COMMUNICATIONS TECHNOLOGIES FOR SCADA SYSTEMS

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ABSTRACT

This paper presents different communications technologies available for SCADA systems to connect industrial remote facilities to centralized control centers. Various communications alternatives are addressed with brief descriptions of their advantages and disadvantages. The paper will also discuss each alternative's possible application for SCADA systems. The paper will consider the kingdom's vast areas and unavailability of public network reach to remote sites when suggesting alternatives. The advances in telecommunications industry, different businesses requirements, and geographical areas specific challenges necessitate continuous assessment of these solutions.

Keywords: *SCADA, Communications, Copper Cable, Coax Cable, Fiber Cable, Radio, Satellite*

الملخص

هذه الورقة تقدم تقنيات إتصال مختلفه و متوفره يمكن إستخدامها لنقل بيانات أنظمة التحكم بالمرافق الصناعية من وحدات التحكم البعيده الى مراكز التحكم الرئيسية. خيارات متعدده يتم طرحها مع ملخص للأيجابيات و السلبيات لكل تقنيه. هذه الورقة أيضاً تناقش التطبيقات العمليه لكل من الخيارات المقدمه. الإتساع الجغرافي للمملكة العربية السعوديه و وجود المرافق الصناعيه في المناطق النائيه ستشكل القاعده للحلول المطروحه. التقدم السريع في تقنية الإ تصالات و التحديات الخاصه لمنطقتنا الجغرافيه وكذلك إحتياجات الصناعه المختلفه تتطلب تقييم هذه التقنيات المتطوره بأستمرار.

1. INTRODUCTION

Many different communications media can be considered for SCADA new projects or to upgrade obsolete SCADA communications systems. The selection of any of these communications media depends on the technical requirements for the application, geographic considerations of remote facilities to be monitored / controlled, the availability of established systems, and economics [O. Usta, et al, 1998]. These different communications technology applicable for SCADA systems are described in subsequent sections with tables showing each technology advantages and disadvantages.

Any media capable of supporting serial binary signaling, including the following may provide the necessary communications facility between SCADA system master and remote terminals:

- Copper Cable
- Coaxial Cable
- Fiber Optic Cable
- Power Line Carrier (PLC)
- VHF/UHF Radio (Conventional or Trunking)
- Microwave Radio
- Satellite (VSAT, LEO, Others)

2. SCADA SYSTEMS DEFINITION / INTRODUCTION

SCADA (Supervisory Controls & Data Acquisitions) is a critical tool to remotely monitor, control, manage the quality / continuity and safety of industrial facilities distributed at various remote sites. The basic elements of any SCADA system are remote process, field devices, remote terminal units (usually called RTU's), SCADA central host and dispatch consoles (usually called master terminal unit or MTU), and communications paths, see Figure I.

Different applications that are usually carried over SCADA communications include:

- Oil, Gas and Chemical Processing
- Pipeline Industries
- Tank Farm Management
- Environmental Monitoring
- Electric Utilities
- Water Utilities
- Security Surveillance
- Transportation Systems

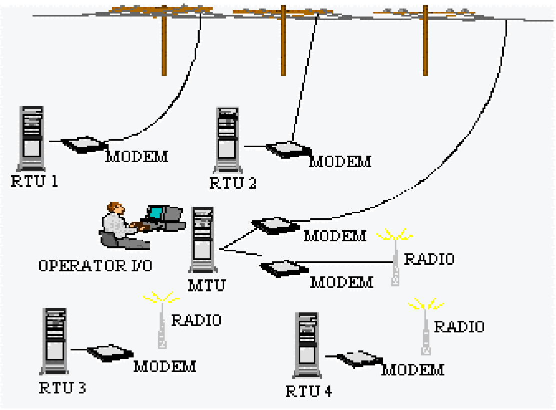

FIGURE I: SCADA SYSTEM MODEL

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SCADA is not a full control system, but rather focuses in the supervisory level. Systems similar to SCADA are routinely seen in factories, plants, etc. These are often referred to as Distributed Control Systems (DCS's). They have similar functions as SCADA systems, but the data gathering field devices are usually located within a more confined area. Communications may be via Local Area Network (LAN) and will be normally reliable and high speed.

Data acquisition refers to the method where information can be automatically or manually exchanged between remote facilities and centralized control centers. RTU's in a remote plant will be exchanging data with connected field devices or sensors, such as flow meter, ammeter, valves, actuators, motors, etc. The central host will be then exchanging data with dispersed RTU's located at remote facilities via communications networks. The operator will have a graphical interface that represents a plant or equipment displayed with their associated readings. As the data changes in the field the operator graphical interface will be updated accordingly.

