Operating Benefits Achieved by Use of Advanced Communications Protocols for DA/DSM Systems

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ABSTRACT

Distribution Automation **(DA)** and Demand Side Management **(DSM)** systems are increasingly being introduced by electric utilities. Implementation of these modern systems helps provide more reliable supply of power reducing utility operating costs, and enhancing both customer and employee satisfaction. One of the most important building blocks of such systems is the communications network. Advanced communications solutions provide services that were not available in the past. In addition to fulfilling the main functions, the same data network may serve as a communications backbone for Automated Meter Reading **(AMR).** [10)]

In radio frequency **(RF)** based DA systems, Remote Terminal Units **(RTUs)** should primarily operate in contention mode (i.e. the RTU initiates transmission when the channel is not busy). This allows fast response and efficient sharing of the media by a large number of RTUs.

In order to allow execution of smart fault detection functions, these RTUs must be time synchronized and send time stamped messages. Use of advanced communications protocols allows implementation of; time synchronization via the media, networking features, remote diagnostics and remote up and down downloading of programs, parameters and databases. This process should be possible without interrupting the normal operation of the system.

This paper focuses on the main considerations and benefits of *advanced communications protocols* used for monitoring and control of DA power grids, DSM and AMR systems.

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1. Introduction

Electric power networks require a modern communications system to provide a base for improved monitoring and management. However, many utilities tend to view Supervisory Control and Data Acquisition **(SCADA)**, Distribution Automation **(DA)**, and Demand Side Management **(DSM)** systems only as tools for improved remote control and status indication.

Experience shows, that DA systems play an important role by providing a means for sophisticated monitoring of Medium Voltage **(MV)** distribution grids. In these systems, communications helps assure quick fault detection and service restoration.

Field installed Remote Terminal Units **(RTUs)**, provide means for remote control of the MV switchgears, capacitor banks, fault detection devices, etc., and also allow execution of smart corrective actions to changes in the power network. Providing advanced RTUs for these systems allows greater utilization of personnel, cost savings, improved reliability, fewer shortages, more reliable operation of the system and enhanced customer satisfaction.

When evaluating their future investment in communications for DA, DSM and Distribution Management Systems **(DMS)**, electric utilities ask some very basic questions: [9)]

- Which *specific needs* are to be served, and which new *goals* are to be achieved?
- What are the *various alternative solutions,* and *w*hich one is the *best-in-class*?
- Will the system handle *critical /extreme events* in an optimal way?
- How much will *system upgrade cost,* and which are the *practical alternatives*?
- What *added value and benefits* are achievable with the selected system?
- What will be the future *migration* path with this system?
- How will the system utilize *future communications solutions*?
- Will the solution achieve *cost savings* and higher *customer satisfaction*?
- Is there a need for a *consultant* to help guide decisions?
- Which *vendor* can the utility trust for providing them a long lasting solution?
- How to calculate the *cost benefits* and *return on investment*?

This paper does not deal with all these questions, but focuses on the main considerations and benefits of *advanced communications protocols.*

2. Selection of Communications Protocols

DA system implementation often starts from a small, pilot system, which is later expanded. Considering this fact, it is the opinion of the authors, that selection of the right protocol is very important. One must take this into consideration already at the pilot phase.

Integration of a modern system requires use of a seven layer protocol that was designed according to the guidelines provided by the International Standards Organization **(ISO)** for Open Systems Interconnection **(OSI)** systems**.** The ISO/OSI protocols separate the communications functionality from the application functionality.

By using the layered protocol approach in DA systems, the programmer will not have to deal with diagnostics, networking, error correction, message retry mechanisms, etc. These are automatically taken care of by the protocol structure, and as a result, the system programmer has to worry only about his application.

Layered protocols allow for future system expansion and improvements to the product without losing the investment spent on the initial installations. Improvements such as secure communications, time-tagging support, synchronization via the network etc., can be added to the specific layer, completely separate from the application program.

