CHAPTER 6

COMMUNICATION NETWORKS

6.1 INTRODUCTION

The majority of the active computing and control devices which will be used during the installation, commissioning and operation of LHC will be remotely accessible from one of the control rooms and from the commissioning stands. Industrial control devices will mostly be accessible via field-bus attachments, other devices will be connected to one of the CERN communication networks. The computers in the accelerator will also have network access to the CERN internal computing services and resources, in particular to databases and file storage.

A comprehensive network infrastructure which provides IP/Ethernet connectivity in most areas of the accelerator is being installed to support the communication services. The exceptions are in areas where the radiation levels expected are too high for active networking components to work reliably. Connections to the high capacity network are specifically possible in the surface service areas, in the underground service galleries and the alcoves.

The Technical Network will not be available for connections along the accelerator in the main accelerator tunnel because of the high radiation levels expected. During the installation and commissioning phases, a medium capacity VDSL cabled network distribution will be available there, with a connection point every 106 m along the beam pipe. The VDSL installation cannot be used while the accelerator is running because of the radiation levels, but the passive components will remain in place and can be re-activated at no cost should the need arise again later in the life cycle of the accelerator.

The data communication network for the LHC will be integrated into a new infrastructure, broadly known as the Technical Network. When the LHC enters the commissioning phase, the Technical Network will comprise the controls network for the PS and SPS accelerators as well as the network used for monitoring and control of the technical infrastructure at CERN. This network will not have direct access to the Internet, but can access the services on the CERN general network, i.e. the campus network.

The interconnection switches between the technical and general networks are located at two separate locations, CCR and PCR. In order to isolate the Technical Network and protect the operation of the technical installations, it is possible to open these interconnections. Recent operational experience, however, has shown that this protection mechanism is insufficient to protect the site from malicious intruders. The current policies, presently under review, will be strengthened and refined, so that by the time of LHC commissioning, more powerful monitoring tools and more efficient controls will be available for the protection of the CERN networks.

It is expected that several hundred people will be working underground during the installation and commissioning phase of the LHC. To provide voice communication between the members of the teams and between the teams and the external world, the coverage area of the CERN GSM portable telephone will be extended into the LHC underground areas. The distribution of the GSM signals will also facilitate wireless GPRS connectivity on portable devices wherever there is GSM coverage.

The general installation of fixed telephones will be limited to safety systems. Usage of such telephones will provide immediate voice communication to the control centre of the fire-brigade. In addition, a Level-3 alarm will be raised when the hand-set of an emergency phone is un-hooked.

An underground VHF radio diffusion system will provide the CERN fire-brigade with portable radio communication identical to the one they have on the surface. No dedicated portable equipment is needed for the underground areas. The emergency service will therefore be able to use a single portable communication system on all CERN sites.

6.2 PASSIVE NETWORK INFRASTRUCTURE

A significant passive infrastructure is needed to support the communication network. A cabled, as opposed to a wireless infrastructure, has been chosen for the data network in order to reach a sufficient level of electromagnetic compatibility (EMC) between communication equipment and the accelerator components.

The cabled network infrastructure will ensure the highest capacity at a predictable performance level of the communication network.

It is important to minimise the time needed for fault isolation and repair. The duration of such interventions represents down-time for the accelerator and must be contained. A carefully planned and executed installation of the passive infrastructure is vital for efficient maintenance of the network and hence, for the operation of the accelerator.

The installation of the cable infrastructure for the communication systems, optical fibres and copper cables, is described in Chap. 7.

6.2.1 Optical Fibre

Optical fibres will be used to support the backbone of the data communication networks in the LHC. In addition, they will be used in the local network distribution as determined by cost, distance and capacity considerations. The optical fibres are installed in mini-tubes, which may contain up to 70 fibres each. The mini-tubes are inserted in protective ducts which can be directly buried in surface trenches or laid on cable trays, where such infrastructure is available. Fibre “blowing” technology is used wherever possible in order to facilitate fibre maintenance and future extensions. The installation of the optical fibres is described in Sec. 7.8 of this report.

