Chapter 3

HARDWARE OF
SUPERVISORY CONTROL & DATA ACQUISITION SYSTEM

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1. Introduction

A typical layout of supervisory control and data acquisition (SCADA) system was given and the following major components of SCADA system were identified in Chapter 1 on "Basics of Supervisory Control and Data Acquisition":

(i) Master terminal unit (MTU)

(ii) Remote terminal units (RTUs)

(iii) MTU-RTU communication subsystem

(iv) Field devices (FDs)

(v) RTU-FD communication subsystem

These components of SCADA system are discussed in detail in the following sections.

2. Master Terminal Unit

It is located in a central place, called control room, from where the complete process is supervised. It is built around one or more computers, which work as servers and workstations. Its major function is to monitor and control (supervise) the controlled process through a number of RTUs distributed throughout the process.

2.1 Schematic of MTU

A simplified schematic of MTU, depicting its basic components and their interconnections, is shown in Figure 1. At the heart of the MTU is a computer or computers, comprising both hardware and software. On one side, it is interfaced with operator(s) through human-machine interface (HMI) and, on the other side, to the RTUs through a digital communication network (data network) and a communication port, as shown in the figure.

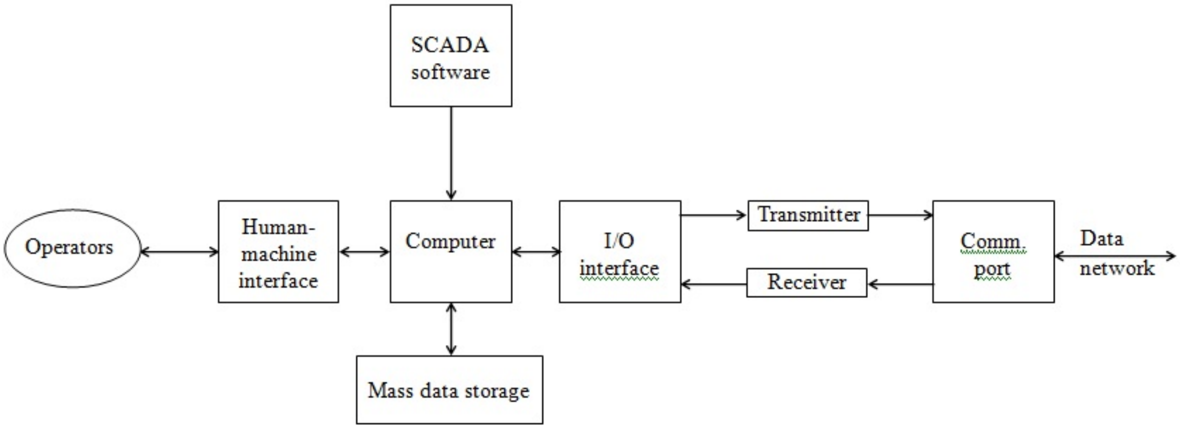

Fig. 1: Simplified schematic of MTU

The number of computers in MTU may be:

(a) ***Single Computer:*** Used exceptionally, because failure of the computer would lead to the failure of the complete SCADA system and thus the controlled process may have to be shut down.

(b) ***Dual Computer:*** Used as a rule to avoid shutting down of controlled process. In the event of failure of one computer (which is active), the other (standby) computer takes over immediately.

The number of processors in the computer may be:

(a) ***Single Processor:*** Rarely used.

(b) ***Multi-Processor:*** Almost always used. This gives the very important benefit that apart from a fast CPU, other processors are optimally designed to perform specific support functions. Thus, in addition to the CPU, the computer may typically have Maths processor, HMI processor and Communication processor.

2.2 Single-Processor Single-Computer MTU

The MTU is built around a computer having only one processor, namely, a central processing unit (CPU). It performs all the functions of CPU as well as the other functions like mathematics, HMI and communication. The architecture, shown in Figure 2, is rarely used, but it is described for easy understanding of the multi-processor single-computer MTU given in the next section.

