

As has been stated earlier, data generated at equipment locations (niches and buildings) should be available simultaneously at more than one location, for instance at the regional level and at the control room to be consumed by console applications. It is not anticipated that there will be significant Niche to Niche communications. This must not however be excluded. Although a number of computers must be able to read the data from equipment locations, only one should be able to write commands to field equipment at any given time. An arbitration mechanism to give permissions to access equipment for commands will be necessary. When command messages are sent to an equipment location it may be necessary to queue the messages for processing. This can be achieved by use of a high level communications protocol such as TCP/IP, but this introduces a large overhead for data transmission of up to 50%. It might be more efficient to queue the requests to the arbitration mechanism that allows commands to be sent to the equipment.

### *C. Determinism*

Application programs typically periodically request current readings and settings from field sensors. It will be necessary to quantify the rate of such requests and guarantee the timely transport of data through the communications systems. The performance of the system must be predictable, that is deterministic. Furthermore because the system will be designed to worst case scenarios, no advantage would be gained by trying to achieve best case performance better than worst case. Thus data transport should be load-independent.

### *D. System Software*

This predictability in the control system should extend to computer operating systems as well as communications equipment. This may mandate the use of real-time operating systems. This would be true for embeded systems using, perhaps, real-time kernels and also for the computers in which run application programs. For these therefore operating systems such as UNIX would be discarded in favour of, for instance, a real-time UNIX.

### *E. Data Stores*

It will be necessary to provide a mechanism to store any data that is acquired to equipment locations or applications programs. This data storage might be for temporary use in shared memory, in a database or a system. As some of this data may be archived for many years it is important that it be stored in a format that does not become obsolete with new versions of the storage utilities. There should be one coherent set of library routines and utilities that can handle these functions. These utilities and library routines must be able to access the structure of the data, not just handle the data set as a whole. The ability to access the data should not depend on the availability of header files that were written at the time with the original application program, and may now be out of date. And they must not need prior knowledge of the structure of the data. The description of the data should therefore be in a standard format, embedded in the data or in a database.

## IV. Possible Communications Architectures

### A. SERIAL CAMAC HIGHWAY

Serial Camac meets many of the requirements of a controls communications architecture, all the data is available from a global level, with no data-hiding, but it is difficult to control access to the equipment. Response times and throughput values using present systems are below the level of performance that we require.

### B. CSMA/CD

IEEE Standard 802.3 is a "listen while transmitting" LAN access technique, commonly referred to as CSMA CD (carrier sense multiple access collision detection). It closely resembles Ethernet with some minor changes in packet structure together with an expanded set of physical layer options. Bit rates supported are between 1 Mbps and 20 Mbps. Collision detection means that collisions i.e. simultaneous bids for access to the medium can be detected early in the transmission period and aborted, thus saving channel time and improving overall channel utilization. When a collision is detected, the user backs off and continues to attempt access until a maximum number of unsuccessful attempts has been reached before generating an error. A contention-based protocol like Standard 802.3 is unsuitable for a number of reasons. It is not deterministic. It can be totally blocked with no critical data able to get through from a critical system. It is not easy, using standard protocols, to arrange that many stations be able to receive the data, and the data producer has to know the address of the recipient. The access protocol works only for short segments of network, requiring bridges between physical networks. Typically, networks which are lightly loaded with random traffic requests are especially suited for CSMA/CD schemes.

### C. Token Rings

The token ring protocol specified by IEEE Standard 802.5 is a polling-based controlled LAN access technique. A station gains the right to transmit on the ring when it detects and subsequently captures the circulating token. This station continues to transmit until it either exhausts all transmission frames or the token times out. The station relinquishes monopoly of the ring by generating a new token which other stations may then acquire. The timing-out mechanism ensures that other stations on the ring have a chance to transmit.

Token passing protocols can be made to be deterministic, but many of the higher level protocols do not take advantage of this feature. Token rings transmission rates can only go as high as 4 or 16 Mbps, meaning that many rings would be needed to achieve the bandwidth requirements of the SSCL. Also, response time is slow due to delays introduced by each station. It is more suited to larger transfers such as file transfers.

### D. FDDI

The fiber distributed data interface has the advantages of the token passing protocol and is much faster (100 Mbps). It can operate over the distances covered by the SSCL.

The delay introduced per station is much lower than for token ring as it does not capture all of a packet before retransmitting it, but captures the token while at the same time retransmitting it to the next station on the ring. If the station is the intended destination, determined by examining the first bytes of the token, the outgoing transmission is aborted and this invalid packet is stripped off of the ring by the station that originated it.

However the use of only a single token on the ring at any time means that for large rings such as at the SSCL, when transmitting small amounts of data, most of the time is wasted transmitting the tokens.