The cables situated in the machine tunnel will be subject to radiation, which will damage the fibre over time. It is expected that the light transmission capability of the fibre will deteriorate so much that it must be replaced in the most exposed zones of the machine after every 3-5 years of operation at nominal beam intensity. The installation technique, using mini-tubes contained in ducts, lends itself to rapid replacement of defective fibres. The optical characteristics of the fibres in the main fibre paths will be continuously monitored as described in Sec. 7.8.4. Based on trend analysis from the monitoring system, the replacement of defective fibres can be planned within the normal maintenance windows during machine operation.

Optical fibres are also used to interconnect the many GSM Base Transceiver Stations (BTS) on the site. These optical fibres share the installation paths with the data communication fibres. CERN only provides the passive infrastructure of these interconnections, i.e. the installed, terminated and tested optical fibre, while the GSM operator is responsible for the transmission system.

Fig. 6.1 illustrates the paths and endpoints of the optical fibre installation. The surface trenches cross private and public land, which constrains CERN for access for installation and maintenance. Not shown are the many man-holes dug in the ground at branch-off points.

Tab. 6.1 shows the lengths of the fibre paths passing through the machine tunnel. The trench crossing the land between LHC Point 1 and Point 8 is 3.8 km long. Tab. 6.2 shows the lengths of the fibre paths on the surface.

Table 6.1: Distances in kilometres between the eight LHC Service (SR) buildings, measured along the cable ducts of the optical fibre installation.

	SR1	**SR2**	**SR3**	**SR4**	**SR5**	**SR6**	**SR7**	**SR8**
SR1		4.2						4.2
SR2	4.2		5					
SR3		5		5				
SR4			5		4.2			
SR5				4.2		4.2		
SR6					4.2		4.4	
SR7						4.4		4.4
SR8	4.2						4.4	

Table 6.2: Distances in kilometres between the Prévessin Control Room (PCR) and the eight LHC Service (SR) buildings, measured along the cable ducts of the optical fibre installation.