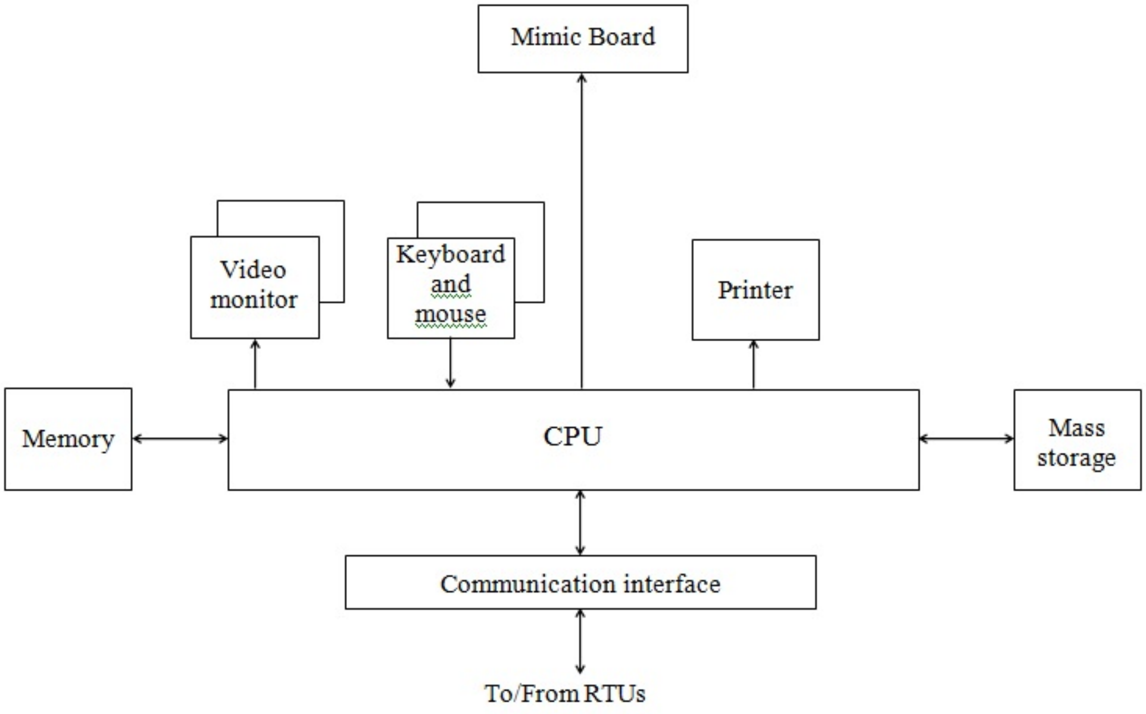

Fig. 2: Architecture of a single-processor single-computer MTU

Memory: Semiconductor memory (RAM and ROM) is essential for the operation of the computer. ROM is required for booting program. Any other program has to be brought to RAM for execution by CPU. RAM also serves as a scratch pad during data processing and as a buffer for input and output data.

Mass Storage: Holds all programs and data off-line.

Communication Interface: MTU communicates through it with RTUs.

Mimic Board: In old systems, a static mimic board was used to display the single-line diagram or a simplified diagram of the process showing major components and their interconnections alongwith process flow. In modern MTUs, there is a dynamic mimic board, which displays not only the process as above but the instantaneous values of the important variables and states of the most important objects on a huge LED or LCD screen.

Video Monitors: Multiple video LCD or LED monitors, 21-inch or larger in size, are connected in the system, on which the operators can see the details of any part of the process or study trends of specific variables etc. through menu-driven software.

Keyboards: Each monitor is usually paired with a keyboard so that the operator (if authorized to do so) can type commands or values.

Printer: Connected for allowing hard-copy of any report generated by the MTU.

The mimic board, video monitors, keyboards and printer are the HMI devices (peripherals) commonly used in the control rooms.

2.3 Multi-Processor Single-Computer MTU

A multi-processor configuration is always preferred to single-processor configuration. In addition to the general purpose and fast CPU, more processors designed to carry out support functions are added. They include (typically) the following as shown in figure 3:

(i) A maths processor designed to perform floating-point arithmetic operations at a fast speed.
(ii) A communication processor designed to handle communication with RTUs.
(iii) An HMI processor, designed specially to carryout I/O operations with peripheral devices for HMI.

Various HMI devices shown in Figure 3 are identical to those discussed in Section 2.2 and all of them are interfaced to the HMI processor.