3. Unique Protocol Features

Use of seven layer type protocols in radio frequency **(RF)** communications based SCADA and DA systems is very innovative. It allows designing advanced systems, in which the communications is optimized for the specific application and type of media. This allows a large number of RTUs to share the same infrastructure and the available RF channels.

3 . 1. Protocol Structure

A seven-layer protocol which is specially designed for RF communications may offer a grade of data reliability over radio similar or superior to that encountered using wireline communications. The Motorola Data Link Communications protocol **(MDLC)** is especially suited for SCADA and for integration of multiple media into a single network. The basic structure of the MDLC protocol and the tasks of the different layers are shown in Figure 1.

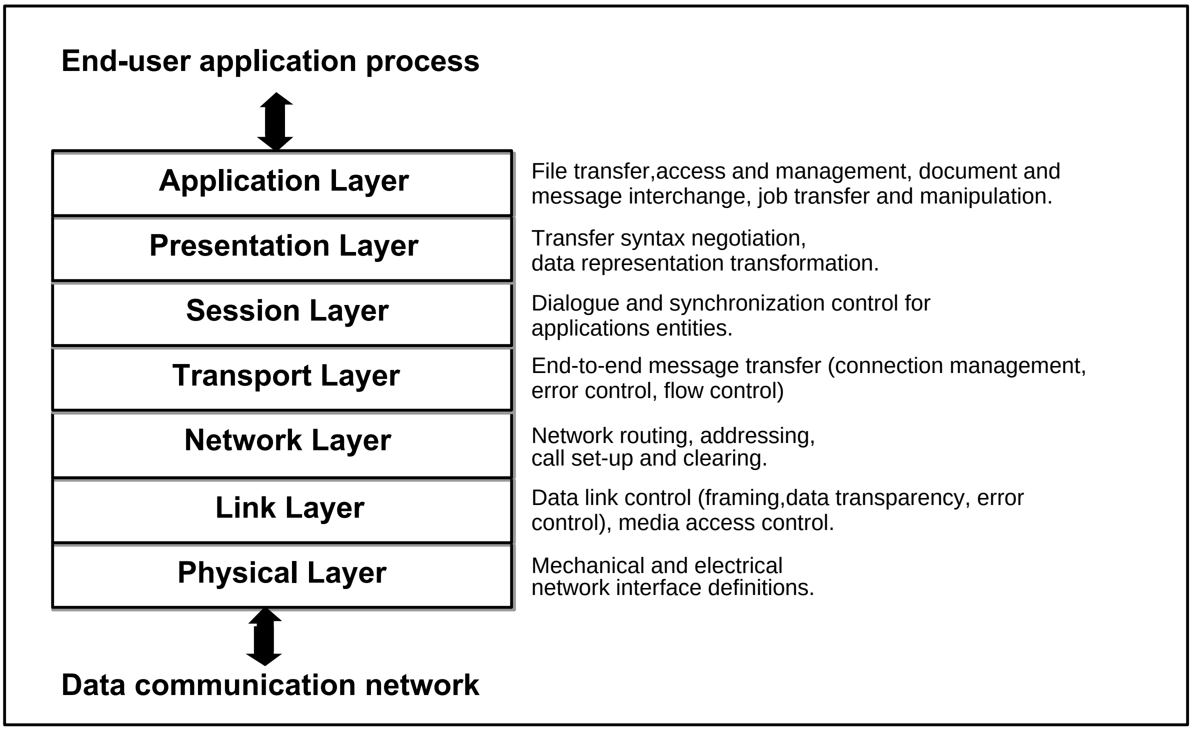


Figure 1. OSI/ISO protocol structure

3 . 2. Data Reliability

The basic reliability of the seven layer protocol is built into the Link Layer. In a radio environment, it is imperative that a powerful CRC-32 error detection code is appended to every transmitted frame. This error detection mechanism makes it virtually impossible for a frame containing a digital transmission error to go undetected by the receiving RTU.