3. COMMUNICATIONS MEDIA

Transmission medium is the physical path between transmitter and receiver in a communication network. The transmission media used for SCADA systems include copper cable, coaxial cable, fiber cable, electromagnetic propagation through the atmosphere, or hybrid media using combinations of different media [Mikal Nordman, et al, 2001].

The various media can be described using the set of characteristics described below [Bill Greeves, 1994].

- Physical description: the nature of the transmission medium
- Transmission Characteristics: include whether analogue or digital transmission, modulation scheme, capacity, bandwidth, and frequency range over which transmission occurs
- Connectivity: point-to-point or multipoint
- Geographical scope: the maximum distance between points on the network
- Noise immunity: resistance of the medium to interference
- Relative cost: cost of hardware and software, installation, maintenance and lease

Yesterday's SCADA systems were based on proprietary architectures and offered little in networking flexibility. Today's SCADA systems are far more developing toward open-standard environment. This will open the door to apply new communications options for SCADA systems [Robert H. McClanahan, 2002].

3.1. Copper Cable

Twisted-pair copper cable is the most popular medium used for SCADA communications and it has been used in its present form for many years. It is similar to copper cables used by telephone companies and contains pairs of conductor. Copper cables used for SCADA purposes can be underground, direct buried or aerial installations. Aerial cables would be more appropriate in the utilities' service area since they may own a large number of distribution poles from which cable could be suspended. Table I shows the Copper Cable advantages and disadvantages [Donald J. Marihart, 2001].

TABLE I: COPPER CABLE ADVANTAGES / DISADVANTAGES

Advantages	**Disadvantages**
No licensing, fewer approvals For utilities' services, existing pole infrastructure could be used Economical for short distances Relatively high channel capacity for short distances	Right-of-way clearance is required for buried cable Subject to breakage Subject to water ingress Subject to ground potential rise due to power faults and lightning Failures may be difficult to pinpoint Inflexible network configuration

3.2. Coaxial Cable

Coaxial cable is simply a transmission line consisting of an unbalanced pair made up of an inner conductor surrounded by a grounded outer conductor, which is held in a concentric configuration by a dielectric. The dielectric can be of many types, such as polyvinyl chloride, foam, Spirafil, air or gas [Roger L. Freeman, 1989]. Coaxial cable can transmit high frequency signals up to several MHz with low attenuation compared to copper wires used for telephone services. Methods of coaxial cable installations are underground, direct buried and aerial constructions. Table II shows the Coaxial Cable advantages and disadvantages [Donald J. Marihart, 2001].

TABLE II: COAXIAL CABLE ADVANTAGES / DISADVANTAGES

Advantages	**Disadvantages**
No licensing, fewer approvals For utilities' services, existing pole infrastructure could be used Economical for short distances Relatively high channel capacity than copper cables More immune to RF noise interference than copper cables	Right-of-way clearance is required for buried cable Subject to breakage Subject to water ingress Subject to ground potential rise due to power faults and lightning Failures may be difficult to pinpoint Inflexible network configuration

3.3. Fiber Optic Cable

Fiber optic as a transmission medium has a comparatively unlimited bandwidth. It has excellent properties as low as 0.25 dB/km. Losses of this order of magnitude, as well as the development of suitable lasers and optical detectors, allow designers to consider fiber optics technologies for systems of huge bandwidth over long distances.

Optical fibers consist of an inner core and cladding of silica glass and plastic jackets that physically protects the fiber. There are three categories of optical fiber distinguished by their modal and physical properties and they are single mode, step index (multimode), and graded index (multimode). Single mode fiber supports higher signaling speed due to its smaller diameter and mode of light propagation. Cable installations could be underground, direct buried, under sea, or aerial. Table III shows the fiber optic cable advantages and disadvantages [Donald J. Marihart, 2001].

TABLE III: FIPER OPTIC CABLE ADVANTAGES / DISADVANTAGES

Advantages	**Disadvantages**
Immune to electromagnetic interference Immune to ground potential rise High channel capacity Low operation cost No licensing required Security, not easy to intercept Can span longer distances without the need for repeaters	Novel technology, i.e. new skills must be learned Expensive test equipment Subject to breakage and water ingress Inflexible network configuration Less-cost-effective, if only used for SCADA low traffic

However, knowing that fiber optic cable is the most preferred solution for SCADA systems due to its reliability and long distances it covers, if these high-speed channels are only used for SCADA low traffic and not fully utilized, then these communications resources are greatly wasted where the spare capacity is used by "nice to have" features rather than "need to have" issues [Goran N. Ericsson, 2001].

3.4. Power Line Carrier (PLC)

Power Line Carrier (PLC) was one of the first reliable communications media available to electric utilities for critical communications channels that could not be subjected to the intolerance and unreliability of leased (common carrier) telephone circuits. PLC uses the power transmission lines to transmit radio frequency signals.

