

Technical Note

TN # 85

Strong Motion Instrument Networks

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| Company: | GeoSIG Ltd Ahornweg 5A, 5504 Othmarsingen, Switzerland, Tel: +41 44 810 21 50, Fax: +41 44 810 23 50, E-mail: info@geosig.com |
| Document: | TN_85_SMI_Network.doc. |
| Author: | Dr. Talhan Biro |
| Checked: | Lukas Gätzi |
| Approved: | Johannes Grob |
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1. Abstract

Whenever more than one Strong Motion Instrument is implemented in the same structure, the question of the Network principle arises. There are three principal Network configurations:

- a. Independent Recording Network
- b. Interconnected Recording Network
- c. Central Recording Network

For each of the above principles, the specifications and advantages are pointed out and typical applications are shown. The different system parameters are discussed in terms of the following modules: Sensor, Recorder, Centre and Interconnection. Common triggering and common timing concepts, as well as network communication methods are explained.

2. Introduction

For most applications, one or more recording stations are placed at different sites to obtain information about the vibrations occurring at each site. The three basic approaches are:

- a. Independent Recording Stations
- b. Interconnected Recording Stations
- c. Central Recording Station

Every approach has its advantages and disadvantages. The final decision about the network approach to be implemented has to be made by the user and to facilitate this decision for the reader, a simple checklist is provided in section 9. We will consider a dam with six sensor sites on or near the dam: 3 at the crest, 2 at the basement, and one in the free field, to demonstrate the three basic approaches of instrumentation.

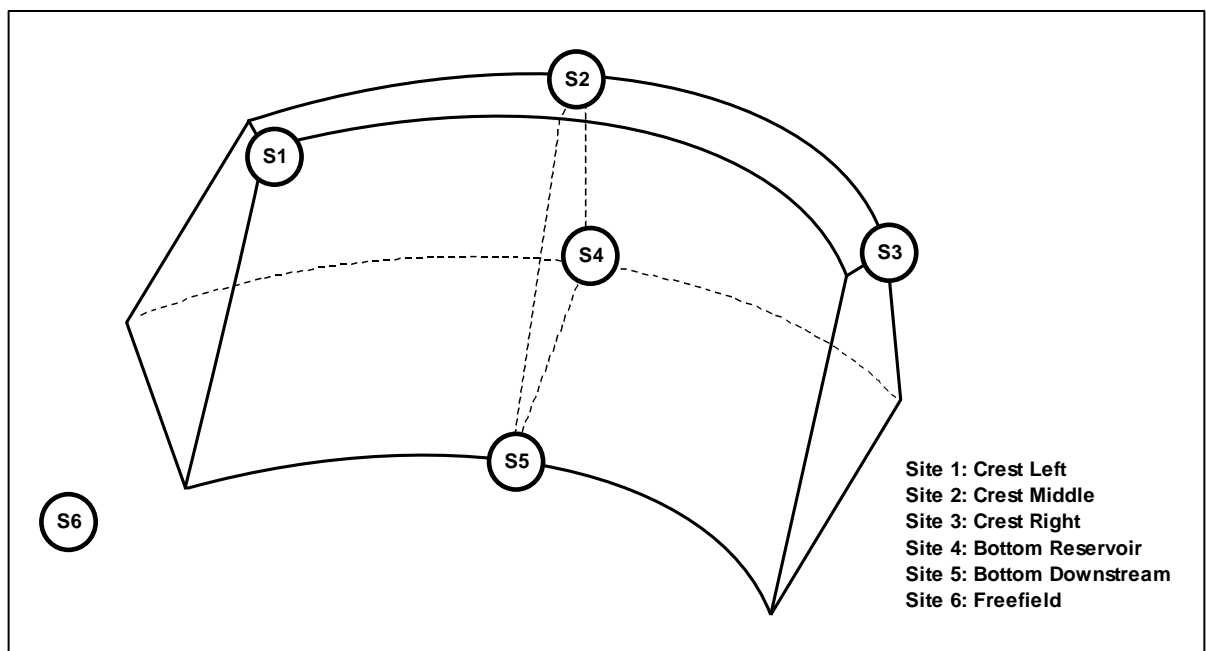


Figure 1. A sample site arrangement in a dam instrumentation

3. Independent Recording Network

This is a Local Recording case in which recording takes place at each station. One or more independent recorders with internal or external sensor are placed on site, as illustrated in Figure 2.