Upon reception of a message, every frame is checked for errors. If no errors are detected, the frame is passed to the upper layers of the protocol, for further handling. A positive acknowledgment is then issued, to the transmitting RTU side. If an error is detected, no acknowledgment is issued and the frame is discarded.

If an acknowledgment is not received, the transmitting end resends the related frame. This is called a *link retry*. If, for example, the probability of losing a frame in a given channel is equal to 1% and the number of retries is set to four, it can be shown that the probability for a frame to be incorrectly received (after the original transmission and the subsequent four retries) is on the order of $1x10^{-10}$.

3 . 3. Alternate Routing

The next level of end-to-end data reliability is provided by the network and transport layers. The network layer is responsible for routing the information through selected RTUs in the system, which act also as communication nodes. It should be emphasized, that one of the roles of the network layer is to establish an alternate communications path (between end points), in case the primary data path becomes unusable. See Figure 2.

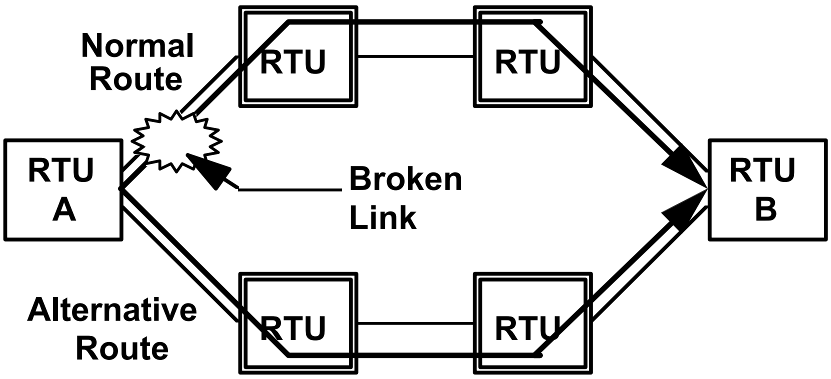


Figure 2. Communication path restructure

The communication between RTU "A" and RTU "B" is done using the upper path of RTUs, which act as communication nodes. Assume now, that this path fails. Consequently, in order to allow information flow between "A" and "B", the Network Layer will automatically activate the lower path (through the other RTUs, also acting as nodes) The result is, that a problem in the upper link does not result in entire system failure.

3 . 4. Message Integrity

The transport layer's responsibility is for end-to-end integrity of the information. If the transport layer at the receiving RTU detects a 'gap' in the received frames, then, after a predetermined time-out it requests the originating RTU to resend *only* the missing information. This process is known as a *transport layer retry*. A full frame retry will occur only when part of the information is lost due to an interruption somewhere in the network. As a result, such re-transmitted frames might arrive at the destination in the wrong order.

When this event occurs, the transport layer at the destination side will “organize” all the acknowledged (error-free) frames in the correct order, and deliver them to the upper layers. The retry mechanism at the transport layer offers this supplementary protection so as to guarantee the *end-to-end integrity* of the transmitted information.

If, due to numerous retries, the time is “too long” the application may request that this message be discarded. This type of requirement is very typical in DA systems.

3 . 5. System Synchronization

The Session layer offers extra protection by synchronization of lenghty transactions. This is of major importance, particularly when an interference causes an interruption in the midle of a transmission. Synchronization by the session layer allows the application to continue sending the message from the point where the communication was interrupted, without the need of starting message transmission all over again.

4. **Communication Protocols for DA**

The fact is, there is no standard protocol for SCADA communications. Different SCADA and RTU vendors offer numerous implementations of three layer and seven layer protocols. However most of these protocols are not compatible with each other.

4 . 1. Protocols types

Protocols used in systems such as the DNP-3 and others, implement only three layers: Physical, Link, and Application. This leaves out the most important function; the *built in Networking layer* function. Without this feature, the data network can not route messages between the RTUs and the MCC. In addition, due to lack of separation between the communication functionality and the application, the programming of the system is more complicated, costs more, and is less “open” for later upgrades.