Since the power system's current carrying conductors offer a robust, reliable and economic link for power system communications, the PLC systems have been used for the applications of power system relaying and control since 1940's. PLC systems operate in on-off mode by transmitting radio frequency signals in the 10 to 500 kHz band over power transmission lines [O. Usta, et al, 1998]. Table IV shows the PLC advantages and disadvantages [Donald J. Marihart, 2001].

TABLE IV: PLC ADVANTAGES / DISADVANTAGES

Advantages	Disadvantages
Located where the circuits are required, for power utilities Equipment installed in utility owned land or structures Economically attractive for low numbers of channels extending over long distances	Dependent on the power distribution system Carrier frequencies often not protected on a primary basis Inherently few channels available Will not propagate through open disconnects Expensive on a per-channel basis

3.5. VHF/UHF Radio (Conventional or Trunking)

SCADA through radio is a mean of communications without the existence of a physical connection between the transmitter and the receiver. It can, for example, be used as a replacement for a physical link where difficult terrain or natural obstacles militate against such link, or where the transmitting or receiving end is in motion and the attachment of a physical link is impossible. The main limiting factor in the use of radio SCADA is distance – and the distance to be covered defines the type of radio system applied and the frequency used.

Development of open, digital radio transmission protocols such as TETRA, and APCO 25, can be future means for remote monitoring and control [Mikal Nordman, et al, 2001]. VHF/UHF Radio is not preferred for long haul transmission, instead it can be attractively applied to connect cluster of RTU's. Table V shows the VHF/UHF Radio advantages and disadvantages [Donald J. Marihart, 2001].

TABLE V: VHF/UHF RADIO ADVANTAGES / DISADVANTAGES

Advantages	Disadvantages
Independent of common carriers and power lines Less civil work, no need for trenches, poles, etc. Low cost equipment compared to microwave Non-line-of-sight propagation Area coverage	Frequency assignments Low channel capacity Subject to interference Limited distances Less reliability

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3.6. Microwave Radio

Microwave radio systems are systems that operate in the microwave frequency spectrum. A microwave is a signal that has a wavelength of one foot (30.5 cm) or less. A wavelength of one foot converts to a frequency of 984 MHz, so all frequencies above 1 GHz are considered to be microwaves. While the microwave frequency range theoretically extends into the light frequencies, the practical uses of microwave are between 1 and 300 GHz. Table VI shows the VHF/UHF Radio advantages and disadvantages [Donald J. Marihart, 2001].

TABLE VI: MICROWAVE RADIO ADVANTAGES / DISADVANTAGES

Advantages	**Disadvantages**
Independent of common carriers and power lines Less civil work, no need for trenches, poles, etc. High channel capacity	Frequency assignments Subject to interference, fading, etc. Limited distances Less reliability Require towers, permanent constructions, etc.

3.7. Satellite (VSAT, LEO)

Satellite-based SCADA is especially useful when the geographic placement of elements in the controlled network is diverse through large areas with “virtually no terrestrial communications networks”, removing the requirements to lay hundreds or thousands kilometers of wire. It is also a good choice when other information such as voice, fax or local area network traffic is combined with SCADA stream. The point-to-multipoint nature of the satellite networks is advantageous for multicasting of polling queries, commands and network timing [Shane V. Hawkins, 1997]. Table VII shows different satellites constellations.

TABLE VII: FEATURES OF DIFFERENT SATELLITES CONSTELLATIONS

TYPE	LEO	MEO	GEO
Satellite	Low Earth Orbit	Medium Earth Orbit	Geostationary Earth Orbit
Altitude (km)	800 - 2000	9,600 – 19,200	36,000
Bands	VHF, UHF, L-Band	L-Band, S-Band	C-Band, K-Band, Ka-Band
Applications	Positioning, Fixed Terminals, Mobile Terminals, Data,	Positioning, Fixed Terminals, Mobile Terminals, Data, Voice	Positioning, Fixed Terminals, Mobile Terminals, Data, Voice

3.7.1 VSAT

VSAT systems (Very Small Aperture Terminal) are designed to provide fixed telephony and data services. VSAT systems are using geo-stationary satellites and offer continuous coverage over a particular area of the earth. While older VSAT systems used the C-band (6/4 GHz), current systems generally use the Ku-band (14/12 GHz) and newer systems use the Ka-band (30/20 GHz). For example, as Figure II shows, VSAT network can be configured as a point to multi-point system capable of allowing numerous remote sites to communicate with a centralized computing facility or HOST. The remote terminals are typically installed at dispersed sites and are connected to the HUB via a satellite link. VSAT remote terminals with low power consumptions are preferred for unmanned remote sites with modest communications requirements.

The cost of VSAT equipment and services has decreased significantly. In addition, Remote VSAT terminal equipment in ruggedized containers can withstand extreme weather conditions, eliminating the need for expensive shelters [Phil Samuels, 1997].