In case of an event, each recorder records independently the time history of the event. An exact correlation between the individual recordings can be provided only if each of the recorders were connected to a common time reference, such as a GPS receiver, in which case common timing would be based on UTC time.

There is no common triggering between the different recorders; therefore it is not possible to correlate the recorded events at different nodes of the network.

The parameter settings and data retrieval have to be performed locally on the site of each recorder.

Error and warning messages are visible on the display of the recorder at each station, which make the detection of a malfunction possible whenever an on-site check is done.

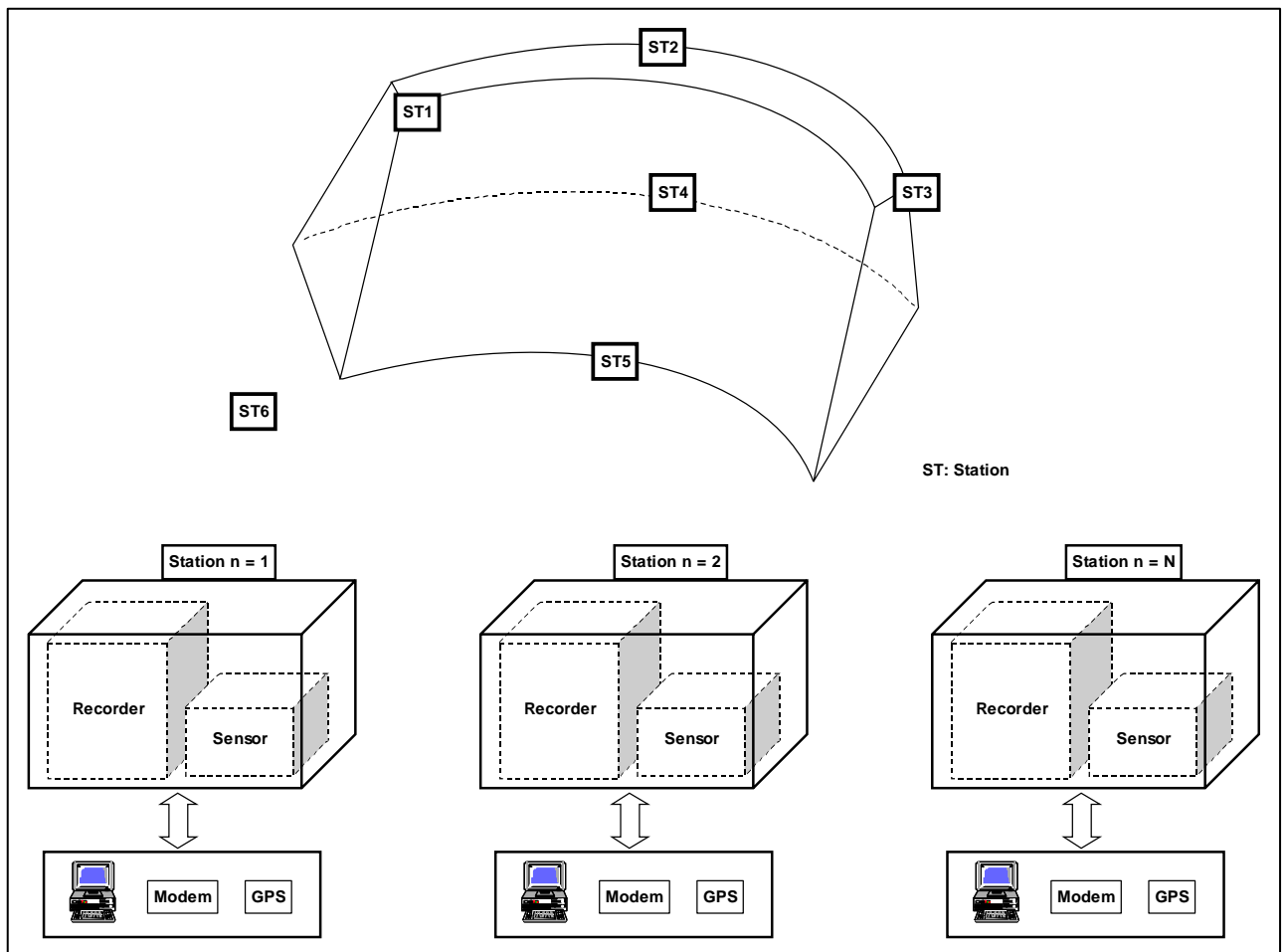


Figure 2. Topology of the Independent Recording Network

4. Interconnected Recording Network

Another version of Local Recording is the Interconnected Recording Network. When interconnection is involved, more options are available in terms of connections, data flow and accessibility, and cost. The three options that are supported by GeoSIG are illustrated in