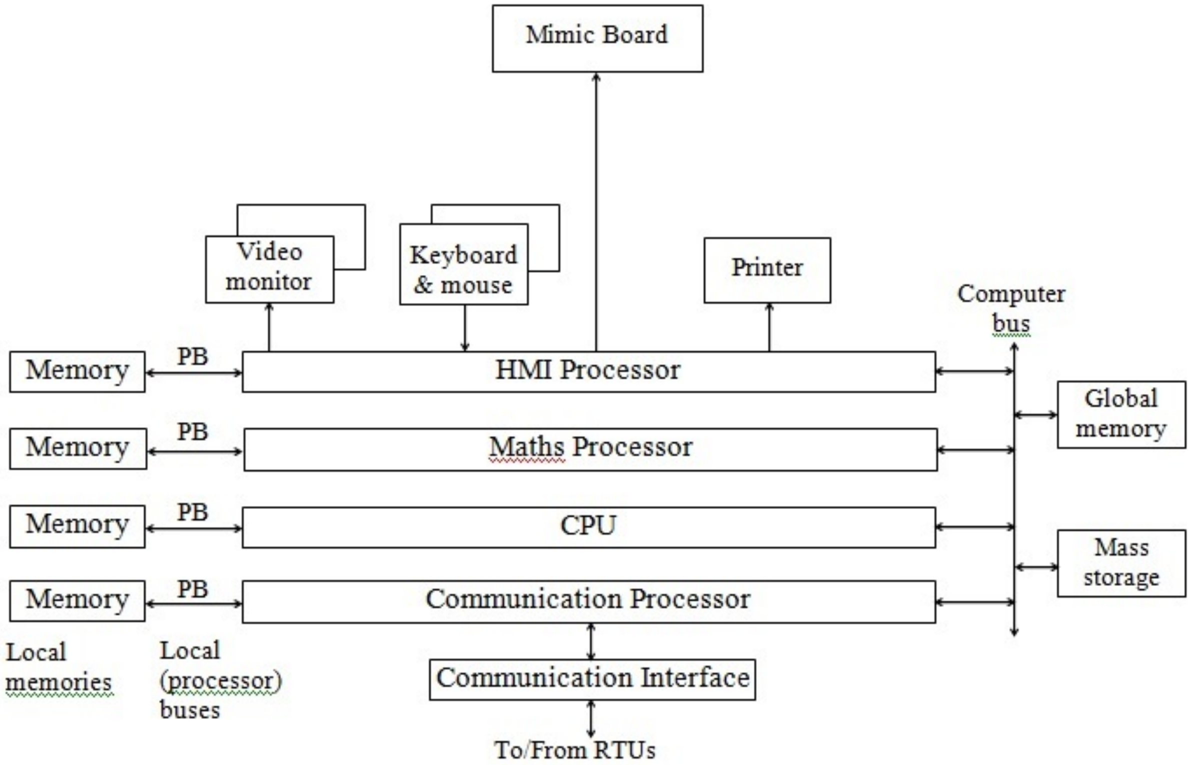

Fig. 3: Architecture of a multi-processor single-computer MTU

Each processor is supported by its local semiconductor memory connected through the processor bus. All the processors, global memory and mass-storage are inter-connected through a common computer bus. The mass-storage stores all the programs and data off-line. Data sharing between various processors takes place through global memory (RAM).

2.4 Dual-Computer MTU

As a rule, MTUs use two computers in one of the following two modes:

(a) Primary-backup computer mode
(b) Parallel-computer mode

2.4.1 Primary-Backup Computer Mode

In this case, the backup computer used is less capable than the primary computer to save cost. So, obviously when the primary computer fails and the backup computer takes over, some of the functions performed by the primary computer become unavailable.

The primary computer which is normally in use, performs the following functions:

(i) It receives data from RTUs.
(ii) It processes the data received from RTUs.
(iii) It sends control instructions to RTUs.
(iv) It transfers results of data processing to the backup-computer regularly.

In the event of failure of the primary computer, the backup computer takes over. There is a small interruption as the backup computer needs to perform data processing before sending control instructions. While the primary computer is carrying out SCADA functions, the backup computer is often put to some secondary (non-SCADA) jobs like operator training, maintenance, salary accounting, inventory management, etc.

2.4.2 Parallel-Computer Mode

In this case, the two computers are identical and hence there is no loss of functionalities when one of them fails. Obviously, this solution is more expensive than the primary-backup solution.

In this mode, both the computers receive data from RTUs and both of them process the data, but only one of them sends control instructions to the RTUs. When this computer (which is in the control of the process) fails, the control functions are also taken over by the second computer, that is, the control instructions are now sent to RTUs by this second computer. Thus there is no interruption or loss of time and there is no loss of functionalities.