4 . 2. Advanced Seven Layer Protocol

It is important to differentiate between radio/wireless and other media. The MDLC is a modern seven layer protocol, especially suited for SCADA applications, RF communications and for integration of multiple media into a single network. It is suitable for DA and DSM applications, since it allows fast and reliable reporting via the RF channel.

While physical media such as lines, fiber-optics, etc., are almost free of interference, radio waves are subject to natural noises that cause errors. Due to its built-in transport and session layers, the seven layer protocol (compared to three layer protocols) supports networking features, and efficient operation in multitasking environments. Without having these layers integrated into the protocol, Remote Terminal Units **(RTUs)** can handle only single-task communications. Obviously this method is less efficient and "consumes" more channel time.

5. Performance comparison

Availability of a wide range of RF solutions (Conventional and Trunked radio, Multiple Address Systems, etc.), and data protocols might create a great deal of confusion. The considerations for selection of an appropriate communications medium and data protocol need to be properly explained, since communications affects the overall performance of the system. The following outlines the most critical and important considerations that were selected for the purpose of comparison. [1) 2)]

5 . 1. System throughput for lengthy messages

The ideal protocol for DA and DSM applications should have the capability to communicate variable length messages, and its throughput should be unaffected by the message length. The selective retry mechanism of the MDLC protocol at its link layer makes it well suited for short and long transactions. The number of frames sent during a single transmission can be programmed, and if an error occurs only frames received in error are retransmitted. Other protocols used in DA systems such as DNP-3, use a stop-and-wait mechanism by which the next frame is transmitted only if the previous frame was successfully received. Figure 3 on the next page expresses the (relative) time needed to perform transfer of a 5 Kbyte message as a function of the bit error rate in the channel.

5 . 2. Calculation of channel needs

Selection of the channel access method will obviously affect the "air time utilization" and the total channel loading. The channel access mechanism at the link layer of the MDLC protocol allows very fast update of the database and display at the SCADA central.

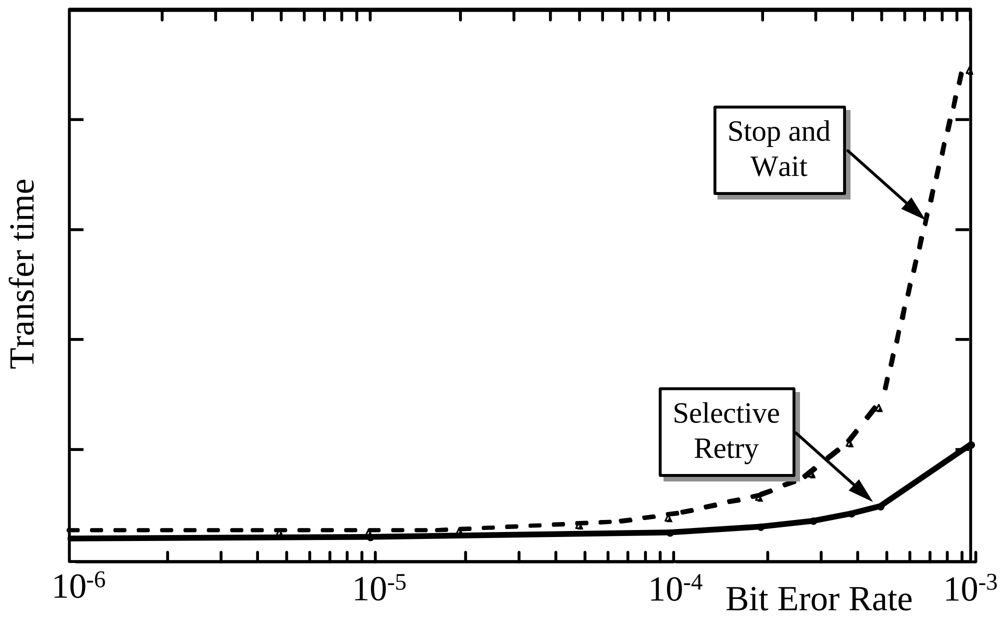


Figure 3. Selective re-transmissions versus stop-and-wait.