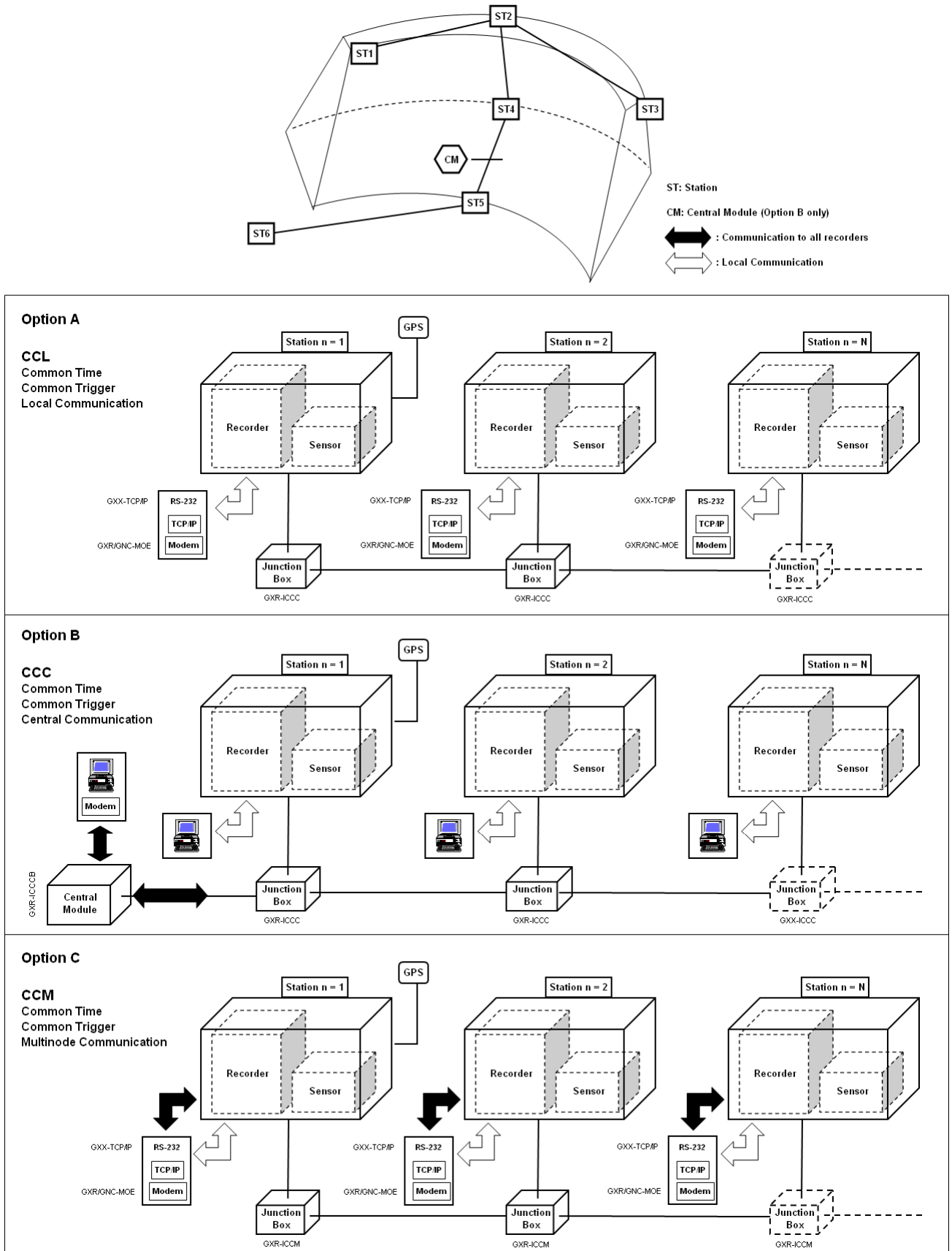


Figure 3 and are described below. A brief functional comparison is also presented in Table 1.

Common Functionality

Connections: Several recorders with internal or external sensors are placed on site and are interconnected with one cable while galvanically isolated from each other. For convenient cabling external junction boxes are used. The interconnection between the stations can be carried out in ring, star, or net topology. Distances between the stations can be as much as 1 km. This is a favourable and cost effective solution for many applications.

Common Timing: One of the interconnected recorders (commonly referred to as the Software Master) is enabled to synchronise and update the internal clock of each of the other recorders (commonly referred to as Slaves) via the network to achieve Common Timing. All stations within the network use the time information to synchronise their internal time to the network time. The time synchronisation is a permanent task for the Software Master. The stations within the network permanently check their synchronisation status. In case of not having the network time information available, the Slave stations base on their internal real time clock. The time of the last successful synchronisation is available in the status information of a Slave station and is written into every event header. A GPS time source can be connected to the Software Master to achieve the time synchronisation of the whole array to the absolute time, which would allow easier correlation with recordings made by other arrays or recorders.

Common Trigger: Triggering functionality of each recorder can be controlled using three flags: 'Internal Trigger', 'Network Trigger Output' and 'Network Trigger Input'. By enabling or disabling these flags the behaviour of each station can be defined precisely as needed in the particular application. This functionality can be summarised as follows:

- enable/disable self trigger: The station triggers if an internal trigger condition is fulfilled and the 'Internal Trigger' flag is enabled.
- enable/disable sending trigger to network: The station transmits an active trigger message to the network if an internal trigger condition is fulfilled and the 'Network Trigger Output' flag is enabled.
- enable/disable accepting trigger from network: The station triggers if an active trigger message arrives from the network and the 'Network Trigger Input' flag is enabled.

If a station is not synchronised to the network it records based on the specified internal trigger condition. An output for Local Communication is available at each recorder for local data retrieval and setting of parameters. The reliability of the monitoring network is high, because a malfunction of a recorder would affect only the location of malfunction in the array. If the network is interrupted, each of the recorders will perform as a stand-alone recorder by recording whenever the instrument's event-recording trigger level is reached.

Option A: CCL (Common Time, Common Trigger, Local Communication)

This type of array enables common triggering and common time in the simplest form. The data are stored locally in every recorder and have to be retrieved locally from each recorder separately, due to the availability of Local Communication only. Similarly, the setting of parameters of each recorder has to be performed on the site of each recorder.

Option B: CCC (Common Time, Common Trigger, Central Communication)

A central communication module is utilised in this option. The module is connected to the network as a central, from which all of the recorders can be accessed for data retrieval and setting of the parameters.