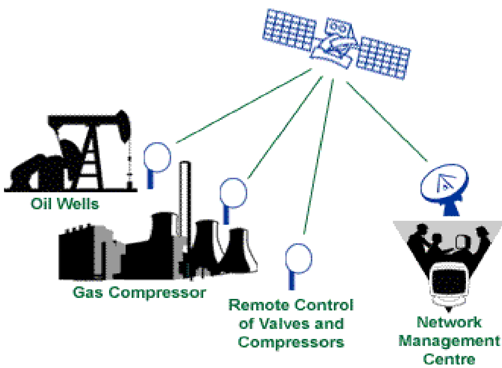

FIGURE II: SCADA SYSTEM VIA VSAT

3.7.2 LEO

When initially introduced, Low Earth Orbit (LEO) systems were promising to allow for end users' equipment with less complexity and low power consumption with a global coverage. LEO system is designed to provide global data and voice services via group of LEO satellites and ground infrastructure. There have been discussions on how LEO systems can provide SCADA communications. The two major challenges for LEO systems to be used for SCADA systems are time latency and re-routing traffic to third party ground stations. Further investigations need to be carried out before considering LEO systems for SCADA communications.

Table VIII shows the Satellite Systems advantages and disadvantages [Donald J. Marihart, 2001].

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TABLE VIII: SATELLITE RADIO ADVANTAGES / DISADVANTAGES

Advantages	**Disadvantages**
Easy to install, short implementation cycle Broadcasting Capabilities Cost effective compared to terrestrial networks Wider Area Coverage Channels coast are almost distance independent	Time Latency May be dependent on other operators Satellite Life Span Downtime are expected, e.g. satellites' eclipses

4. DESIGN EXAMPLES

Engineers designing SCADA systems need to consider all communications alternatives to come up with the most efficient and cost effective solutions. Alternatives are only rejected after proofing they are not efficient or not cost effective.

As in the example shown in Figure III, cluster of remote well sites RTU's are connected through VHF/UHF radios and then they are all connected back to a centralized operation control center through a satellite link. This example is only showing that various communications technologies can be implemented for SCADA projects if applicable.

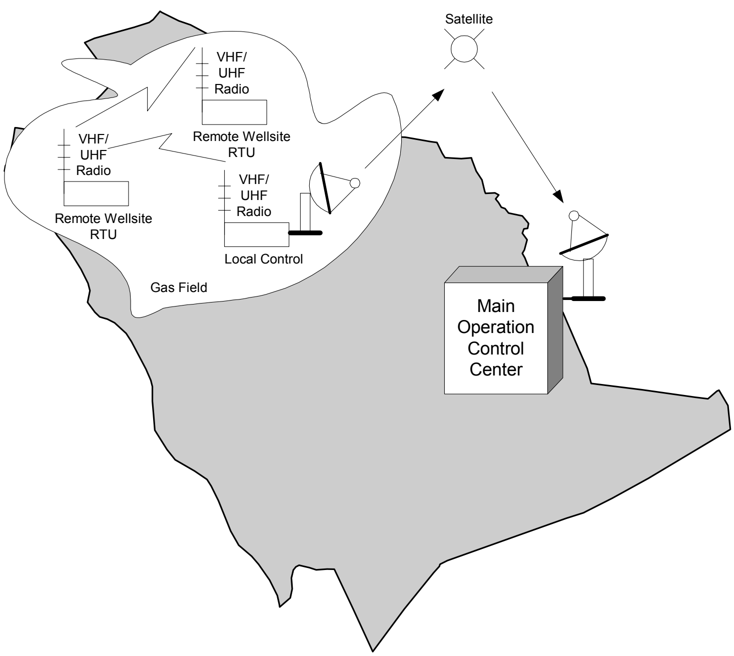

FIGURE III: SCADA COMMUNICATIONS EXAMPLE

5. CONCLUSION

Communications technologies are no longer an obstacle for SCADA systems implementation. The limitations of using tailored solutions for SCADA systems are actually “the imagination of the human being”. The paper here summarizes recommendations for the communications technologies available for SCADA projects as following:

- Fiber Optic cable for connecting major facilities control centers, and between the master terminal unit and group of RTU’s if high traffic is anticipated.
- Microwave may be used in very limited applications.
- Leased circuit can be utilized if the public network already exists within vicinity.
- Satellite remote monitoring is viable to connect very remote facilities.
- UHF radio can be used to connect clusters of RTU’s and then gathered traffic can be transported to the main control centers by long haul transmission.

In addition, while designing SCADA communications projects, all alternatives need to be assessed for each project to identify the most cost effective solutions where either one communications media or hybrid configurations can be implemented.

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