3. Remote Terminal Unit

These are located in the field (inside the plant), distributed throughout the process and interfaced with the process through field devices. The RTU has two major functions:

(a) To acquire data from the controlled process through sensors, process it, and keep the processed data in memory and transmit the same to the MTU on demand.

(b) To receive control instructions in the form of control signals and set points from the MTU and deliver the control signals to actuators and the set points to automatic controllers.

An RTU is built around a microprocessor or a micro-controller. Instead of designing and manufacturing RTUs specifically for this purpose, PLCs are very often configured and programmed to work as RTUs. The reasons for this practice are as follows:

(a) PLCs are manufactured in a wide range of sizes and capabilities, including easily expandable modular configurations.

(b) PLCs can in general perform all the functions required of RTUs.

(c) Prices of RTUs are low because of their widespread use in industrial and process controls.

3.1 Inputs and Outputs of RTU

As explained earlier, an RTU is connected to the MTU-RTU data communication network on one side and to various field devices on the other side. This is illustrated in Figures 4(a) and 4(b).

(i) Inputs to RTU from Ordinary Field Devices

As shown in both the figures, there are two types of inputs from ordinary (un-intelligent) field devices to the RTU:

(a) ***Analog values*** of controlled and uncontrolled variables in the controlled process obtained through analog sensors.

(b) ***Status information*** of remotely and locally controlled objects in the controlled process obtained through status sensors.

(ii) Outputs from RTU to Ordinary Field Devices

As shown in both the figures, there are two types of outputs from the RTU to the ordinary (un-intelligent) field devices:

(a) ***Discrete control commands*** to the actuators of the remotely controlled objects in the process, that is, the objects to be controlled from MTU.

(b) ***Set points*** to the closed-loop controllers of the controlled variables in the process.