Option C: CCM (Common Time, Common Trigger, Multinode Communication)

The data of every recorder can be accessed and retrieved from any of the recorders in the array. Similarly the parameters of every recorder is adjustable from any of the accessed recorders. This provides an extremely versatile system to operate.

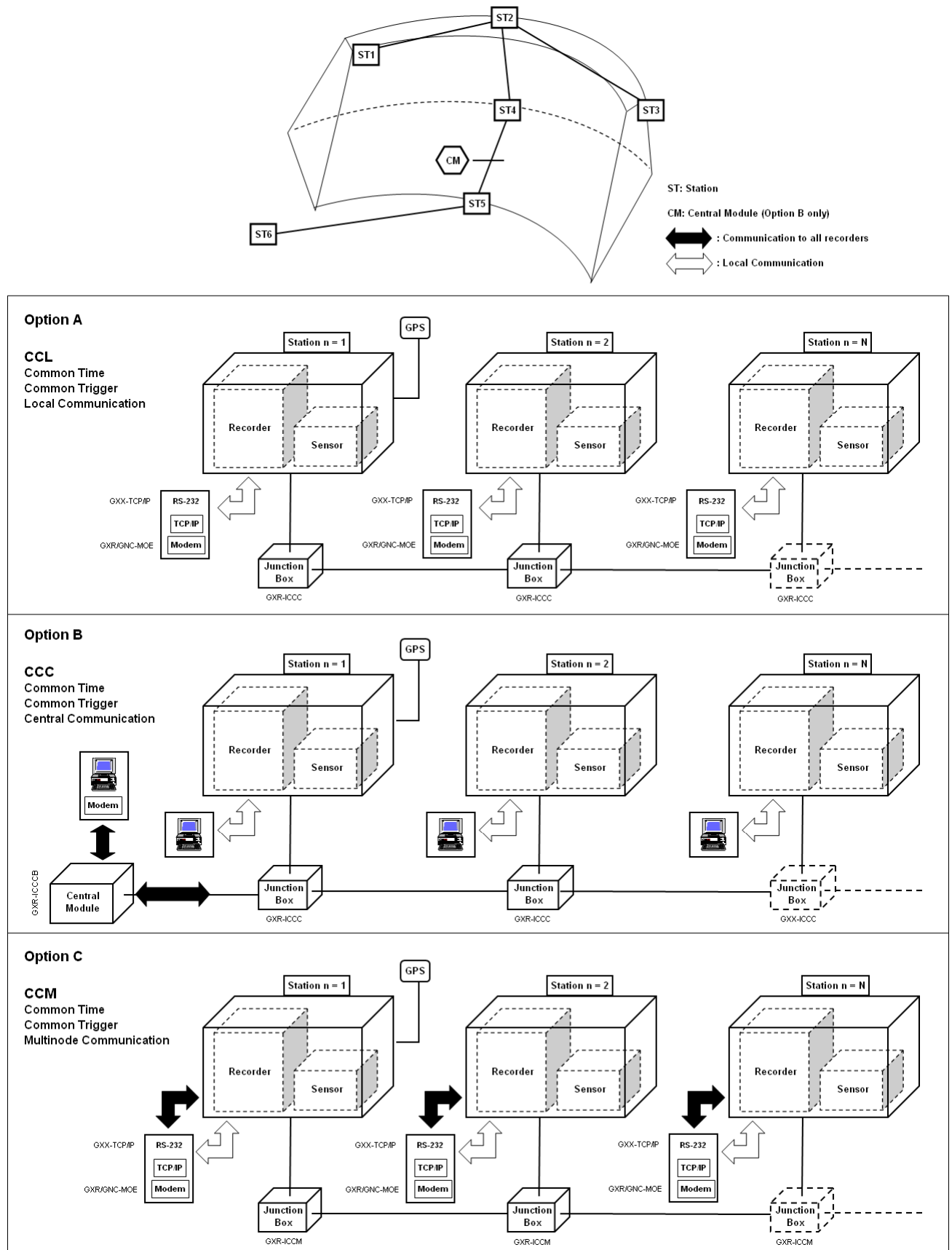


Figure 3. Topology of the Interconnected Recording Network Options

Comparison of options

Table 1. Functional comparison of interconnected network options

| Option | Common Timing | Common Triggering | Communication from | | |
|------------|---------------|-------------------|--------------------|-------------------|-------------------|
| | | | Local Recorder | | Central Module |
| | | | To Local Recorder | To Every Recorder | To Every Recorder |
| CCL | ✓ | ✓ | ✓ | | |
| CCC | ✓ | ✓ | ✓ | | ✓ |
| CCM | ✓ | ✓ | ✓ | ✓ | |

5. Central Recording Network

For this type of network, sensors installed at several locations are connected to the Network Centre where central recording equipment takes place as illustrated in Figure 4. Central recording is available in two options depending on the required ease of accessibility to data, storage space, and versatility in network administration and cost.

The analogue signal of every sensor in the network is transmitted through its own connection (star topology), continuously to the central recorder (optionally via a ±5 V differential voltage transmission or a 0-20 mA current-loop).

Option A: GNC-CR Central Recorder

Digitiser and Recorder Module Cards within the GNC-CR digitise and record the incoming data. Thus, all the data is stored in the Network Centre .

The operation mode of the GNC-CR is event recording as trigger levels are reached. The on-line surveillance, common triggering and time synchronisation for the network is accomplished by GNC-CR, which as well displays the status of each sensor on-line.

An optional Alarm Output can be defined in a way similar to selecting the event-recording trigger, thereby enabling the user to be informed immediately of the occurrence of an event or of a warning or error. Lightning and overvoltage protection is used for the sensors, and Network Centre. Other options for the GNC-CR include a GPS Receiver, and a landline or GSM modem.

Option B: CR-4 PC Based Central Recorder

Digitizer Module Cards within the CR-4 digitise the incoming data from the sensors. The digitised data then are recorded on an integrated industrial PC in the CR-4.

The operation mode of the CR-4 is event recording as trigger levels are reached, plus permanent recording into the ringbuffer taking the advantage of the integrated PC.

By monitoring continuously the sensors, CR-4 detects events depending on the software settings on the PC, generates associated alarms and automatically processes the recorded data.

The utilisation of a PC greatly improves task handling, data storage, communication and interaction capabilities as well as allows easy update of software, without reprogramming the firmware in the DSP.

