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Technical Consultation on the Use of Satellite Communications for Remote Monitoring of Field Instrumentation Systems

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16. Abstract

The increasing emphasis on the maintenance of existing infrastructure systems have led to greater use of advanced sensors and condition monitoring systems. Wireless sensors and sensor networks are emerging as sensing paradigms that the structural engineering field has begun to consider as substitutes for traditional tethered monitoring systems. The primary objective of the project is to review the state-of-the-art in satellite communication utilization in remote sensing to identify the current methods used for automated remote sensing including system availability and reliability, network performance and transmission error rate, and network protocol.

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INTRODUCTION

The increasing emphasis on the maintenance of existing infrastructure systems have led to greater use of advanced sensors and condition monitoring systems. Wireless sensors and sensor networks are emerging as sensing paradigms that the structural engineering field has begun to consider as substitutes for traditional tethered monitoring systems. An advantage of wireless structural monitoring systems is that they are relatively inexpensive to install because extensive wiring is no longer required between sensors and the data acquisition system. Researchers are discovering that wireless sensors are an exciting technology that should not be viewed simply as a substitute for traditional tethered monitoring systems. Rather, wireless sensors can play greater roles in the processing of structural response data; this feature can be utilized to screen data for signs of structural damage. In addition, wireless sensors have limitations that require novel system architectures and modes of operation (Lynch, 2006).

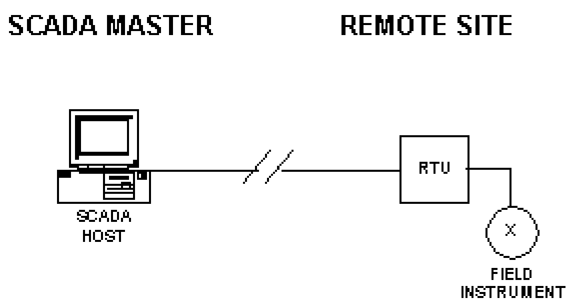
Moreover, sensory-based monitoring of structural systems is critical for evaluating the performance and heath condition of the structural system and assuring its safety during its life span. A structural health monitoring system measures key structural parameters systematically and provide valuable information regarding structural integrity, durability and reliability of the structural system. Deployment of a sensor-based monitoring system involves four main areas as; a) data acquisition, b) data processing, c) data transmission (communications), and d) data analysis. This project reviews some of the current designs of reliable wireless communications network to be used for transmission of sensory collected data from remote structure locations to a central data acquisition and analysis center.

Basically Supervisory Control And Data Acquisition (SCADA) wireless networks is a well established technology that is widely used for operation, monitoring and control of industrial systems and infrastructure such as power plants, power transmission systems and oil pipelines. SCADA is a common process automation system which is used to gather data from sensors and instruments located at remote sites and to transmit and display this data at a central site for control, monitoring and analysis purposes. The collected data is usually viewed on one or more SCADA Host computers located at the central monitoring, control and data analysis site. Therefore, supporting a large scale distributed measurement and monitoring systems (such as SCADA) requires reliable and rugged networks that can connect thousands of remote sites and operate in inhospitable regions where no traditional infrastructure exists.

This established SCADA technology can be easily adapted to support sensor based monitoring of infrastructure systems. A real world SCADA system can monitor and control hundreds to hundreds of thousands of I/O points. A typical Water SCADA application would be to monitor water levels at various water sources like reservoirs and tanks and when the water level exceeds a preset threshold, activate the system of pumps to move water to tanks with low tank levels.

Common analog signals that SCADA systems monitor and control are levels, temperatures, pressures, flow rate and motor speed. Typical digital signals to monitor and control are level switches, pressure switches, generator status, relays & motors. However, new analog and digital monitoring signals can be easily included in the systems to support any other infrastructure sensor device.
There is typically another layer of equipment between the remote sensors and instruments and the central computer. This intermediate equipment exists on the remote side and connects to the sensors and field instruments. Sensors typically have digital or analog I/O and these signals are not in a form that can be easily communicated over long distances. The intermediate equipment is used to digitize then packetize the sensor signals so that they can be digitally transmitted via an industrial communications protocol over long distances to the central site.

Typical equipment that handles this function are Programable Logic Controllers (PLC's) and Remote Terminal Units (RTU's). These devices employ de- facto standard industrial data communication protocols such as Modbus, AB-DF1, and DNP3.0 to transmit the sensor data. Typical physical interface standards are Bel 202 modem, RS-485 & RS-232.



The SCADA Host is usually an industrial PC running sophisticated SCADA MMI (Man Machine Interface) or HMI (Human Machine Interface) software. This software is used to poll the remote sites and store the collected data in its centralized SQL or Oracle database. Logic can be configured in the SCADA Host software which then monitors and controls plant, field equipment and remote infrastructures. Specialized application software such as bridge performance analysis can be deployed on top of HMI and MMI software.