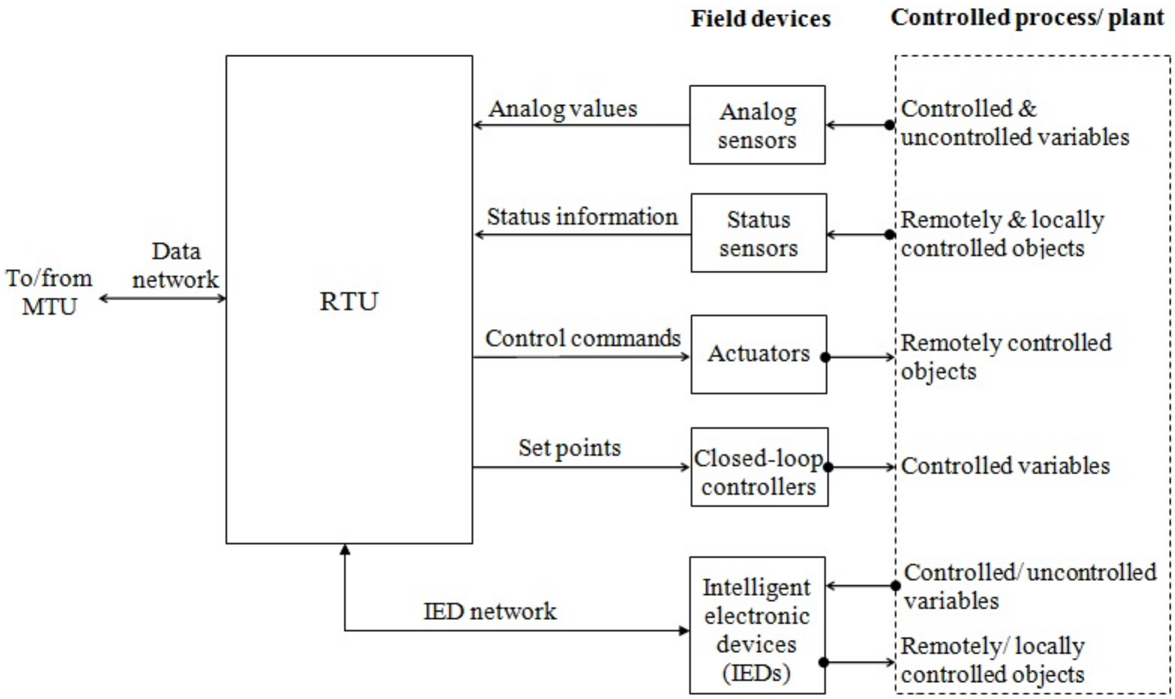

Fig. 4(a): Inputs and outputs of RTU, IEDs communicating through RTU

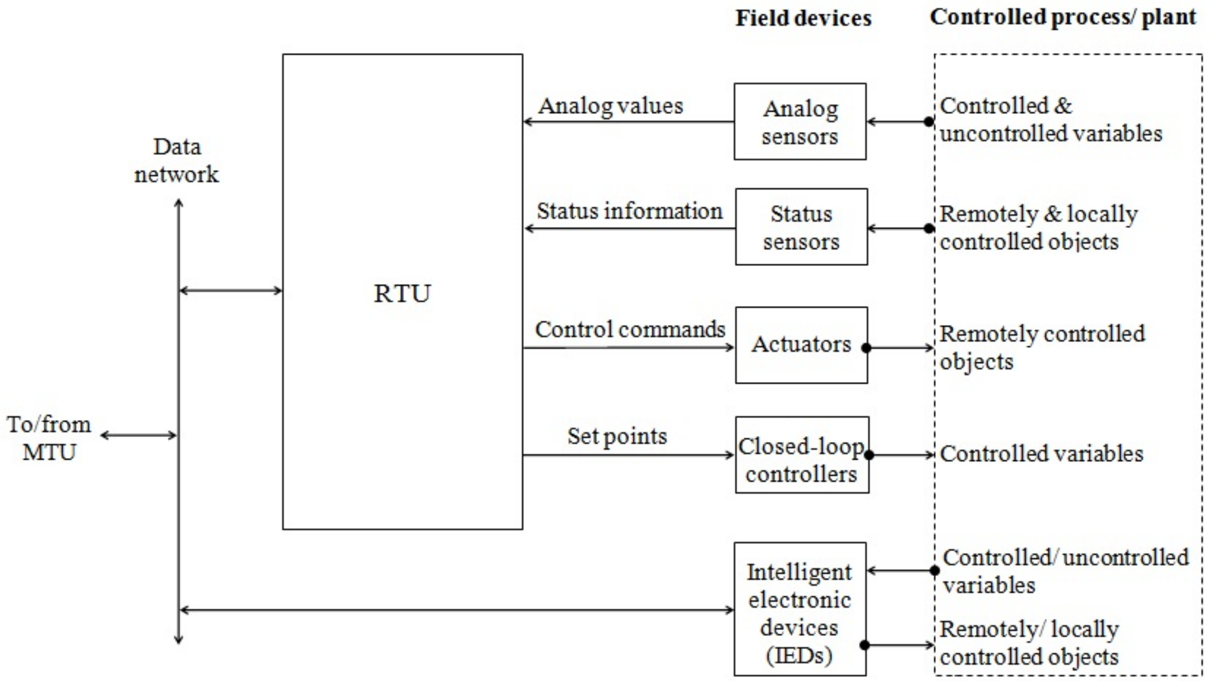

Fig. 4(b): Inputs and outputs of RTU, IEDs communicating directly with MTU

(iii) Communication with Intelligent Field Devices

If any of the field devices are intelligent electronic devices (IEDs), equipped with data communication port or network connectivity, they can communicate with the RTU on a LAN created for this purpose. Thus these IEDs communicate with the MTU through an RTU to which they are networked. This type of arrangement is illustrated in Figure 4(a). Alternatively, the IEDs can communicate with the MTU directly, as shown in Figure 4(b). Some examples of the IEDs are the intelligent digital protective relays, digital feedback controllers, sequence-of-events recorder, alarm annunciator, smart multifunction meters, smart sensors and intelligent actuators.

3.2 Architecture of RTU

Smaller RTUs are built with fixed architecture and generally around an 8-bit microprocessor or microcontroller. Larger RTUs are designed with modular architecture and around a 16-bit microprocessor or microcontroller. As explained earlier with reasons, programmable logic controllers (PLCs) are very often configured and programmed as RTUs.

The modular architecture of a typical large RTU is shown in Figure 5. As shown, the system bus is used to interconnect the CPU and the various modules, which are briefly described below:

(a) ***CPU:*** The bi-directional data bus of the system originates from the CPU, which is usually a 16-bit microprocessor, but sometimes an 8-bit microprocessor.