	SR1	**SR2**	**SR3**	**SR4**	**SR5**	**SR6**	**SR7**	**SR8**
PCR	3.8	5.4	9.2	9.5	10.1	6.5	7.7	4.6

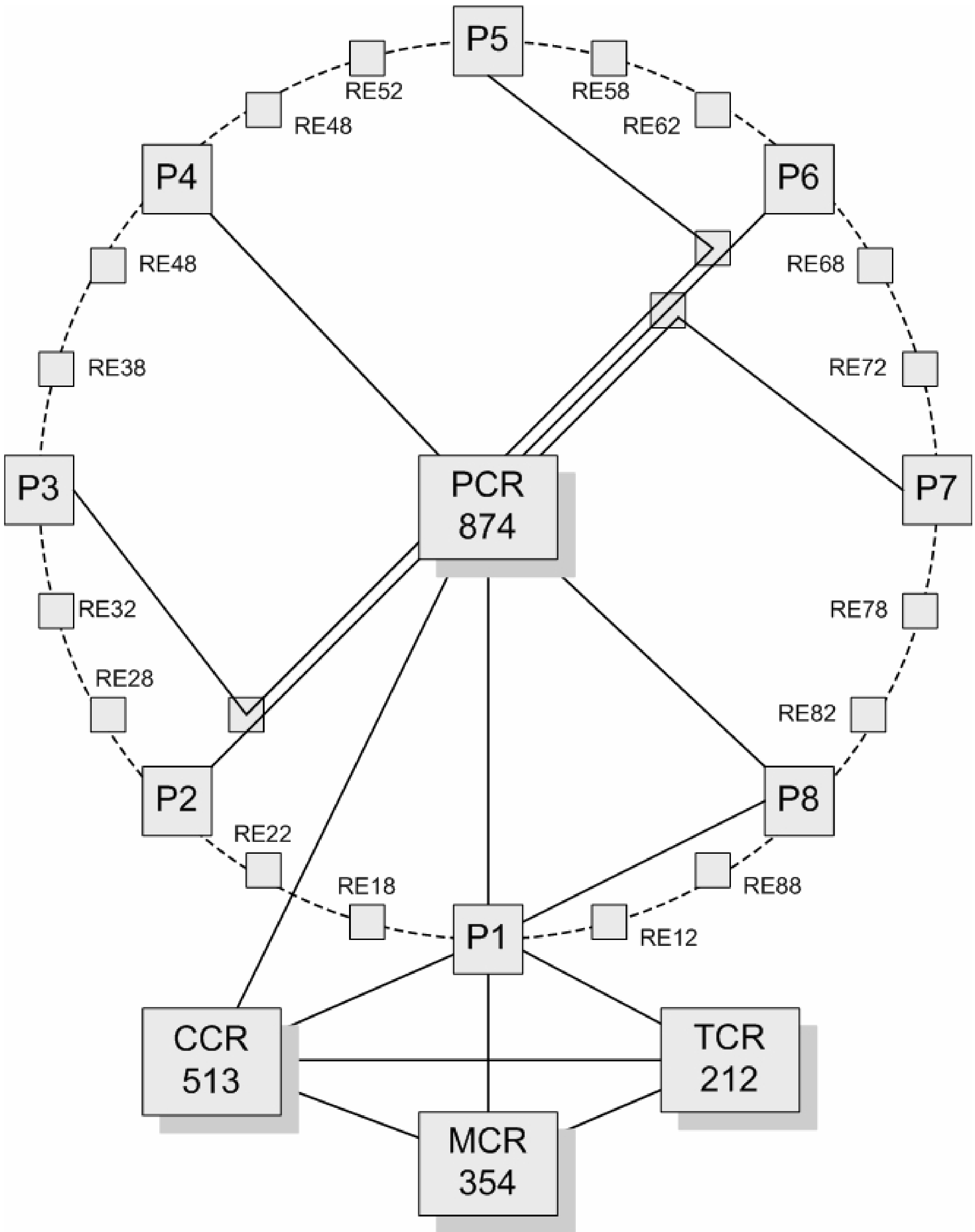

Figure 6.1: Installation paths for the optical fibres in LHC. The full lines show the surface trenches and the dotted lines show the ducts installed in the tunnel sectors.

6.2.2 The Leaky Feeder Antenna Cable

It has been specified that two voice communication systems must be available everywhere in the LHC underground areas [1]. The two systems are:

- The bi-directional VHF radio of the fire brigade,
- The GSM portable telephone system.

The goal is to unify and simplify the communication between personnel wherever they may be situated. The underground installation extends the coverage of the existing GSM and radio communication systems used on the CERN surface sites. In order to satisfy the requirement of universal coverage, segments of the leaky feeder antenna cable have to be present in all underground areas. These segments are interconnected by broadband splitters/combiners, which are passive components with a cut-off frequency at 2 GHz.

The GSM and the VHF communication systems use this omnipresent longitudinal antenna in diplex operation. A total of 49 km of antenna cable will be installed in the main LHC machine tunnel, the service and the access galleries, the experimental caverns and in the two transfer lines from the SPS. Most of the SPS machine is already equipped with such a system.

6.2.3 Copper Cables

The local network distribution is primarily based on structured cabling with telecommunication cable of category 5e terminated on standard RJ-45 connectors. Compliant cable installations reach up to 100 meters, measured along the cable path at 100 Mbit/s.

The VDSL network in the LHC tunnel is wired in a point-to-point configuration where the individual lines emanate from the underground service areas and the alcoves and are distributed along the beam line of the accelerator. Telecommunication cables of category 5e wires will be used for this installation.

It is possible that telecommunication cable of category 5e will become obsolete and that it will be replaced by a superior category 6 type before the LHC is brought into operation.

6.3 ACTIVE NETWORK INFRASTRUCTURE

The passive network infrastructure interconnects the active networking devices. Such devices are active in the sense that their operation requires the continuous supply of electrical power. This is a sensitive factor because an outage of the electricity supply will directly cause downtime of the communication network. Several precautions have been made to minimise the risk and consequences of such situations, see also Sec. 6.4.

6.3.1 Switching and Routing Equipment

There are two conceptual levels in the network: the backbone and the edge. The backbone is built of a number of powerful and complex IP/Ethernet switched network routers. The routers feed the edge devices where the user equipment is connected. The edge is built of much simpler devices: IP/Ethernet network switches.

The selected router models have been used at CERN for many years, their characteristics are well known and they have proven to be reliable in our environment. The backbone routers are designed for redundancy and have a modularised construction which allows hot-swap of the line interface modules. The redundant structure also incorporates duplicated switching fabric and power supplies which can be replaced without service interruption. The software is able to identify redundant paths to other networking devices and react intelligently when a broken path is detected.