Data acquisition is accomplished firstly by the RTU's or PLC's scanning the field inputs connected to the RTU / PLC. This data is usually collected at a polling rate configured by the operator. The polling rate is determined by the number of sites, the amount of data at each site, the maximum bandwidth of the communication channel and the minimum required display and control time.

Once the data has been acquired at sent to the SCADA, the MMI software will scan the acquired data (usually at a slower rate.) The data could then processed, analyzed and if required alarm conditions and message will be generated. There are 3 common types of data collected:

- 1. Analog - used for trending
- 2. Digital (on/off) - used for alarming
- 3. Pulse (i.e. revolutions of some kind of meter) - accumulated /counted

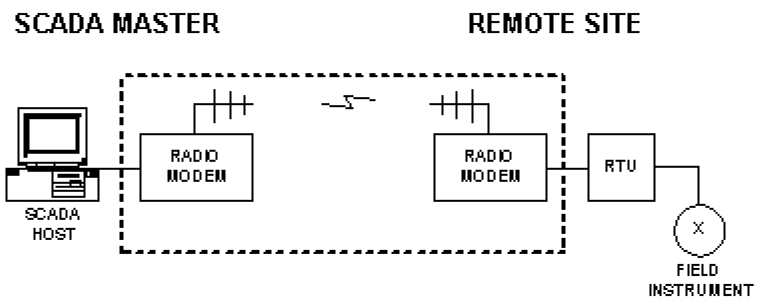
The primary operator interface is a set of graphical screens which show a representation of the equipment being monitored. Real-time data is displayed numerically or graphically as changing bars, circles, lines or other shapes over a static background. As the acquired data changes in real-time, the bar, circle, line or other representative shape is updated. Further, any necessary statistical analysis can be performed using collected data.

SCADA communications can employ a diverse range of both wired (lease line, dial-up line, fiber, ADSL, cable) and wireless media (licensed radio, spread spectrum, cellular, WLAN or satellite). The choice depends on a number of factors that characterize the clients existing communication infrastructure.

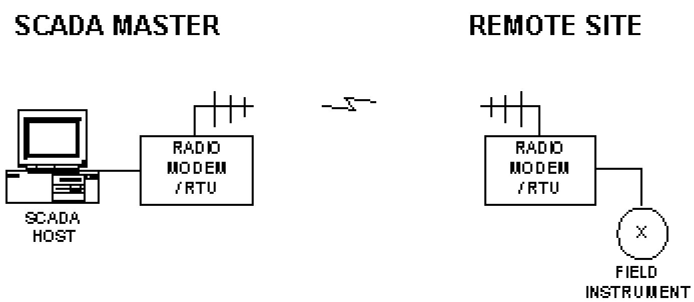
Factors such as existing communications infrastructure, available communications at the remote sites, data rates and polling frequency, remoteness of site, installation budget and ability to accommodate future needs all impact the final decision. In complex SCADA architectures, there can be a variety of both wired and wireless media and protocols involved to get data back to the central monitoring site.

SCADA systems differ from DCS's (Distributed Control Systems) which are generally found in plant sites. While DCS's cover the plant-site, SCADA systems cover much larger geographic areas. Often SCADA Systems are required to interface to a plantsite DCS if there are remote sensors, instruments or motors and pumps that must be controlled/monitored by the plantsite DCS.

Certain types of applications like those in Oil & Gas, Electrical & Water Utilities, Water & Wastewater and Environmental Monitoring inherently require SCADA communications because of the remoteness of the assets (i.e. Oil wells, water wells, generator stations). Furthermore, due to the remoteness many of these often require the use of wireless communications. In these cases, the traditional solution is to add a radio modem stage to the standard SCADA architecture shown above.



Next generation SCADA equipment offers another level of integration by placing the wireless communications and RTU functionality together in the same package.



In addition to this higher level of integration, next-generation SCADA equipment also support TCP/IP, UDP or other IP based communications protocols as well as strictly industrial protocols such as Modbus TCP, Modbus over TCP or Modbus over UDP all working over private radio, cellular or satellite networks. The UNICON IP can act as an Ethernet Serial gateway to enable older legacy serial equipment to connect to TCP/IP networks. Coupled with Host software such as NETSCADA, this enables implementation of powerful IP based SCADA networks over mixed cellular, satellite systems and land line systems.

COMMUNICATIONS NETWORK

Today, the utility, pipeline transport and transportation industries face growing challenges in how they manage their core operations and remote monitoring. For utility companies, new regulations require them to upgrade their communications networks to safeguard core infrastructure and ensure their services remain always available. Investments in green energy are extending their power generation operations deep into remote geographies, far beyond the reach of terrestrial and cellular networks. And the adoption of smart grid standards requires real-time monitoring of energy load distribution across all their substations and customer locations.