### E. TDM

Time Division Multiplexing (TDM) is widely used in the Telecommunications industry. It is the method used for passing voice and data channels over common copper and fiber optic media. The system consists of a network in which a channel that is a multiple of 64 Kbps or 1.544 Mbps is assigned between two geographical locations [5]. There may be many channels between these two locations, each channel carrying specific information with all the channels sharing the same fiber media.

The TDM system with its established industry standards of supported transmission rates will be able to address our requirements as outlined below.

## V. TDM Performance

### A. Response Time

The equipment employed has very low overhead, typically 10 $\mu s$ per node which is less than the speed of light delay imposed by the distance around the Collider. Since it is a point to point network and not a ring, the time to transmit a message is halved as the message does not have to return to its source.

### B. Throughput

Throughput is determined by the number of channels assigned to any link. Standards exist for TDM equipment at a number of data rates. Low speed systems use asynchronous transport at (for example) 1.544 Mbps (called T1 or DS1) and 45 Mbps(called DS3).

At higher rates, synchronous systems often based on fiber optic technology are available. These are defined in the Synchronous Optical NETwork (Sonet) standard. This standard specifies rates that are defined at 55 Mbps (called OC1) which can transport 28 DS1 signals and multiples of that rate. The rates are not exact multiples as some overhead information passed for network management which uses the same number of bits regardless of the link speed. OC3 for example can handle 84 T1 signals and runs at 155 Mbps. Commercial equipment available now is capable of transporting 2.5 Gbps (OC48) over a single fiber optic cable.

Work is continuing with multiplexors at OC192 that should be commercially available in a few years, but additional fibers can always be utilized for increased bandwidth. Standard fiber optic cables consist of up to 250 fibers in a 3/4" diameter cable, giving present total capacity of 625 Gbps.

### C. *Reliability*

This type of equipment is used throughout the commercial telephone system where an interruption of service could be disastrous. As this equipment is (as in our case) installed in remote locations, many network management and diagnostic features are built in.

Redundancy is an important feature in these systems. Dual redundant optics and power supplies, and the possibility of building redundant ring networks, are standard features. The use of redundant rings affords network integrity. Data is automatically rerouted the opposite way round the network should the fiber break or otherwise fail.

### D. *Data Accessibility*

As each data channel is independent of all other data channels, there can be no contention in the network. Data from embedded systems or regional computers can be made globally available as the network will have the capacity to handle all data.

## VI. TDM IMPLEMENTATION

### A. *Interface to front end equipment*

In each of the equipment locations, for instance Collider niches [Fig. 2], a number of different systems have to be interfaced to the TDM communications system. These include beam monitors, quench protection, ramp generation, vacuum and cryogenics.

These systems will use VXI, VME, STD or CAMAC bus standards or may in some cases be acquisition and control interface cards directly connected to the TDM network. Each of these systems would normally have a 64 Kbps interface to the TDM network. Where a higher interface rate is needed, it would be a multiple of 64 Kbps or a full T1 interface at 1.544 Mbps (24 individual 64 Kbps channels).

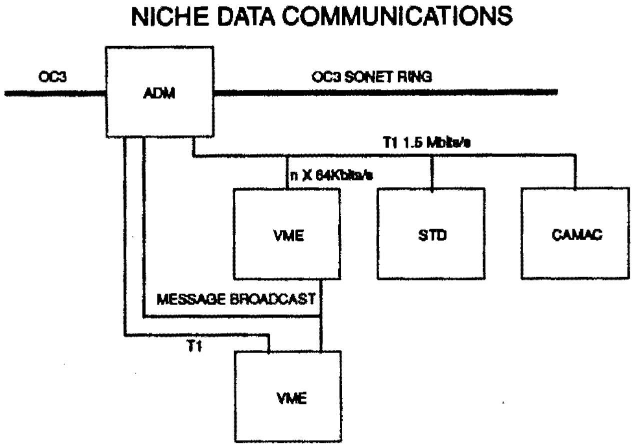

Figure 2: Collider niche data communications

### B. *Message broadcast system*

Some systems also have an interface to a message broadcast system[6]. This uses a T1 interface to distribute, from the control room, medium speed synchronization signals (called events). These signals are characterized by being repetitive such as the 720 Hz clock event or signals that are needed in many locations such as an injection warning event.

### C. *Long distance links*

At each equipment location, the low speed T1 signals are multiplexed using an add-drop multiplexor (ADM) onto a high speed OC3 Sonet link [Fig. 1]. This link will connect all equipment locations in a region. A region would be a Collider or HEB sector (the Collider has 10 sectors, the HEB 2), the Linac, LEB or the MEB. At one location in each region the OC3 link will interface to a global OC48 (2.5 Gbps) Sonet link. This will be a Sonet ring that will connect together all the regions and the control room.