The network switches are less complex and less specialised equipment. Several brands will be used in order to match the specific needs of the technical environment in terms of the number of outlets, power requirements and interface options for the interconnections to the backbone routers.

The routers support modules with transmission rates of 10, 100 or 1000 Mbit/s and modules exist with ports for both copper wire and optical fibre. Both multi-mode and single-mode optical interfaces are available. Gigabit ports on optical fibre are used almost exclusively in the links between the backbone routers. In the local distribution to the edge devices, the transmission rate will be determined as required by the number of connections and the expected performance of the end-user equipment.

In the Technical Network for the LHC, the complex components of the network have been lifted out of the underground areas and installed in the surface service buildings. What remain underground are essentially the edge switches, the optical fibre and the copper cable interconnections. There are several reasons for this decision: surface space is available at much lower cost and the accessibility for maintenance is much easier. In addition, the environmental conditions, i.e. radiation, humidity and temperature, can be kept under much stricter control in the surface buildings. The backbone routers of the LHC Technical Network are installed in the service building (SR) at each of the eight LHC intersection points, near the Prévessin Control Room (PCR) in building 874 and in the Computer Centre (CCR) in building 513 (Fig. 6.3).

The active networking devices honour quality of service options (QoS) in the TCP/IP protocol suite. The data communication network will therefore be well prepared to support latency and jitter-sensitive applications like real-time control, voice and video transmission.

6.3.2 Support for Mobile Telephones

The radio signals of the GSM telephone system are exchanged between the portable phones and the Base Transceiver Station (BTS) by means of the leaky feeder antenna cable. The installation of this passive component is described in Sec. 6.2.2. When the network is fully deployed, there will be two typical configurations of the BTS installations in the LHC:

- One BTS with its aerial is installed in each of the eight surface service buildings. It covers the surface area, and it feeds the leaky feeder antenna segment which descends the vertical shaft to the tunnel floor. There, a broadband splitter/combiner feeds the antenna segments in the relevant service and access galleries. The same splitter/combiner also feeds the antenna segments in the left and right direction of the adjacent long straight sections of the machine tunnel.
- One small BTS is installed in each of the 16 alcoves. It feeds the leaky feeder antenna cable going up to the mid-arc point of the machine tunnel. This BTS also feeds the antenna segment in the direction of the adjacent intersection point where it will join the other segment described above.

Each BTS will be connected by optical fibre to the Base Station Controller (BSC) of the GSM operator. The BSC will be situated on the premises of the operator, together with the Mobile Switching Centre (MSC) where the CERN communication traffic is inserted into the GSM operator's global communication networks. The network configuration, with BTS units distributed around the tunnel, will make it possible to implement a future personnel search facility on the existing infrastructure should the need arise.

The GSM infrastructure supports the 900 MHz band. Use of the higher GSM frequencies would have required installation of a more expensive and unwieldy antenna cable, and/or the installation of additional electronics in areas with significant radiation exposure from the circulating hadron beams.

The GSM operator also supports wireless GPRS data communication with access to the CERN computer networks. This will conveniently provide a data communication facility wherever there is GSM coverage, albeit at a modest speed of up to 50 kbit/s.

6.3.3 Support for the Radio of the Fire Brigade

The portable bi-directional VHF (~160 MHz) radio is the main communication equipment used by the fire-brigade during their interventions. The authorities of the host states have authorised one VHF radio channel for exclusive use by the CERN fire-brigade. Two other channels are available to allow communication with auxiliary rescue services in the two CERN host states.

The transmission of the radio signals shares the leaky feeder antenna cable with the GSM system in diplex operation. The VHF signal is picked up by an aerial at each of the eight intersection points. It is inserted onto the cable by means of a passive combiner device. In each alcove, a passive VHF by-pass device ensures VHF transmission continuity across the opposite antenna cable segments all the way to the mid-arc point of the tunnel. Fig. 6.2 illustrates how the major components are interconnected in a typical LHC Sector.

6.4 NON-INTERRUPTED OPERATION

The communication infrastructure will support voice and data communication without interruption during the normal operational cycles of the accelerator: commissioning, operation and maintenance. Both of these systems rely on the optical fibre infrastructure.