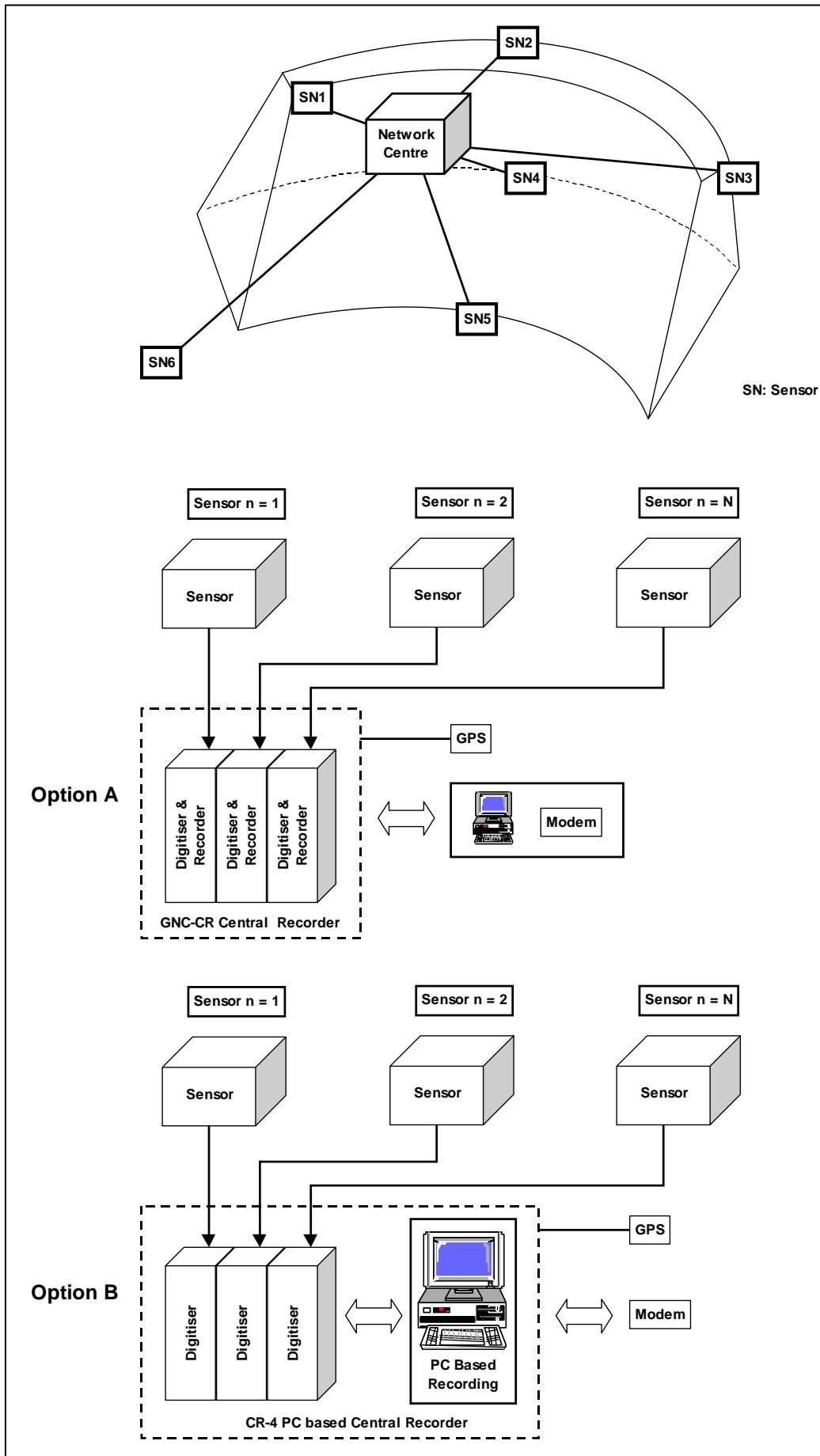


Figure 4. Topology of the Central Recording Network

6. Common Functionality in Instrumentation Networks

Optional features for each recorder in the Independent and Interconnected Recording Networks are:

- GPS receiver, which can obtain accurate real time (UTC)
- Landline or GSM modem, which can enable automatic dialling capability and allow external access and control of the system through a Network Centre
- Status printer to facilitate on-site printing.

Integration of one or more recorders in the local safety system (e.g. for generation of an alarm) is also possible.

Many of the functions (processor, time update, A/D conversion, etc.) of an instrument network are permanently and automatically checked internally. Other functions (sensor link, filter response, memory, etc.) may be checked periodically by the user. The system can be programmed to execute this periodic test automatically at periodic intervals or to disable it.

The optional Data Analysis Package of Windows-based GeoDAS software can be used to perform several functions using data obtained by any of these networks.

7. Further Options and Network Terminology

- Centralised Power Supply Option

In some applications power may not be available on every station site. In this case the power can be provided from the Central station through the network. A cable with two more wires for power is used in this case. Due to safety reasons only 48 VDC is made available on the network interconnection, which corresponds to the voltage on a public phone line. Within each station a galvanic isolation is implemented and the voltage is transformed to the required level needed by the switched power supply.