Figure 4 shows results of simulation for a system using variable data rates. The charts present the average delay for the MDLC protocol transmitted via radio at various channel bit rates, compared with a polling scheme that uses 9600 bps.

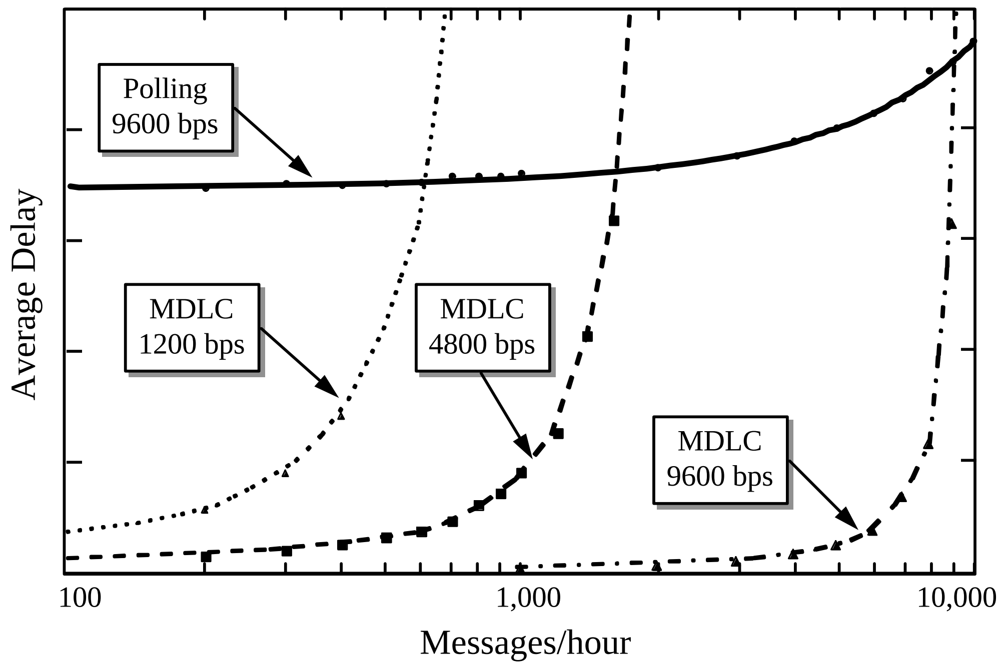


Figure 4. Polling vs. contention type reporting

5 . 3. Sorting messages during “avalanche” condition

It has been argued, that in a contention environment, a sudden avalanche in the system, (i.e., multiple RTUs transmitting simultaneously), results in severe uncontrollable performance degradation. MDLC uses a modification of the well-known Carrier Sense Multiple Access **(CSMA)** channel access control method, in order to avoid this catastrophic behavior. In MDLC, the time needed to resolve an avalanche situation is almost linearly proportional to the number of RTUs involved in the avalanche. Figure 5 illustrates the behavior of a system using the MDLC protocol and compares it with the normal behavior of another (similar type) system using non-persistent CSMA method.