### D. *Interface to regional computers*

The regional computer would also be interfaced to the regional OC3 link. This is to allow it to control regional control loops if necessary. Data arriving from equipment locations would be available to the regional computer as well as transported to the central control room via the OC48 link.

### E. *Interface to Functional computers*

In the control room functional computers running accelerator applications programs will need to have access to data arriving from the equipment locations over the Sonet links. The physical attachment to the TDM networks will be from VME-based Sonet interfaces running

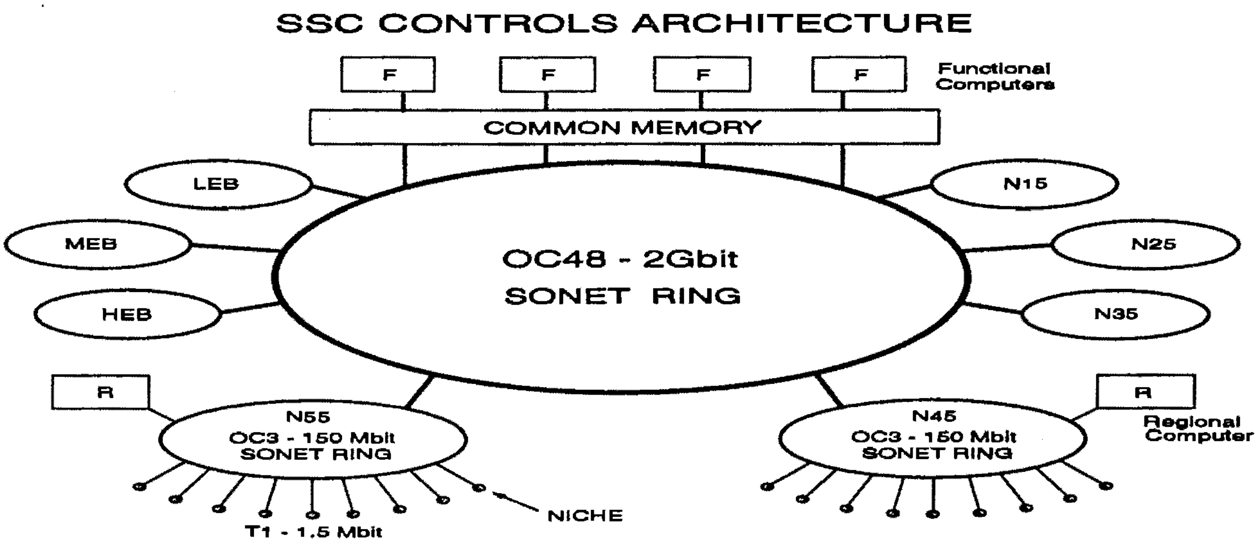

Figure 1: SSC Controls Architecture

at OC3. These OC3 signals will be obtained from an add-drop multiplexor on the OC48 ring. Each functional computer will have access to the data, not only from the OC3 to which it is directly connected but also from all other functional computers. The data arriving will be memory mapped into the virtual address space of all of the functional computers.

## VII. Conclusions

The SSCL performance requirements appear to be attainable with today's technology. Furthermore, the communications network will be largely commercial, thus meeting the reliability and inevitable future capacity upgrades. TDM technology is well-understood and well-established and would not become obsolete during the lifetime of the project.

## VIII. Acknowledgments

The choice of implementation using parallel communication and memory mapping was influenced by the control system of the Advanced Light Source at Lawrence Berkeley Laboratory[7]. Many of the original concepts were proposed by C. Saltmarsh (SSCL) and C.R.C.B. Parker (CERN) who is pursuing some of these ideas for use in the LHC control system at CERN.

## References

[1] Site Specific Conceptual Design, SSCL-1056

[2] M.E. Allen, C.G. Saltmarsh, S.G. Peggs, D.A. Dohan, and V.E. Paxson, "Demands Placed on the SSC Laboratory Control System by the Engineering and Operational Requirements of the Accelerators," International Conference on Accelerator and Large Experimental Physics Controls Systems, 1989, Vancouver, Canada.

[3] K. T. Dixon and J. Franciscovich, "SSC Accelerator Availability Allocation", 1991 International Industrial Symposium on the Super Collider, Atlanta, Georgia.

[4] M. Allen, S.M. Hunt, H. Lue and C.G. Saltmarsh, "A High Performance Architecture for Accelerator Controls" , 1991 International Industrial Symposium on the Super Collider, Atlanta, Georgia.

[5] ANSI T1.102,"DS1, DS1C, DS2 and DS3 Levels of Digital Hierachy."

[6] K. Low and R. Skegg, "The Prototype Message Broadcast System for the SSC", IEEE Transactions on Nuclear Science vol. 38, No. 2, pp325-328, April 1991.

[7] S. Magyary et al, "The Advanced Light Source Control System ", Nuclear Instruments and Methods in Physics Research, A293(1990) 36-43, North Holland.