(b) ***RAM Module:*** The semiconductor RAM (or RWM) is meant to be used as a scratch pad by the CPU during program execution as well as for holding any variable data. Its modular design allows us to use a memory size as per the needs of application.

(c) ***ROM Module:*** The semiconductor ROM (or PROM or EPROM) is meant for storing all programs and fixed data, such as various constants needed in the calculations and the system information, both of which do not change during program execution.

(d) ***Communication Module:*** It handles bi-directional communication with MTU over a data network. Generally, more than one communication ports are available to give flexibility in choosing the network protocol.

(e) ***Analog Input Module (AIM):*** It handles the analog signals representing analog values coming from analog sensors. The module has necessary signal conditioning circuits, a multiplexer, sample and hold circuit and ADC, along with other circuitry required for multi-channel data acquisition. It is generally designed for 4 to16 analog input channels.

(f) ***Digital or Discrete Input Module (DIM):*** It handles the digital (binary) inputs representing status information coming from status sensors placed on or connected to the remotely and locally controlled objects. The module has necessary input ports and interface circuitry for reading the status information into the system. It is generally designed for 8 to 32 binary inputs (often called as digital input lines).

(g) ***Digital or Discrete Output Module (DOM):*** It is designed for outputting discrete (binary) command signals to the actuators of remotely controlled objects. It has necessary output ports and interface circuitry for handling 8 to 32 binary outputs (often called as digital output lines).

(h) ***Analog Output Module (AOM):*** It is designed for outputting set points in analog signal form. The CPU outputs the digital values of set points to this module, which has DACs and interface circuitry to convert the digital values to analog signals in standard form, e.g. 4-20 mA signals. The module is designed generally for 2 to 8 analog output channels.

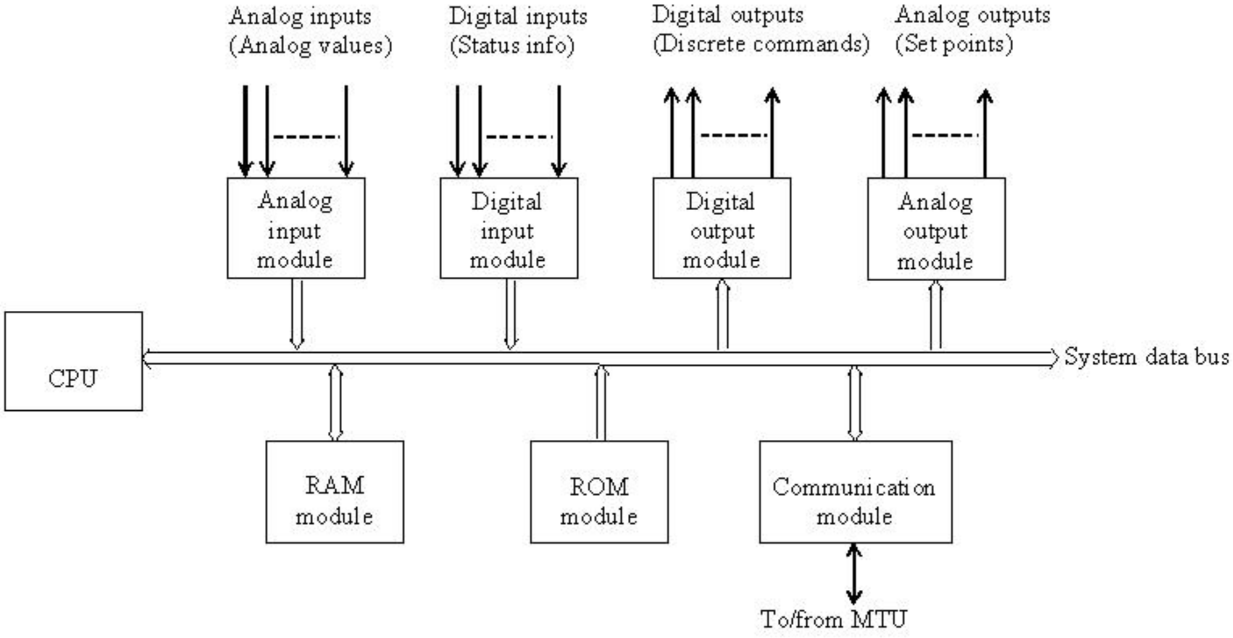

Fig. 5: Architecture of a modular RTU

4. MTU-RTU Communication Subsystem

Providing separate links from RTUs to the MTU would have following disadvantages:

(a) Cost of laying cables (copper or optical fibre) would be very high.