Cable trenches and ducts pass across private land to reach the remote sites of the LHC, which means that there is always a risk that someone gains access to the cable itself or to the man-holes at the cable junctions. Whether by accident or design, the cable may be damaged and transmission interrupted. Protecting the installation under lock and key is a precaution which may not be sufficient to deter an intruder. Sec. 6.4.2 describes how the Technical Network for the LHC is prepared to deal with this eventuality by providing redundant signal paths.

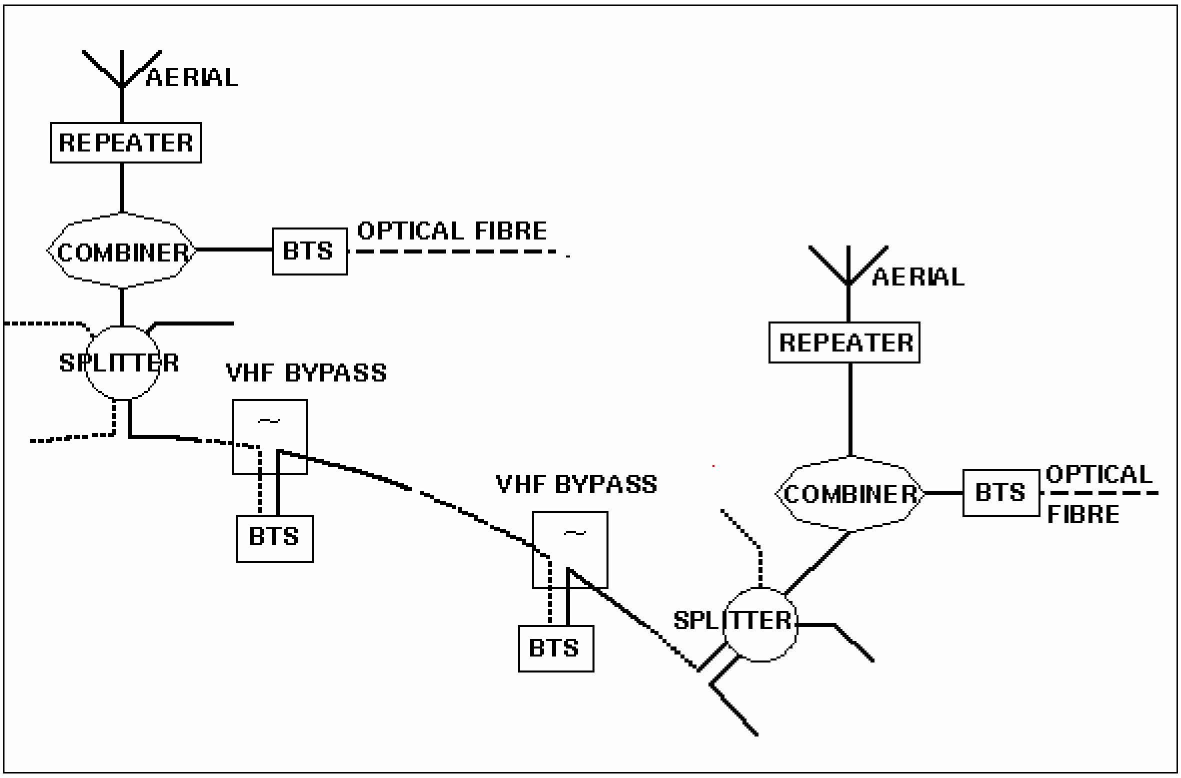

Figure 6.2: Schematic illustration of the leaky feeder antenna with the supporting components in an LHC sector.

Environmental perturbations may also occur during operation. It is important to minimise the impact such events will have on the availability and performance of the communication services. Risks are related to the reliability of the equipment and also to possible interference with the physical components of the installation: cables, connectors and active devices. Additional risk factors include the stability of the electrical power supply and the environmental conditions: i.e. the radiation level, the ambient temperature, the humidity and settling dust brought by the air flow due to the ventilation.

The primary voice communication system is the portable GSM telephone infrastructure covering the CERN sites in the two host states. The extended coverage underground is ensured by the optical fibres, the leaky feeder antennas and active BTS equipment which are installed both in the service areas on the surface and in the alcoves underground. The reliability of the GSM service relies both on the operational quality level of the service provider and on the availability of the CERN specific installation.

