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Application of Wireless Communication for Monitoring of Critical Infrastructure

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Abstract

Numerous mining, industrial and logistics systems operate in remote areas and rely on critical equipment and infrastructure for their continued operation. Consequently it is essential to monitor the health of infrastructure on a continuous basis in order to detect unsafe conditions and provide timeous information for maintenance. A number of proven wireless telemetry technologies such as satellite, GSM and UHF radio can be used for these applications. This paper will present case studies demonstrating the application of wireless communication in the monitoring of critical infrastructure. This paper will be of interest to designers, production and operations personnel, maintenance engineers as well as consultants.

Introduction

Extensive infrastructure networks such as those deployed in the generation and distribution of electrical power, rail transportation and mining are located across a large geographic area. The failure of key assets and equipment can result in a serious disruption to operations with consequent loss of revenue. It is usually impractical to allocate personnel to monitor this infrastructure on a continuous basis.

There has been a continual increase in the application of continuous monitoring to identify and detect imminent failures through remote monitoring and diagnosis. While such monitoring is unable to detect all failure modes, investments have a high benefit to cost ratio with payback periods of a few months in a many of cases. Monitoring of critical equipment has two main objectives:

- Prevent equipment failure
- Continuously monitor equipment performance to ensure operation is close to or at peak efficiency

Achieving these objectives increases revenue while reducing costs. Remote monitoring uses sophisticated technologies and tools to assess equipment performance and condition which can be used to predict potential equipment malfunction or failure. These are usually located at a central regional or national site which is used to monitor a number of sites. As field equipment is located some distance from the central site a key element in the success of remote monitoring is the communication network used to send site data to a central station for display and analysis.

Remote Monitoring Components

Remote monitoring equipment consists of the following components:

- Sensors
- Data acquisition system
- Power supply
- Communications network
- Central site where site data is analysed, displayed and archived

A number of different messages may need to be sent between the site and the central station. These include:

- Alarm messages. These are often time critical and notify of failure or imminent failure conditions. These may be sent to other equipment to initiate shutdown or require control room operators to provide the necessary intervention. These messages are compressed into a small number of bytes and need to be transmitted securely in order to prevent false alarms.
- Status messages. These are used to report changes at the remote site. They may be sent only when there is a status change in addition to being reported periodically.
- Configuration messages. It may be necessary to change a recording or reporting parameter on the remote site. This is often done when the remote device connects to the server. These messages may include changes in calibration, alarm limits or updates of system parameters such as date and time.
- Heartbeat messages. Equipment that send data infrequently needs to connect to the central server at a fixed interval so the remote site is seen to be operational. The heartbeat message can be combined with the status message so that it is sent at least once in a predetermined period.
- Performance Reports. The remote monitoring system can be used to collect valuable information on the performance of the critical equipment. The analysis of this data can be used for a number of diverse purposes including improving plant safety and performance, triggering preventative maintenance actions and improving equipment design

Each of these message formats will have differing requirements on the communications system. These are summarised in Table 1.

Message Type	**Time Critical**	**Message Size**	**Direction**
Alarm	Yes	Small	Remote to control
Status	Yes	Small	Remote to control
Configuration	No	Small	Control to remote
Heartbeat	No	Small	Remote to control
Performance	No	Large	Remote to control

Table 1: Communication requirements for messages

The communications network provides a critical link between the field sites and the central control room. The long-term operational success of the communication system, is dependent on two factors. These are reliability and performance [1].

Reliability is a measure of the availability of the equipment over a period of time. Reliability figures indicate how well an item of equipment can be expected to perform, for a specified period, under a stated set of operating conditions. Reliability is directly affected by the quality of the equipment design and manufacture as well as the conditions under which the equipment is operated over its lifetime and the level of maintenance undertaken. The reliability will impact the time period the communications link will be unavailable. It may not be possible to quantify communications reliability when messages are sent over a third party communications network.

The second factor that will affect the success of a telemetry system is the performance of the communications links between the central site and the remote units. The performance of the communications links will be measured by the time it takes to make a connection (network latency), the speed of data transfer (network bandwidth) and the number of data errors that occur over a period (network error rate). When the number of errors that occur on a link becomes so high that the data information cannot be interpreted, then the link will become unusable. Error rate will also affect the bandwidth as messages will have to be resent if they are corrupted which will reduce the throughput.