Pipeline transport companies are confronting similar business pressures. They require greater visibility into operations at remote locations that are scattered across thousands of miles of rugged terrain. In order to monitor and control their facilities, they need instant access to unmanned sites to address local problems remotely. And demand for increased pipeline station automation requires greater bandwidth at remote sites, surpassing what traditional narrowband SCADA networks can support.

The need to monitor, access and protect critical remote operations and infrastructure is forcing industries and pipeline operators to upgrade their legacy communications systems. They require a next-generation network solution that can monitor real-time operational data with greater precision, handle broadband applications like Voice- or Video-over-IP and provide constant connectivity to every facility, no matter how remote.

Wireless communications network is required in those applications when wire-line communications to the remote site is not available, prohibitively expensive or it is too time consuming to construct wire-line communications. For particular types of infrastructures like Oil & Gas, Water & Wastewater and certain transportation infrastructures, wireless communications is often the only solution due to the remoteness of the sites.

Wireless communications network can be built using private radio systems (licensed or unlicensed), cellular networks or satellite communications networks; each of these has its unique set of characteristics given in the Table below.

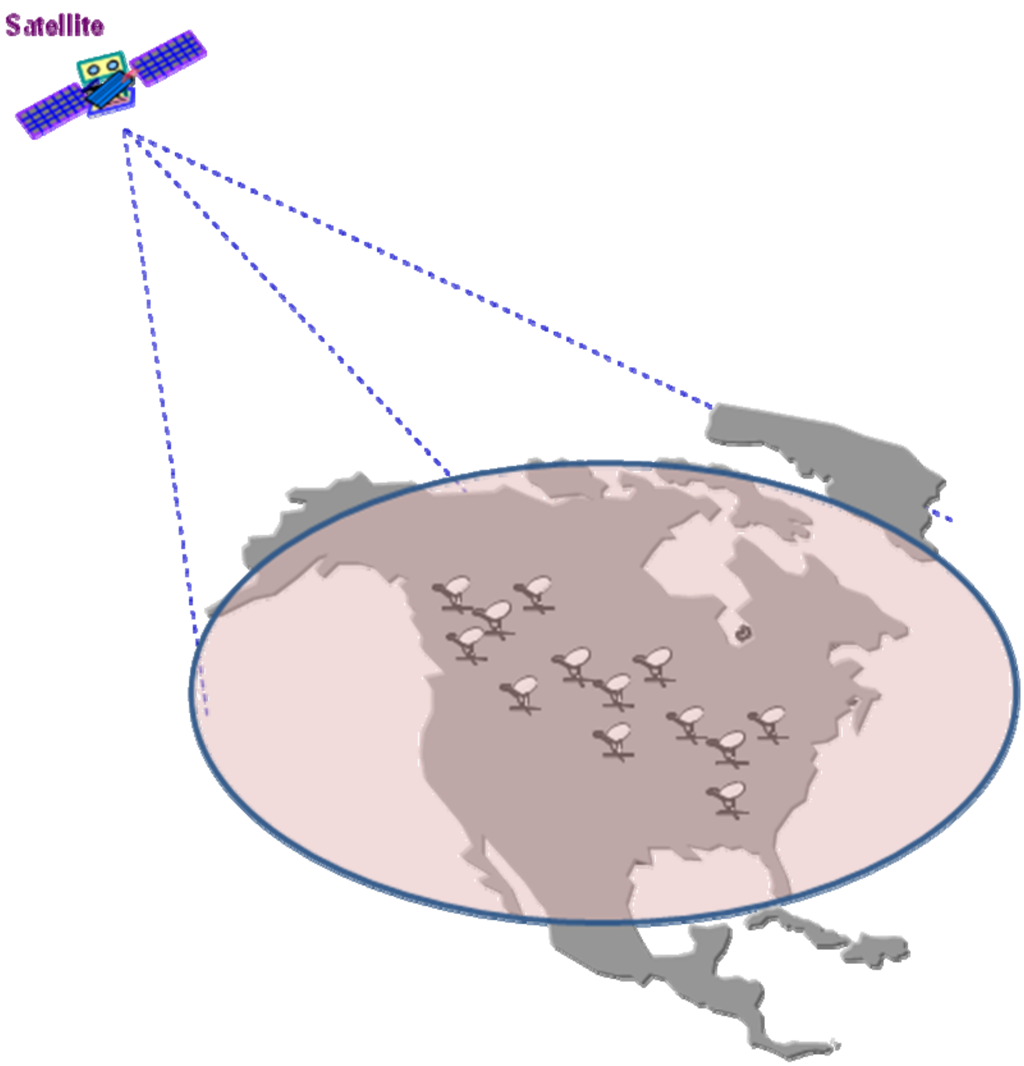
	Private Licensed (i.e. UHF)	Private Unlicensed (i.e. SS)	Cellular	Satellite
Typ. Range (miles)	20 - 40	20	cell site coverage	North America
Licensing Required	Yes	No	No	No
Setup Time	Moderate	Fast	Fast	Fast
Data Rate (kbps)	9.6	9.6 to 19.2	9.6 to 128	1.2 to 2400
RTU / RF integration	Not usually	Yes	Yes	Yes

One major difference between Private Radio and Cellular or Satellite is that Private radio has no associated monthly fees. Once you build your hardware infrastructure, you own it. With Cellular or Satellite Service providers, there is an associated monthly fee.