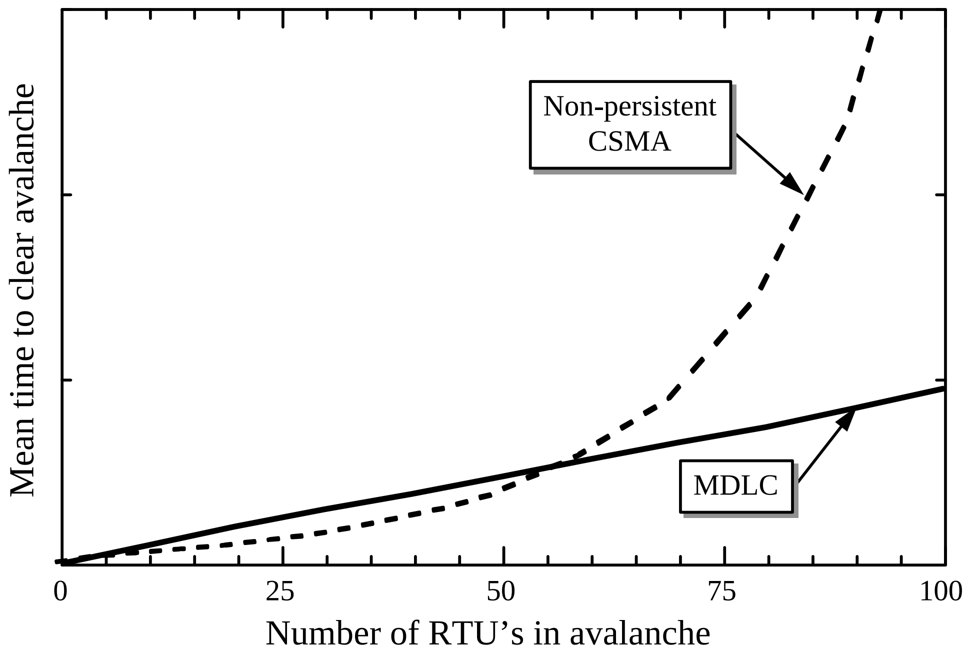


Figure 5. MDLC vs. non-persistent CSMA

6. **Protocol Interface to Master Control Centers**

The main component in a Distribution Management System **(DMS)** is the Master Control Center **(MCC).** It can consist of a single site computer or a multi-site networked system. In a typical system, the RTUs are linked to each other and to the MCC via one or multiple communications media (radio, lines, fiber-optic, etc.), integrated into a single network.

The operation of the DA systems depends very much on the communication performance. Following are some of the most important characteristics of such network:

1. Fast *reporting on alarms* generated by a field event
2. Fast communication for commands initiated by the *MCC*
3. Efficient handling of "avalanches" (i.e., simultaneous reporting by many RTUs)
4. In RF based DA and DSM, air-time efficient polling of all the RTUs
5. Provision for redundancy in the communication network
6. Additional operating features such as:
   - ◊ Efficient integration of multiple media into a single network
   - ◊ Transmitting simultaneous messages to all or a selected group of RTUs (broadcast)
   - ◊ Peer-to-peer link involving any pair of RTUs (using more than one media).
   - ◊ Providing 100 % Communication coverage using Store & Forward **(S&F)** solutions
   - ◊ Efficient solutions for remote maintenance of RTUs via the communication channel

In 6.1- 6.3 three connectivity concepts between RTUs and MCC are described:

6 . 1. Use of a Protocol Driver in the MCC

One option to interface the MCC to the RTU network is by installing a special software driver inside the SCADA computer. The advantage of this solution is, a more "direct" connection between the MCC and the RTUs, since the MCC communicates with the RTUs using their native protocol. However, altering the standard SCADA package by adding a communications driver is not a preferred option, since the SCADA packages become "tailored" to the driver. Once the vendor of the application package changes the software version, it might become necessary to perform changes also in the MCC protocol driver.

6 . 2. MODBUS Interface

The system may use any SCADA application which supports the MODBUS or MODBUS Plus type protocol. It must be noted that transmission of time stamped messages is not supported by the standard version of the MODBUS protocols. As seen in Figure 6, the MCC on the right side of the figure interfaces to the MDLC based RF network via a MODBUS- MDLC Front End unit.

In case the selected MCC uses the MODBUS Plus protocol, there is a need to use a MODBUS Plus to MODBUS gateway, which interfaces to the MODBUS Front End unit.