(b) The number of communication ports required on the MTU would be equal to the number of RTUs, which would be unmanageable and cost too much.

Therefore, a digital two-way data communication network connecting the MTU with RTUs is used. However, depending on the size of the process/ plant, three different solutions can be considered:

(a) Local Area Network (LAN)

If the process is within single premises, a LAN can be built, as illustrated in Figure 6.

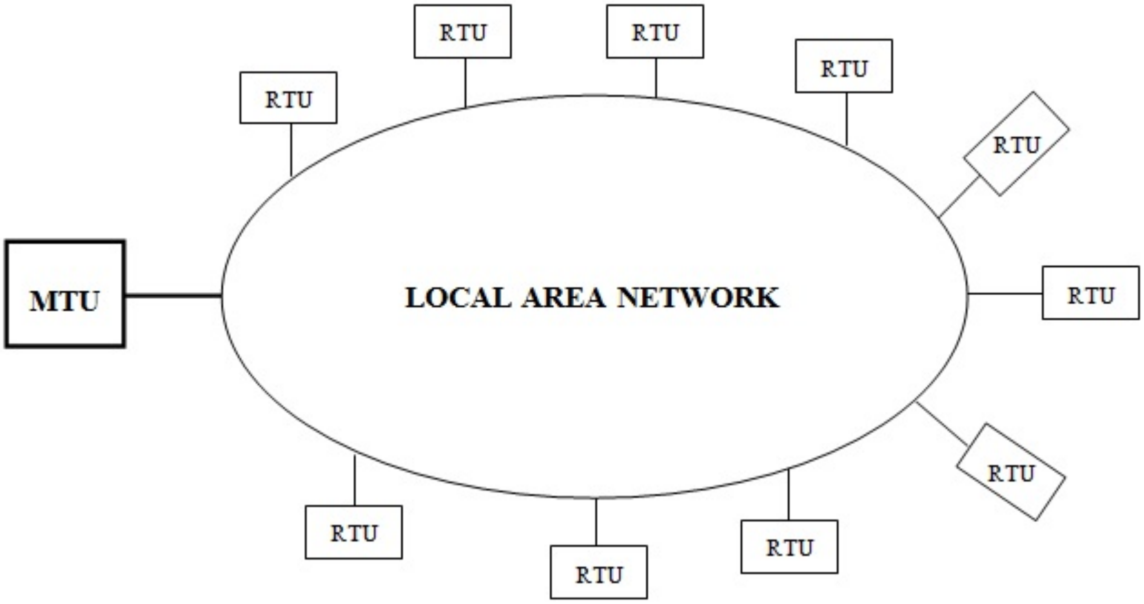

Fig. 6: MTU-RTU Communication through LAN

(b) Wide Area Network (WAN)

In those cases where the process is distributed over several sites, a WAN can provide a good solution. This is illustrated in Figure 7. Typically, each site will have a LAN and these LANs will be inter-connected through some existing public communication networks or lines, thus forming a WAN. Thus the WAN would usually

(a) include both private and public communication infrastructure,
(b) use more than one communication technology, and
(c) involve several types of signal transmission media (copper cable, radio link, optical fibre cable).

Since the data would flow through public communication networks/ lines, the data security issues of the SCADA system need to be considered carefully WAN is opted.