For the decision maker, it comes down to deciding between a large capital investment and no monthly service fees OR a smaller capital investment with monthly service fees. If the remote assets and infrastructures are well within the service providers coverage area, cellular network alternative would be the most cost effective communications network for transmission of the sensors collected information to the data analysis center. However, for commercial reasons, the cellular networks mainly cover populated metropolitan areas and suburbs and they may not be available in remote rural locations. In these cases, the ideal alternative would be a satellite based data communications network. Basically, due to large scale coverage of high-power satellites footprints, satellite communications network can be used at any remote location to support required connectivity to the data analysis center. Satellite network inherently are reliable and can be designed for any specified performance specifications and network availability using TCP/IP protocol.

However, often it is more typical to have a mixture of solutions; using both cellular and satellite networks. With Cellular or Satellite, one is leveraging the vast existing infrastructure of the Service Provider. The advantage of Cellular or Satellite is that the user has access to very wide coverage of the existing services. If cellular communications makes sense as the overall network solution, it is possible to use Private Radio as "Last Mile Links" to these few remote sites that fall outside of the Cellular coverage maps to extend the coverage from the Cellular to a Private network to get to these remote assets.

Advancements in satellite communications enable high-speed, two-way connectivity that can support traditional SCADA applications and meet the bandwidth requirements of emerging broadband applications. In remote areas, satellite IP connectivity is the most reliable, functional and cost-effective transport technology, extending farther than alternative methods, delivering 99.8% availability and enabling data rates equivalent to terrestrial networks. A typical satellite footprint coverage is shown in Figure-1.



Fugure-1: Typical Satellite Coverage Footprint

NETWORK ARCHITECTURE

The typical wireless communications network architecture is based on a Point-Multipoint (star topology) system with one master data monitoring and analysis center located at the hub connecting to remote sites via satellite channels using RTU, PLC or TCP/IP data communication protocols including protocols such as Modbus, AB-DF1, and DNP3.0.

Each PLC or RTU at the remote site is programmed with a unique system address and those addresses are all configured into the central monitoring and analysis host computer. The central site may polls these addresses and stores the acquired data into its database. It will perform centralized alarm management, data trending, data analysis and management.

Modern SCADA Host MMI's can easily accommodate many different types of industrial protocols and the architecture allows multiple clients to view the same data and seamless expansion to handle additional remote sites and i/o points. There are companies (such as Bentek Systems) that provide complete turnkey infrastructure sensor monitoring and data acquisition wireless communications solutions from the SCADA Host MMI to the Satellite or Cellular communication or Private Radio communications.

Wireless sensor monitoring and data acquisition networks can range from Point-Multipoint Spread Spectrum systems using Modbus protocol to IP-based enterprise-wide systems which use IP protocol to integrate a variety of applications such as multipoint sensor monitoring network with SCPC (single channel per carrier) channels and corporate VPN.

Using the next generation intelligent satellite network platforms, infrastructure management institutions and operators can support multiple IP applications through a single network infrastructure including capabilities and features as:

- Video surveillance of remote facilities for visual monitoring
- Increased remote site safety and security
- Real-Time Traffic Management
- DVB-S2 standard with significant bandwidth efficiency
- Utilizing IP-based D-TDMA protocol
- Dynamically bandwidth allocation
- QOS services and priority features
- Centralized network management
- Full integration with other type of network and terrestrial lines
- Multi-application Support and Prioritization

- Data Video VoIP applications
- Seamless connectivity to thousands of remote sites
- High network reliability
- Scalability from 1 Kbps to 20 Mbps
- AES encryption

Private satellite networks are secure and circumvent public infrastructure. Using Adaptive Coding and Modulation (ACM) technology automatically optimizes link quality during rain, solar outages and other conditions to maintain required network performance and ensures high reliability of the network even during adverse weather conditions. In terms of the hardware reliability, due to the fact the remote locations are in isolated areas it can be difficult, expensive and time consuming to perform maintenance work. Therefore, the communications equipment must be robust and the service downtime due to remote equipment shall be minimized. A typical Multipoint-to-Point satellite network along with an integrated VPN IP network is shown in Figure-2, Figure-3 and Figure-4 respectively.