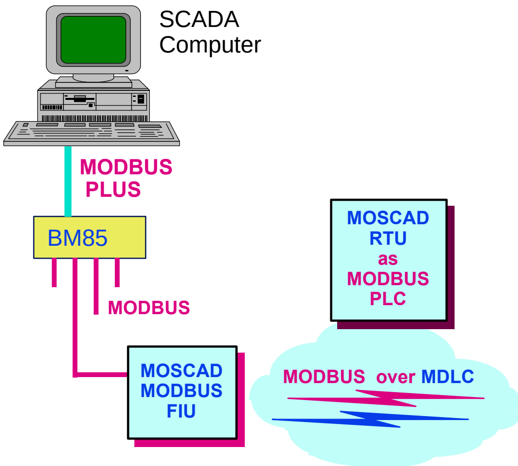


Figure 6. MODBUS type Interface to a Wireless System

6 . 3. TCP/IP over Ethernet LAN Protocol

In wide area DMS systems advanced tier MCCs operate in a LAN configuration, using the TCP/IP industry standard interface. This allows connecting several operator terminals, storage media and peripheral devices into a single integrated network. The MDLC based TCP/IP Gateway allows seamless connection to field terminals - RTUs via radio and other media. See Figure 7 for illustration of connectivity to a UNIX based MCC.

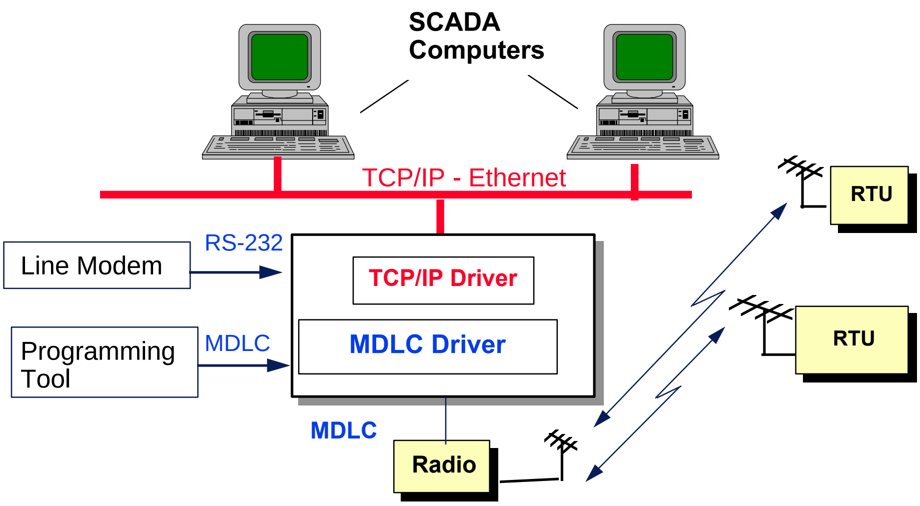


Figure 7. TCP/IP based Interface

7. Use of Multiple communications in one system

Normally DMS and DA systems use a large number of small to mid size RTUs, connected via a wide area communication infrastructure . These RTUs are typically not required to carry out frequent and lengthy communication sessions, which allow for many RTUs to share the same channel. If, for example a channel becomes overloaded, due to use of a non-optimal protocol, the performance of the entire system is degraded.

In a typical system, not all RTUs use the same data channel across the network, since the same communications backbone may not be available at all locations. In addition, in an evolving DMS or DA system, there may be a need to connect together several existing devices or new ones that were supplied by different vendors. It is expected, that these units use different communication media and different protocols.