Wireless Communications

Information between the field site and central control room can make use of any combination of third party or internally available communications infrastructures or can use a purpose built communications network.

The most common method of connecting equipment will make use of existing landline technologies such as the PSTN or a fiber optic cable in the plant. However as discussed above there are a number of applications where no convenient landline communications infrastructure is available. In these cases it may be necessary to use wireless communications between the field stations and the control room. However it is sometimes possible to use a hybrid of wireless communication from the field station to the closest landline which can be used to connect to the control room.

A number of wireless technologies can be used. These include GSM, satellite, microwave, dedicated radio links and wireless LAN. While it is useful to have two way communications between the remote site and the control room this is not always necessary. Even where two way communication is required this can be achieved with half duplex links. Acknowledgement of messages following communication will result in a higher degree of confidence in the monitoring system.

GSM

GSM networks have proliferated and coverage is available in almost all cities and towns and along major road networks. Often services are available from two or more service providers with a variety of pricing options. GSM networks also provide virtual private networks through gateways or APN's. GSM networks provide data communications via a number of options such as short messages (SMS), circuit switched data (CSD) or TCP/IP over 3G connections. With the large number of users it is very cost effective and the terminal equipment is widely available from a number of suppliers. GSM does have a limited range from a base station which is theoretically 35km. Practically however, the transmit power on the field equipment limits this to around 20km.

GSM is widely used for remote monitoring applications where coverage is available. In all three case studies presented this is either used as a primary or backup communication system. For critical data the reliability and performance of the GSM network should be considered. GSM network reliability and availability is high but networks do occasionally fail. There is the risk of data interception and hacking into equipment and GSM modems lock up on some networks and have to be reset periodically.

Satellite

Satellite communication offers the promise of global connectivity to a central control room. This is an ideal technology for mobile and fixed installations that operate in regions where there is no infrastructure (e.g. marine). There are two satellite technologies:

- Low earth orbit (LEO) satellites that orbit between 200km and 1200km above the earth's surface. They orbit in periods between 90mins and 2 hours. A constellation of 16 to 30 satellites can be used to cover the earth's surface. These satellites are ideal for short narrowband communication.
- Geostationary satellites that orbit at 35786 km above the equator and move synchronously with the rotation of the earth. These provide a direct link between a remote site and an earth station.

The cost of using satellite communication is often prohibitive for large data volumes but can be attractive for small infrequent messages such as critical alarms.

UHF Radio

UHF radio is a cost effective approach for concentrated point-to-point or point to multipoint communication. While range is limited to around 50km, clusters of remote sites can be connected to a single high site or repeater. In this way the range can be extended.

UHF radio has a significant benefit that the network is private and only data from the connected equipment makes use of the network. In addition no third party network is used and reliability and availability is directly controlled.

The capital cost and expertise required to deploy a radio network is often a deterrent to using this technology but properly designed and installed equipment will have short paybacks as there are no data costs. There are costs for the annual licence fee (minimal) and ongoing site maintenance.

A comparison of the communication technologies is summarized in Table 2.

	Landline	GSM	Satellite	Radio
Coverage	Limited	Limited	Global	Global
Latency	Low	Low	Low to high	Low
Bandwidth	High	High	Limited	Medium
Modem Cost	Low	Low	Medium	High
Data Cost	Low	Low	High	Low
Reliability	Good	Good	Excellent	Excellent
Power	Low	Low	Low	High

Table 2: Comparison of communication technologies

Antenna Considerations

The choice of antenna for wireless communication will depend on the signal strength and presence of interference. Omnidirectional antenna such a simple whip or dipole are low cost and easy to deploy. Directional antenna offer the benefit of greater power in one or more directions allowing for increased performance on transmit and receive and reduced interference from unwanted sources. Directional antenna need to be installed with the correct altitude and azimuth setting in order to line up the signal between remote and master stations. In a point to multipoint system the master station needs to be equipped with an omnidirectional antenna or a phased antenna array to provide for signals from different directions.

Power Considerations

Remote monitoring stations may not have a conveniently located utility power source which can be used to supply power to the telemetry equipment. Battery powered equipment can be used with either replaceable or rechargeable batteries. Solar photovoltaic (PV) panels can be used to recharge where there is adequate sunlight. The continuous current drain of the measurement and communications systems may require an impractical power supply design. In such cases consideration should be given to operate the equipment in a non-continuous mode.