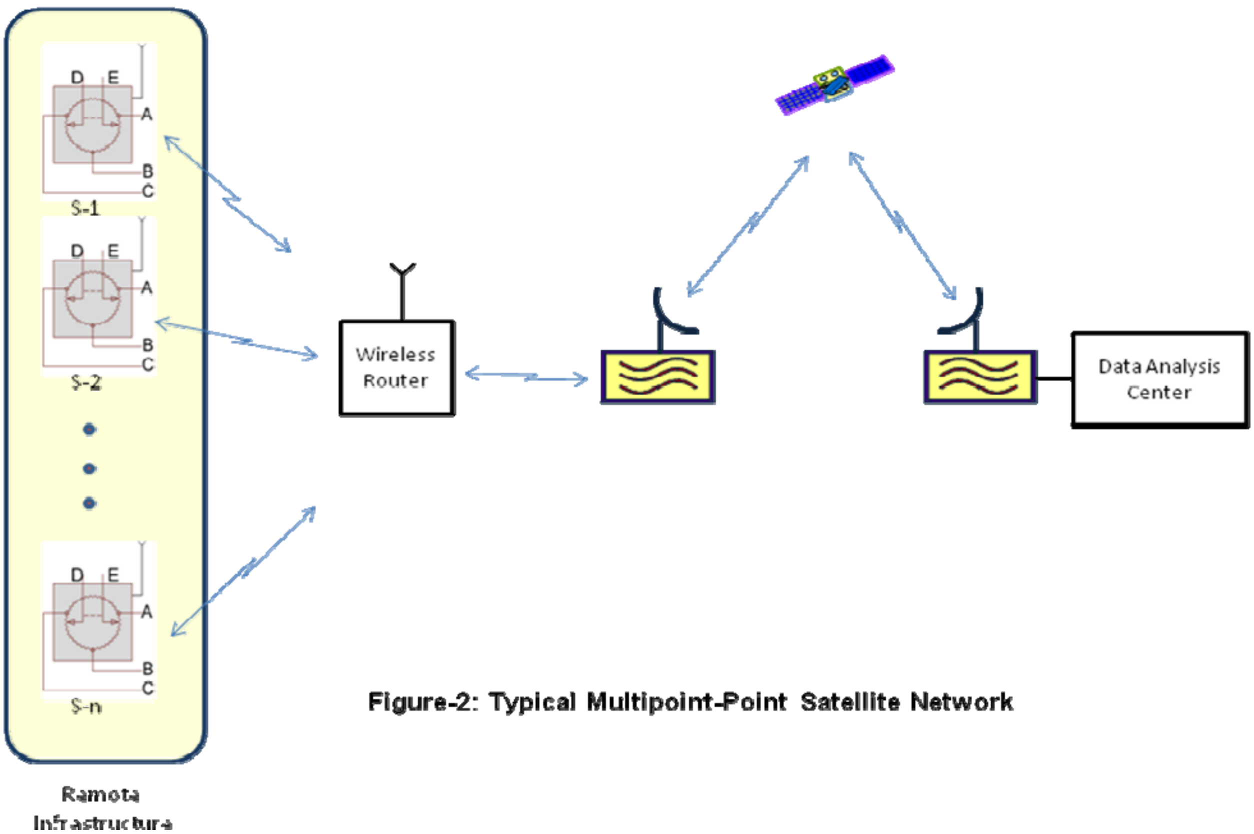


Figure-2: Typical Multipoint-Point Satellite Network

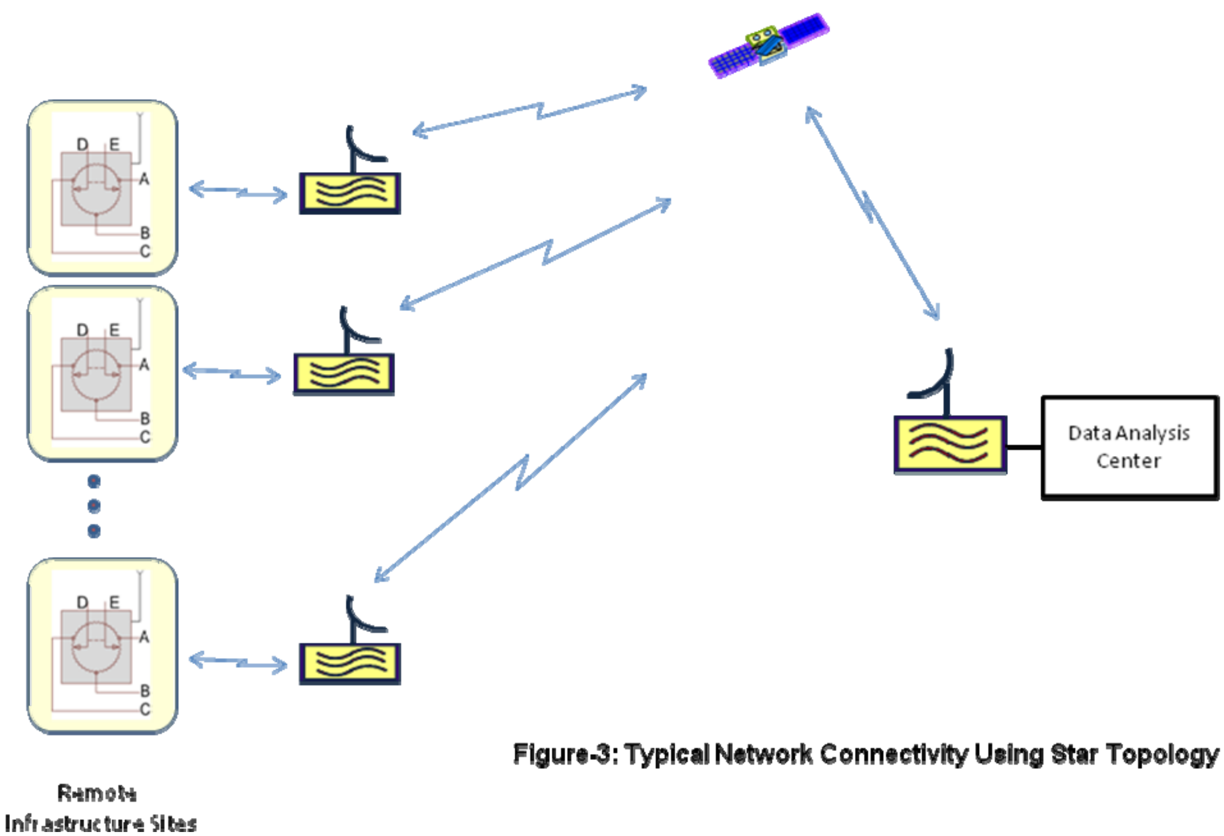


Figure-3: Typical Network Connectivity Using Star Topology

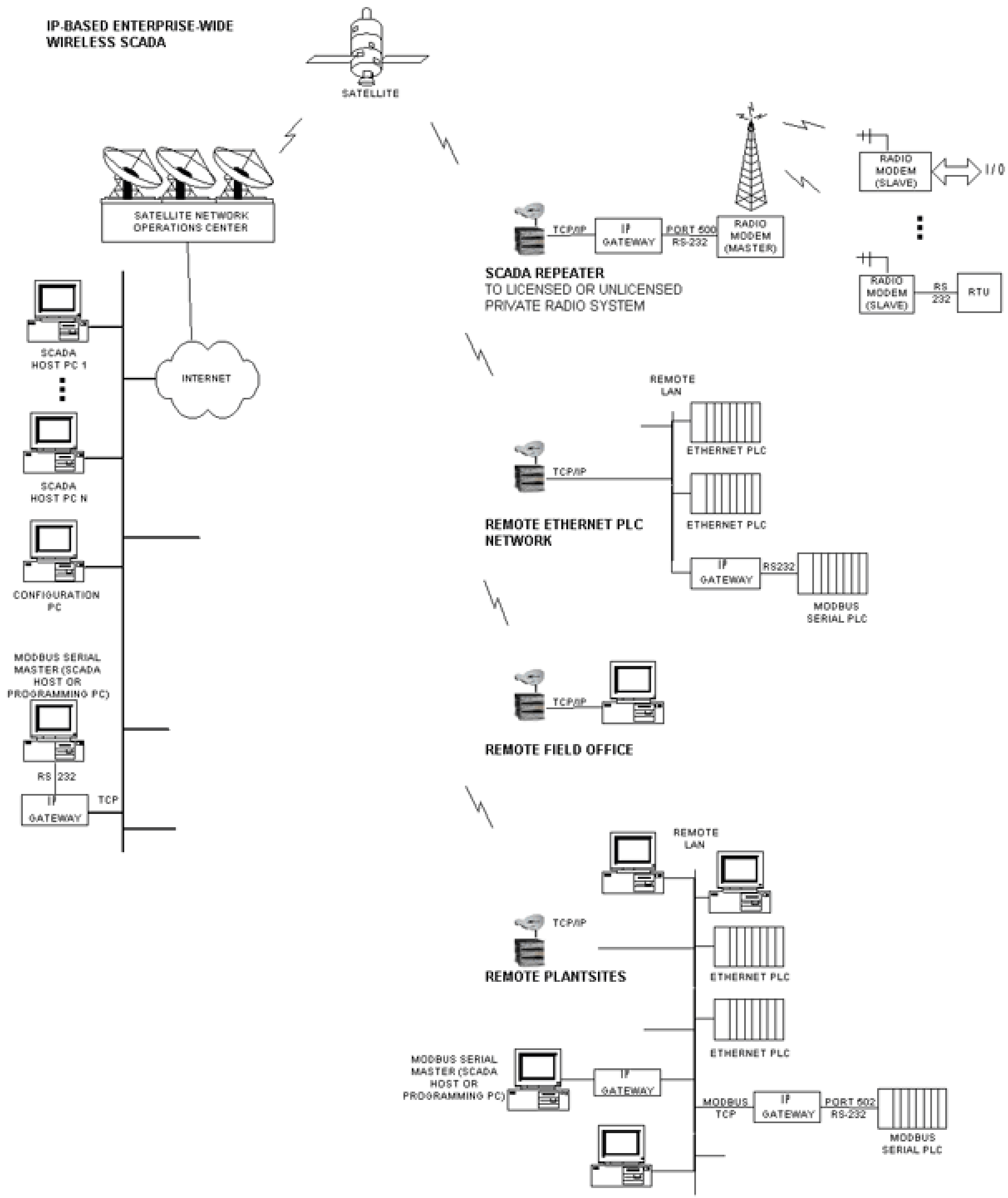


Figure-4: Typical Point-Multipoint IP Based Enterprise Satellite Network

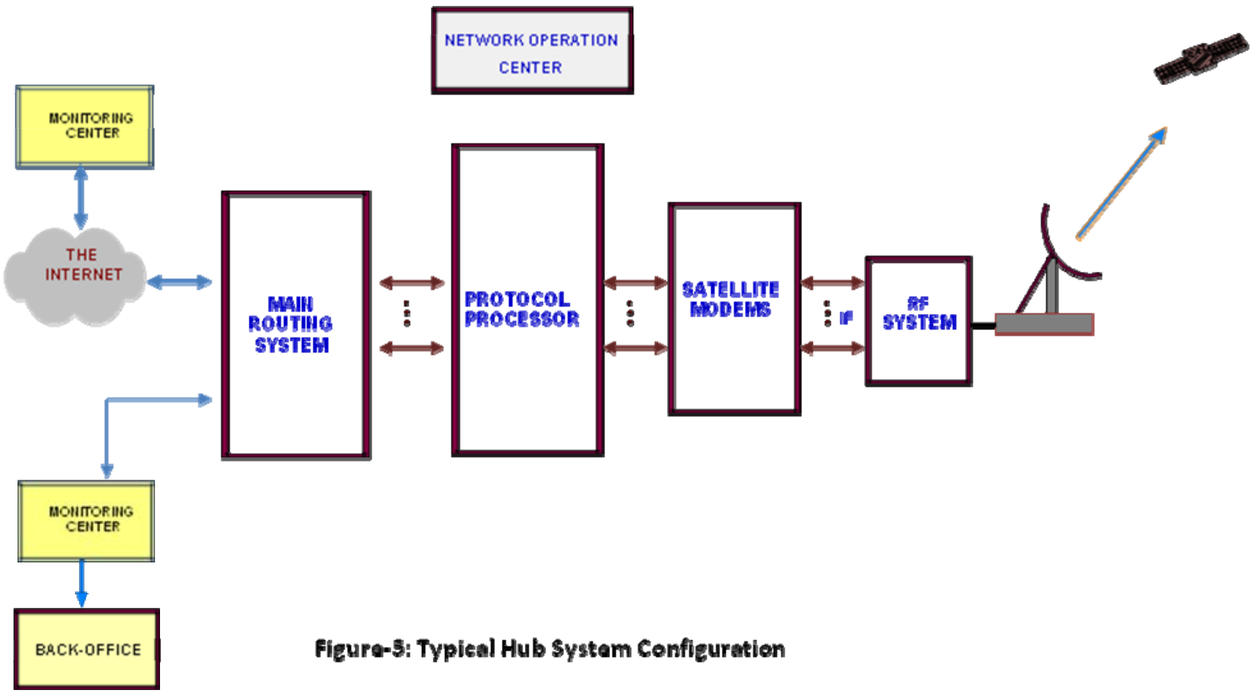


Figure-5: Typical Hub System Configuration

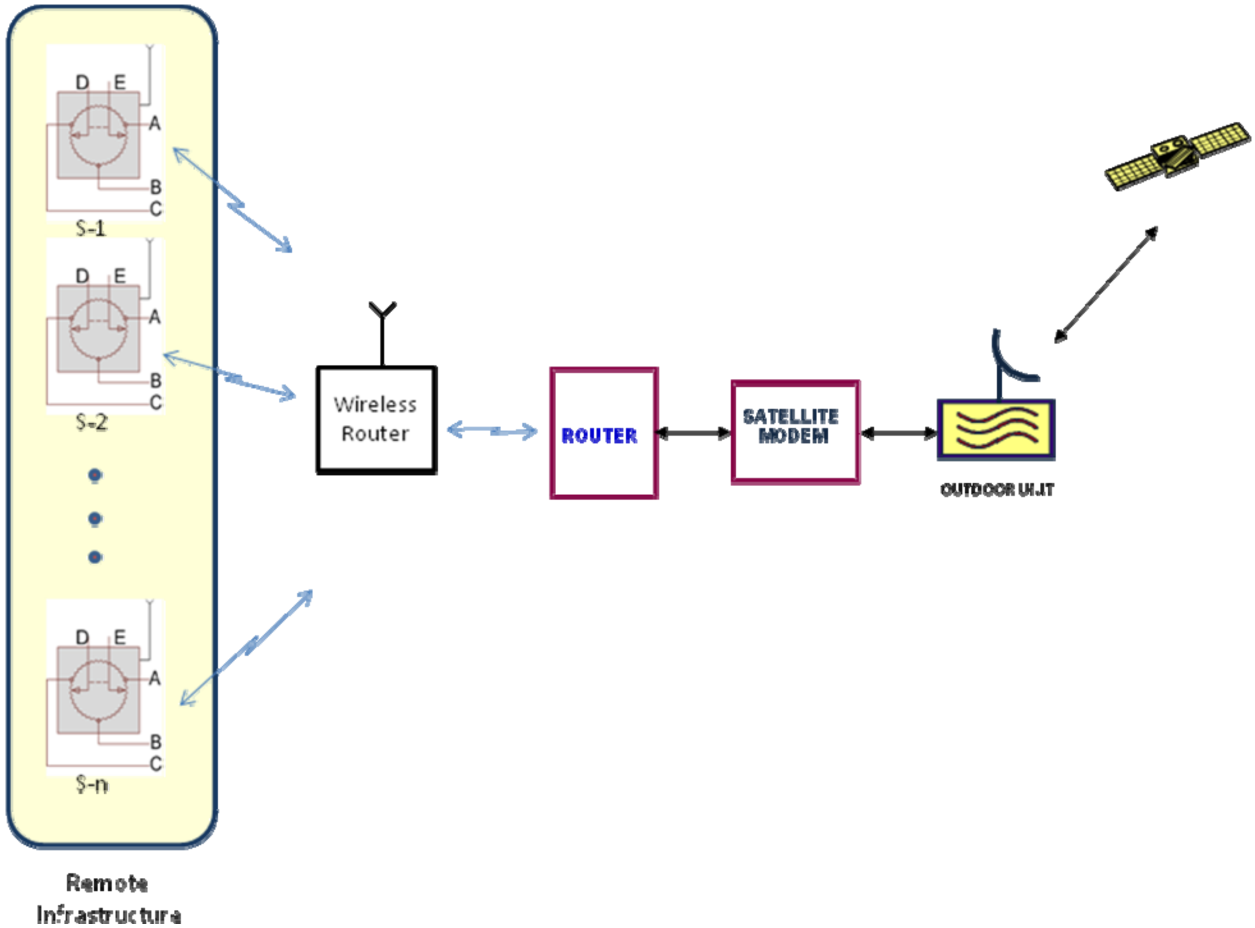


Figure-6: Typical Remote Site Configuration

FREQUENCY RANGE

North America commercial satellite service providers (SES World Skies, Intelsat, etc.) have satellites operating in C-band, Ku-Band and Ka-band frequencies. C-Band satellites operating at 6, 4 GHz uplink and downlink frequency range provide highly reliable link performance