Data communication will be provided by the Technical Network. This is an IP/Ethernet network running on the cabled infrastructure using active routers and switches. These components are installed both in the surface service areas and in the underground galleries. Fig. 6.3 depicts the backbone routers and indicates their interconnections. The technical network alone does not offer the resiliency required to transport vital alarm information to the control rooms (TCR and SCR) in the sense laid down in the earlier alarm recommendation [2]. It has, however, been qualified as one out of the two diversely redundant transmission paths which are required for the transport of vital alarm information.

The equipment chosen to support the backbone of the technical network for the LHC has already been deployed on a large scale at CERN. The switched routers have been in operation for several years, first in the CERN campus network and then in the technical network to support controls for the PS and the SPS accelerators and for the support of the site-wide monitoring of the technical services. As a result of this experience, the network support team is already familiar with the equipment. Hence, the maintenance and service interventions will be executed efficiently and with confidence from the start.

6.4.1 Supporting Services

Experience of network support gathered from the operation of SPS and LEP, shows that the supply of electrical power is the most critical factor affecting network availability. With active components in the system, the availability of the communication network can never surpass the availability of the electrical power. Reliable, non-interrupted supply of power is mandatory in order for the data communication network to be useful for post-mortem data collection and transport of alarm information. For this reason, the supply of un-interrupted electrical power has been requested for technical network.

The situation is similar for the voice communication systems. Handling of fault and alarm situations in the accelerator often implies interventions in the underground by equipment specialists or the fire-brigade. Voice communication is vital for the experts to be able to work efficiently and to coordinate the actions between them and the control rooms. For this reason, the active components of the voice communication system need to be supplied with electrical power from an un-interrupted supply.

Electronic equipment is usually specified to operate in an ambient temperature of up to 40 °C. The ambient air temperature in many of the technical areas of the LHC can only be contained at that level by artificial cooling and ventilation. In the case of a break-down of these services there is a risk of service interruptions, caused by over-heating of the equipment, these failures may be transient or permanent. Operation can only be restored when the supporting services have been restored. If the equipment has been damaged by over-heating, it must be replaced which will incur additional cost and down-time.

6.4.2 Redundancy

The guiding principle for the design of the backbone of the data communication infrastructure is to avoid a single point of failure. In order to achieve this, at least two separate transmission paths between every node (router) in the backbone of the network are required. The paths are preferably chosen such that they do not share cable ducts which pass through the same physical area. The redundant paths traverse separate nodes, while the termination ports of the redundant paths reside on separate modules in the routers. By this design, a single failure, whether it is a broken fibre, a faulty termination port or a faulty module, will not be sufficient to completely isolate a router from all of its neighbours.

The optical fibre installation for the data communication in the LHC is rich enough to satisfy this requirement. Multiple interconnections between the backbone nodes of the communication network are possible by exploiting the fibre ducts in the surface trenches and in the underground tunnels. The backbone router in each of the eight LHC service buildings is connected to the PCR and also the CCR routers by the surface link and also through the two neighbouring service buildings through the left and right underground sectors. Fig. 6.3 shows the routers in the LHC backbone of the technical network and the redundant optical fibre paths which interconnect the routers.

If a broken link is detected, the router will activate the selection procedure of one of the back-up links. The choice will be based on the router's perception of the links relative performance. It is worth noting that this mechanism will also make the communication system much less susceptible to service interruptions during maintenance phases of the accelerator.

The equipment which is the source of the LHC alarm messages is situated on the surface in each of the intersection points, where both the technical and the general networks are present. The alarm equipment will be connected to both networks by separate interfaces and ports, and the transmission of the messages will follow separate paths to the alarm servers for processing. The configuration eliminates a possible communication failure in the event that a single port or connection cable should fail.

The lines for the GSM service provider are terminated in building 513. From this location an SDH dual ring interconnects the major nodes in the GSM terrestrial backbone. The base stations, which are situated on the surface of each of the LHC intersection points and in the underground alcoves, are fed by point-to-point links from these nodes. This arrangement does not provide end-to-end redundancy, but a damaged optical fibre will only have a limited adverse impact on the local service.