Case 1: Electrical Distribution Monitoring

The performance of critical mining equipment often depends on a reliable and high quality electrical power supply. In addition the performance of the equipment and production cycles can be correlated with the load current.

Remote monitoring equipment is installed in the distribution panel or substation feeding the critical equipment. The voltage and current of a number of three phase feeders can be monitored simultaneously. Quality of electrical supply parameters such as rms voltage, transients, supply interruptions, unbalance and harmonics can be measured in addition to load current and energy consumption. An example of the site equipment installed at a rock crusher at a quarry is shown in figure 1.

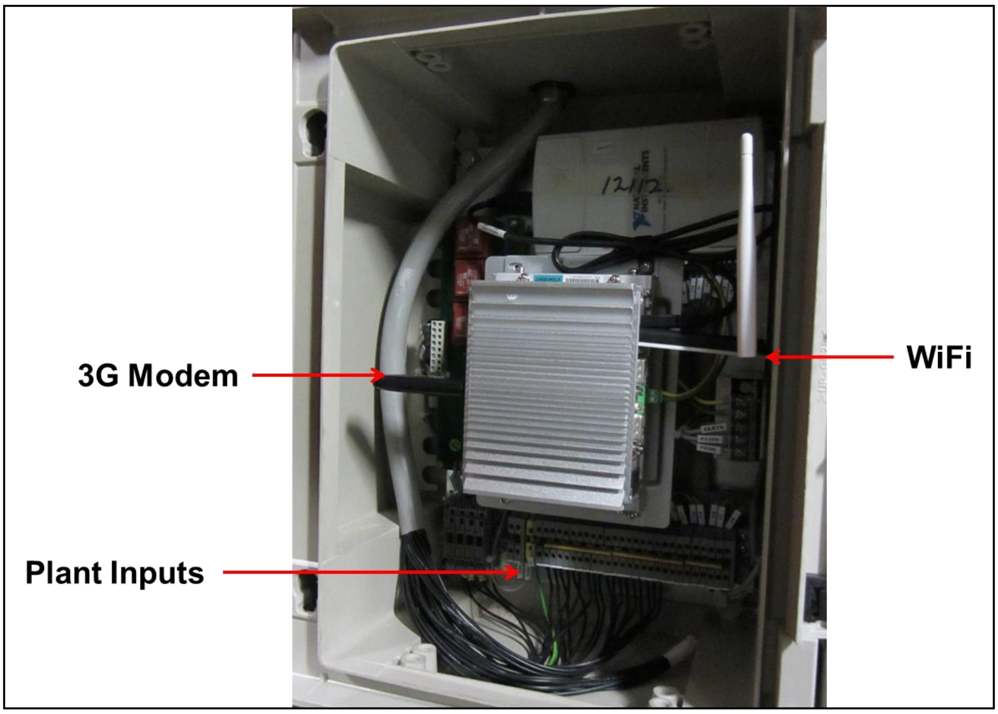

Fig.1 Remote electrical distribution monitor

GSM communications is used in the majority of these installations. Data is accumulated and sent at preset intervals to a central database. It was found that the GSM communications failed after a period between 1 day and several weeks. The problem was traced to the USB GSM modem becoming unresponsive. This problem persisted despite changing the modem and then trying different modem brands. The problem was eventually cured by performing a power reset on the modem when it became unresponsive. Since this modification was made data has been received continuously for the past 9 months. An example of the site data is shown in figure 2.