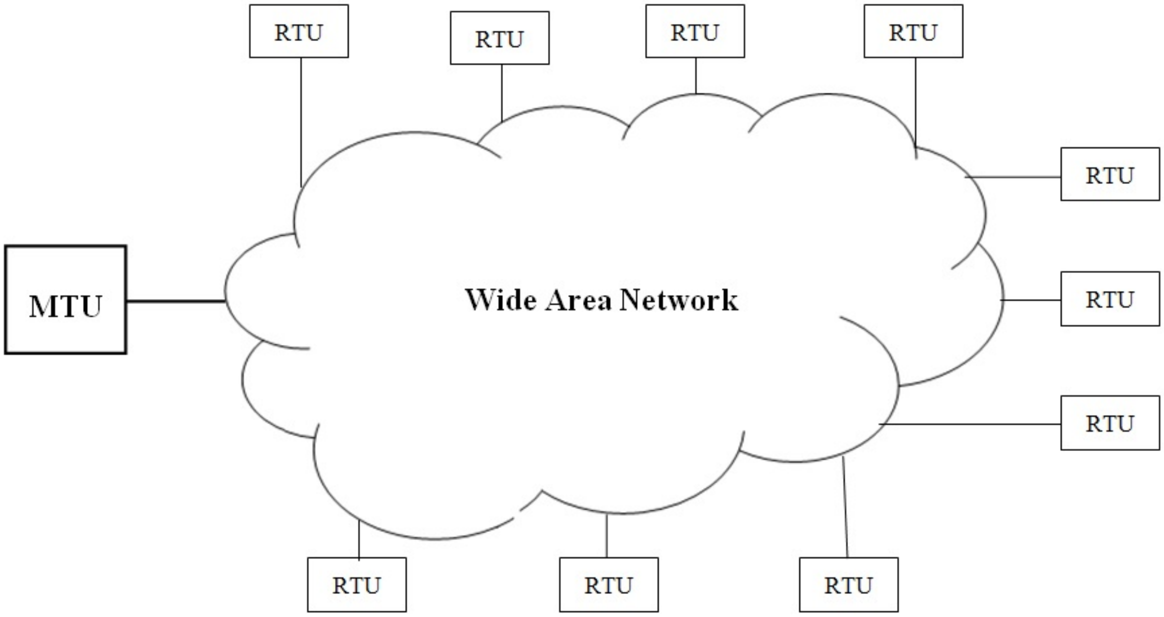

Fig. 7: MTU-RTU Communication through WAN

(c) Internet

For a very extensive process, like a public utility spread over a large country or several countries, Internet can provide the most economical solution. But the data security could be an extremely difficult issue to handle.

5. Field Devices

These devices are located in the field (i.e. in the plant) and serve as interfaces between a RTU and the controlled process. These may typically include the following:

(a) ***Analog Sensors*** for sensing analog variables, like temperature, pressure, force, torque, power, current and frequency sensors.

(b) ***Status Sensors*** for sensing the status or positions of controlled objects and usually give a binary output. Examples are proximity switches, auxiliary contacts, level detectors, limit switches, etc.

(c) ***Linear and Discrete Actuators*** for correcting the controlled variables and operating the controlled objects, respectively. Example are solenoids, stepper motors, servo-motors, special electro-mechanical devices, electromagnetic relays, reed relays, solid-state relays, circuit breakers, contactors, electro-pneumatic and electro-hydraulic actuators, and so on.

(d) ***Feedback Controllers:*** Set-points for these controllers are decided by the MTU and sent either through to RTUs or directly. Sometimes, a feedback controller is implemented inside and forms part of an RTU.

(e) ***Intelligent Electronic Devices (IEDs):*** These are microprocessor-based devices equipped with a data communication port. Examples are intelligent digital protective relays, digital feedback controllers, sequence-of-events recorder, alarm annunciator, smart multifunction meters, smart sensors and intelligent actuators. They can communicate with the RTU on a LAN. Thus their communication with the MTU is through the RTU to which they are networked. Alternatively, the IEDs can communicate with the MTU directly on a separate LAN.

6. RTU-FD Communication Subsystem

One of the two types of communication is used between an RTU and the associated field devices: analog communication and digital communication. Combination of the two is also not uncommon.

6.1 Analog Communication

The input to or the output from ordinary (un-intelligent) field devices is a dc voltage or current signal. Accordingly, the traditional control systems, distributed control systems and early SCADA systems commonly use 24-V voltage signal for communication with discrete field devices (like proximity sensors and solenoid-operated valves) and 4-20mA current signal for communication with linear or analog field devices (such as temperature/ pressure/ level transmitters and modulating valves). However, this analog communication approach involves cumbersome, time-consuming and expensive cabling and makes the maintenance of connection cables and terminals a very difficult task.

6.2 Digital Communication

If digital or data communication is used between an RTU and the associated intelligent electronic devices (IEDs) in the field, only a single cable with one or two twisted pairs of conductors would generally suffice to connect them together in a network. The data rates required here are generally quite low and distances are short. Depending on the network size, either a LAN (local area network) or a PAN (personal area network) can be set up. Alternatively, a wireless network technology can be used, which would need no cabling but require appropriate data security measures to be incorporated.