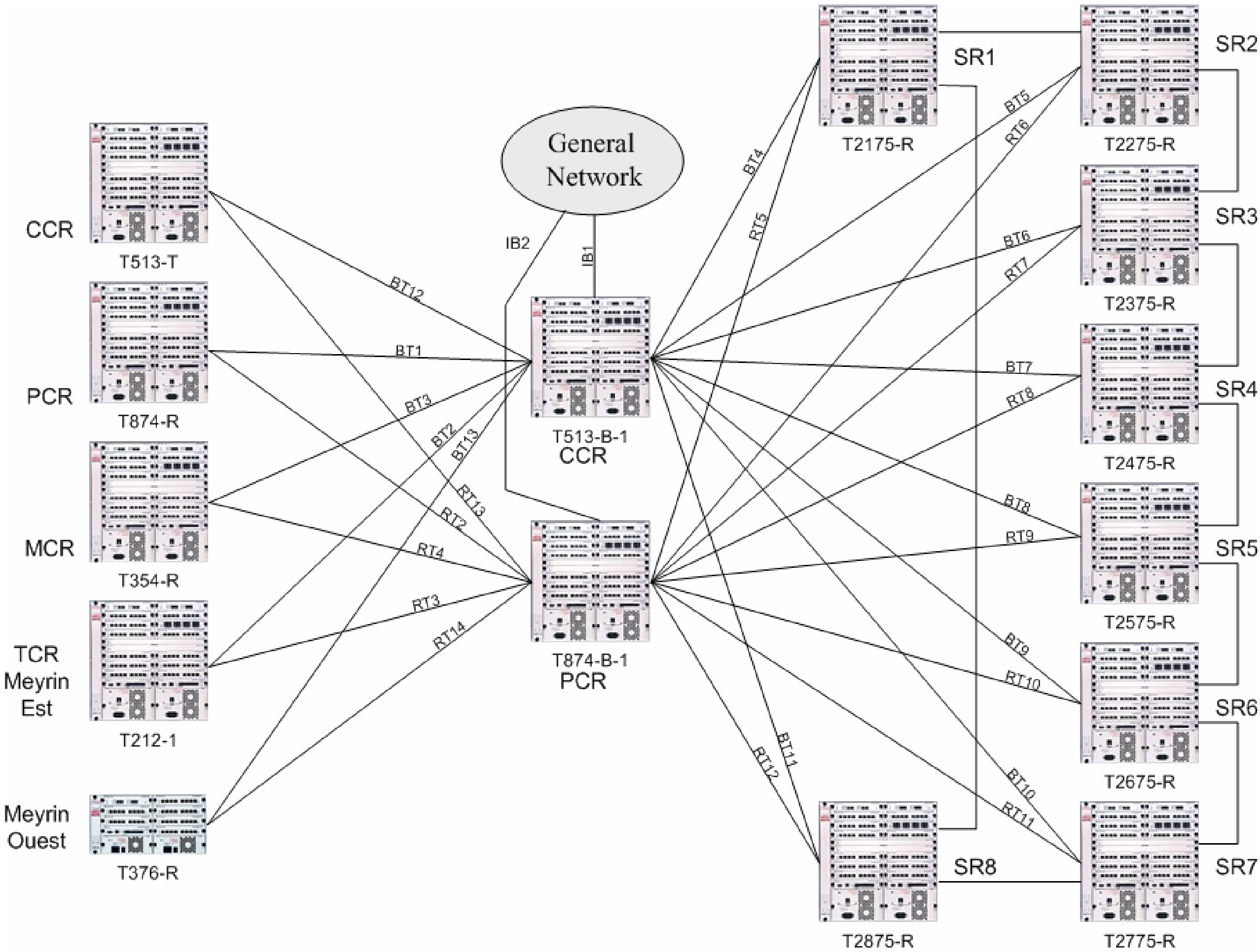

Figure 6.3: The principal routers in the backbone of the Technical Network and the redundant optical fibre paths.

REFERENCES

[1]. LHC Engineering Specification “VOICE AND DATA COMMUNICATIONS IN THE LHC UNDERGROUND AREAS” (LHC-C-ES-0002.00 rev 1.0)

[2]. Recommendations for the LHC Safety Alarm System (DG/DI/LE/jf/98-57)