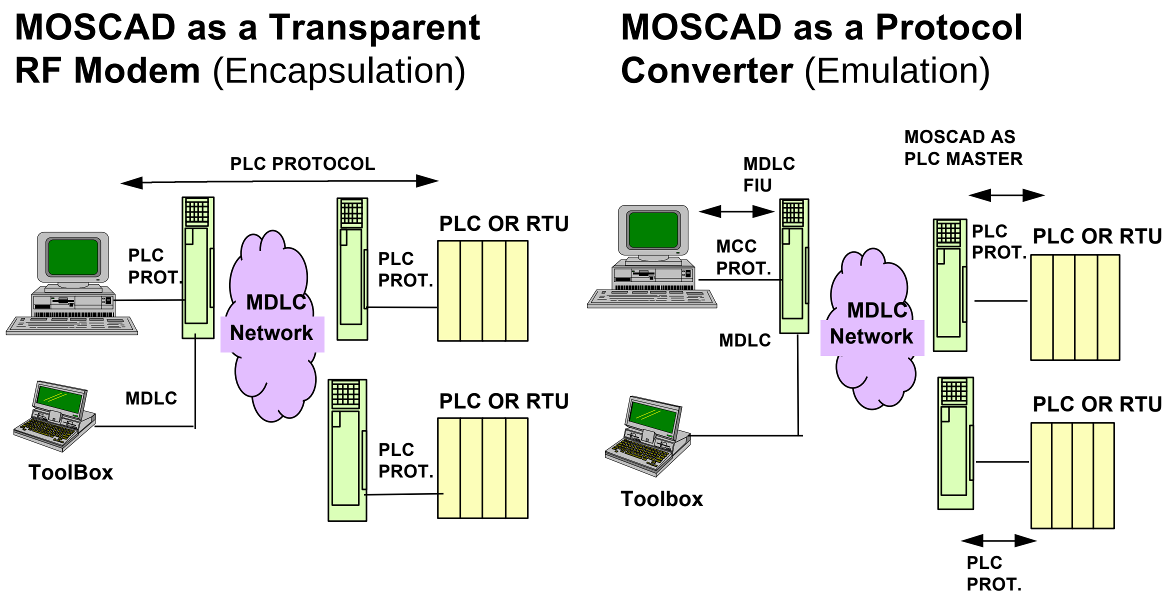
As can be expected, there are a number of solutions that allow linking of MCCs with RTUs and PLC that use different communications protocols and different media. This requirement is very typical for system upgrades and expansion projects. There are two valid concepts one may use, known as; protocol emulation and protocol encapsulation. Both are acceptable, and the selection depends on the components to be used and the communications network.

7 . 1. Protocol encapsulation

In this case the MCC and the RTU/PLC are connected to a pair of smart RF Modems, which encapsulate and de-capsulate the RTU/PLC and MCC protocol (all must be of same type) within the MDLC protocol. While transmitting over the air, the MDLC based RF network provides absolute data transparency to "its users" and does not interfere with the RTU/PLC/MCC message (monitoring, alarms, control, etc.), which the original protocol carries. See Fig. 8 (a) for illustration of a network utilizing the encapsulation concept.

7 . 2. Protocol emulation

In this configuration there are also two MDLC based smart RF Modems, one at each side. See Fig 8 (b) for illustration. The RF modem at the MCC side is acting as a Front End Processor (FEP) and it communicates with the MCC using its native protocol. At the remote side, the PLCs/RTUs are being polled by another RF modem (next to it), using the protocol of that RTU/PLC. In this case, the MCC and each RTU or PLC may use *different protocols.*



(a) (b)

Figure 8. Encapsulation vs. Emulation of protocols

8. Summary

This paper summarizes the needs for advanced communications protocols in DA, DSM and DMS systems. These benefits, as explained, are expressed in more reliable operation of the system, ability to integrate multiple media into one communication network, cost effective utilization of the available communications infrastructure, etc.

Use of modern seven layer protocols results in many additional improvements, which also should be taken into consideration. These benefits include: simpler programming resulting from separation of the communication and the application functionalities, less costly system upgrades and expansions, and improved maintenance procedures.

By automating the distribution network, utilities can provide more reliable service to their customers through use of more advanced communications concepts. The integration of advanced communications protocols with DA and DSM systems more than justifies the investment

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