due to less susceptibility to rain fade attenuation but require a large antenna size and are not suitable and cost effective for this application. Ka-Band satellites operating at 26, 40 GHz frequency range require a much smaller antenna but due to high frequency range are more susceptible to rain fade. Ku-Band satellite networks with 12, 14 GHz frequency range are ideal for remote infrastructure monitoring network, using a

1.2 meter satellite antenna, remote terminals can be deployed within short period of time providing reliable connectivity to the central monitoring system.

MODULATION AND CODING

Modulation and coding of the satellite channels shall be optimized in terms of network monthly recurring cost and network performance specifications. In general, a QPSK modulation with ½ or ¾ Forward Error Correction (FEC) coding will provide satisfactory link performance however, spread spectrum techniques would result in greats link performance and network availability.

NETWORK AVAILABILITY

Both uplinks and downlinks at both directions shall be budgeted for appropriate uplink and downlink rain margin. The rain margin is a function of site location, rain-zone characteristic and desired link availability. For typical data network, 99.5% link availability would be appropriate. For hub locations, uplink power control unit shall be utilized to minimize the rain fade effect increasing the overall network availability.

ELECTRIC POWER & OPERATION ENVIRONMENT

With electric power availability issues at the remote sites, the remote field equipment shall be capable of operating with DC electric power. This enables cost effective connectivity to a solar powered system connected to a DC UPS system. Not every remote site might be located in an environmentally controlled facility. For this reason, the indoor and outdoor units shall be capable of operating in environments as harsh as -30 to +55 degrees C.

HUB AND REMOTE SITE EQUIPMENT COST: Remote site satellite communications equipment including satellite a 1.2 antenna, satellite indoor and outdoor units would be in the range of $600-$1000 per site depending to the number of the site and selected equipment. The installation cost could be anywhere between $200 to $400 per site. The hub cost could range from $100,000 to $800,000 depending to the number of the remote locations.