- Galvanic Isolation

There exist differences between ground potentials, which have to be considered. To avoid the adverse effects of such potential differences, the solution is to make sure that all the recorders have a galvanic isolation against each other. This isolation can be achieved by using a single twisted pair interconnection or a two fibre optic interconnection. In the case of twisted pair cables, the galvanic isolation is acquired by optocouplers and in the case of a fibre optic interconnection the galvanic isolation is accomplished by the fibre approach itself.

In any case the stations have to be connected to the local Ground (Protection Earth) and in the case of twisted pair interconnection cables a sufficient over voltage protection has to be installed.

- Over Voltage Protection

Over voltage protection prevents damages and disturbances caused by electrostatic discharges and lightning. The fibre optic interconnection approach needs no over voltage protection from the interconnection lines. However, a standard over voltage protection for the power supply of the station is recommended.

8. Physical Implementation of Interconnecting Hardware

After the required network type is defined, the physical implementation has to be considered. The most important issue to consider is the type of cable connection principle used between the network nodes as well as between sensors and recorders. The analogue sensor signal must be transmitted to the recorder over the distance between the sensor and the recorder. The single-ended voltage transmission is adequate for short distances. For longer distances either differential voltage or current-loop transmission must be used. The differential voltage transmission requires high impedance input, therefore it is obvious that the noise impact has to be considered. Current-loop transmission in the ranges of 0~20 or 4~20 mA are widely used in the industry. This transmission scheme is immune against noise impacts and furthermore different cable resistances do not influence the signals.

Following tables highlight the differences between physical network interconnection options for digital and analogue transmissions, respectively.

Table 2. Comparison between the digital network interconnections

| Principle | Low Signal '0' | High Signal '1' | Max. Distance | Galvanic Isolation | # of Masters | # of Slaves | Signals |
|--------------------|----------------|-----------------|---------------|--------------------|--------------|-------------|-------------------------------|
| RS-232 | < 3 V | > 3 V | 30 m | Optional | 1 | 1 | TxD, RxD, GND |
| RS-485 | U1 > U2 | U1 < U2 | 1000 m | Optional | 1 | 32 | A1, B1/ B1, B2 |
| Fibre Optic | no light | light | 2000 m | Integrated | 1 | 1 | Transmit Fibre, Receive Fibre |

Table 3. Comparison between the analogue network interconnections

| Principle | Negative fullscale | Positive fullscale | Max. Distance | Galvanic Isolation | # of Masters | # of Slaves | Signals |
|--|--------------------|--------------------|---------------|--------------------|--------------|-------------|-------------------|
| Single-ended Voltage Transmission | - 5V | + 5 V | 5 m | Optional | 1 | 1 | Signal, GND |
| Differential Voltage Transmission | - 10 V | + 10 V | 100 m | Optional | 1 | 1 | Signal, Reference |
| Current-Loop | 0 mA | 20 mA | 1000 m | Optional | 1 | 1 | Signal, GND |

9. Basic Guidelines to Construct a Strong Motion Instrument Network

To facilitate a systematic approach for network designers, a checklist is provided below, in which most of the points that are suggested to be considered are listed:

1. Network type

- Select the Network type depending on the basic needs for Common Timing, Common Triggering and communication scheme.

2. Network topology

- Number of stations to be interconnected
- Locations of the stations (dam, field, building)
- Maximum distance between the network nodes and between sensors and recorders

3. Interconnection

- Twisted pair (two lines), simple and cost effective (select cable with a total cable resistance of 100 Ohm)
- Fibre optic (two lines), more difficult to install and more expensive
- Requirement of centralised power supply for stations without local AC power

4. Recorder / Central Module / Network Centre features and options

- GPS receiver for Software Master
- Landline modem or GSM modem
- Status printer for any recorder
- Common alarm output
- Centralised data storing availability at Network Centre

5. Miscellaneous

- Galvanic isolation from the Software Master / Central Module to all the other stations in the network
- Over voltage protection (at least 1.5 kW (1 ms))