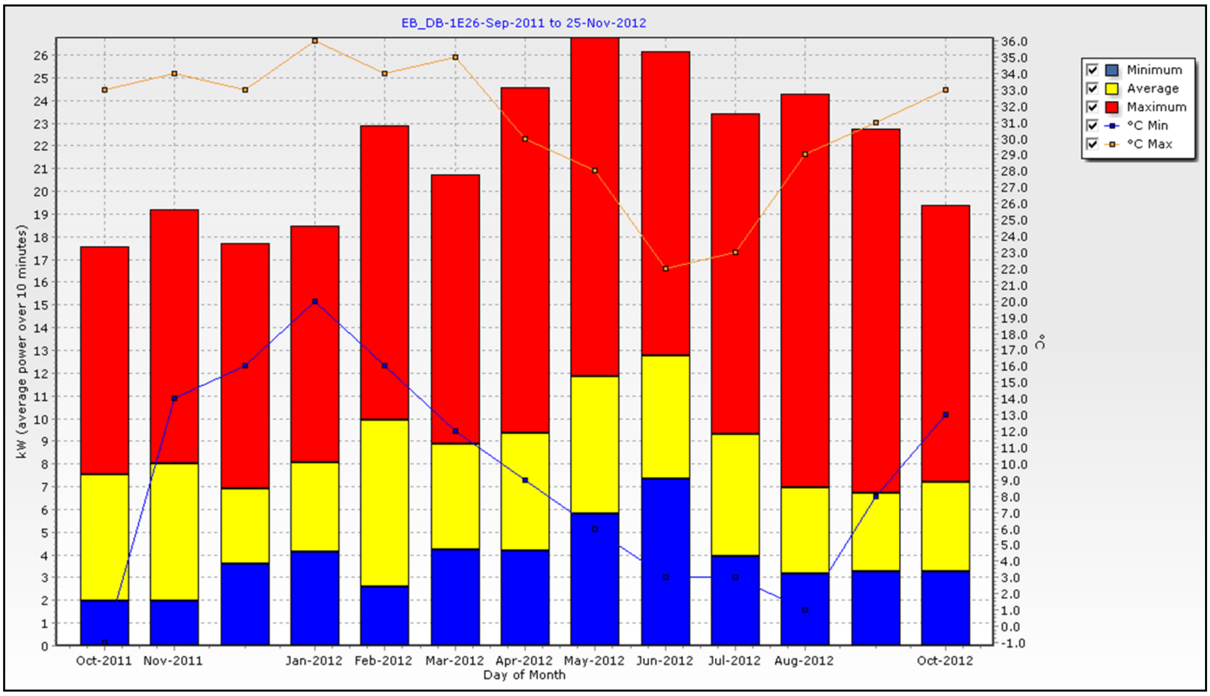

Fig. 2. Example data from remote electrical distribution monitor

Case 2: Rail Stress Monitoring

Rail freight lines make use of continuous welded rails where rail stress is responsible or contributes to the occurrence of rail breaks, track buckling (kick-outs), block joint failures, certain track geometry deviations and component failures in turnouts [2]. High risk locations were selected as remote monitoring sites to identify and alarm in the event of rail breaks or kick outs. These sites which are located along the rail line communicate alarms and continuous measurement data back to a central control room at frequent intervals.

A mix of communication technologies has been used which includes GSM, radio and satellite. While satellite offers a number of benefits it was found that the communication costs and equipment size was not attractive. GSM communications is used where the signal is available. A 5W UHF data radio is used to connect to a high site or repeater where there is no GSM. The radio high sites are linked to the control room using optical fibre.

A number of issues had to be considered for the implementation. These included:

- UHF Radio equipment was not suitable for outdoor installation and had to be housed in a weather proof enclosure
- Equipment was installed below a high voltage overhead line
- No power supply was available so the equipment is battery powered with a solar charger and communications is event triggered
- There is severe lightning activity in some regions where the equipment is installed
- Sites are difficult to access due to location and terrain

- Directional antenna are used as the RF signal had to be confined to limit spill over.

An example of the installation is shown in figure 3.

Fig. 3. Example of radio site installation

Case 3: Safety Monitoring of Mine Equipment

Equipment used for the loading of bulk explosives into drill holes on an open cast mine is remotely monitored to ensure safe operation. A number of parameters are monitored during the operation and if any safety limits are exceeded the operation is shut down. Previously production would be lost as a technician would have to be called out to fix the problem. Remote communications is used to report the fault to a control room which can assist the operator to restore safe operation. Where the problem cannot be fixed the diagnostics will identify the problem so the correct spares and skills are sent to the repair.

A mixture of GSM modes are used for wireless communication. When available a 3G data link is used for reporting alarms. SMS is used as a backup in weak signal areas. Circuit switched data is used for live remote control of the equipment as the latency on 3G connections can be unacceptably high.

In addition to remote communications to the control room the equipment also makes use of a wireless GPS receiver to check that the loading hose is at the correct drill hole. This uses a low power ISM band transmitter as the distance is less than 30m. A system block diagram is shown in figure 4.

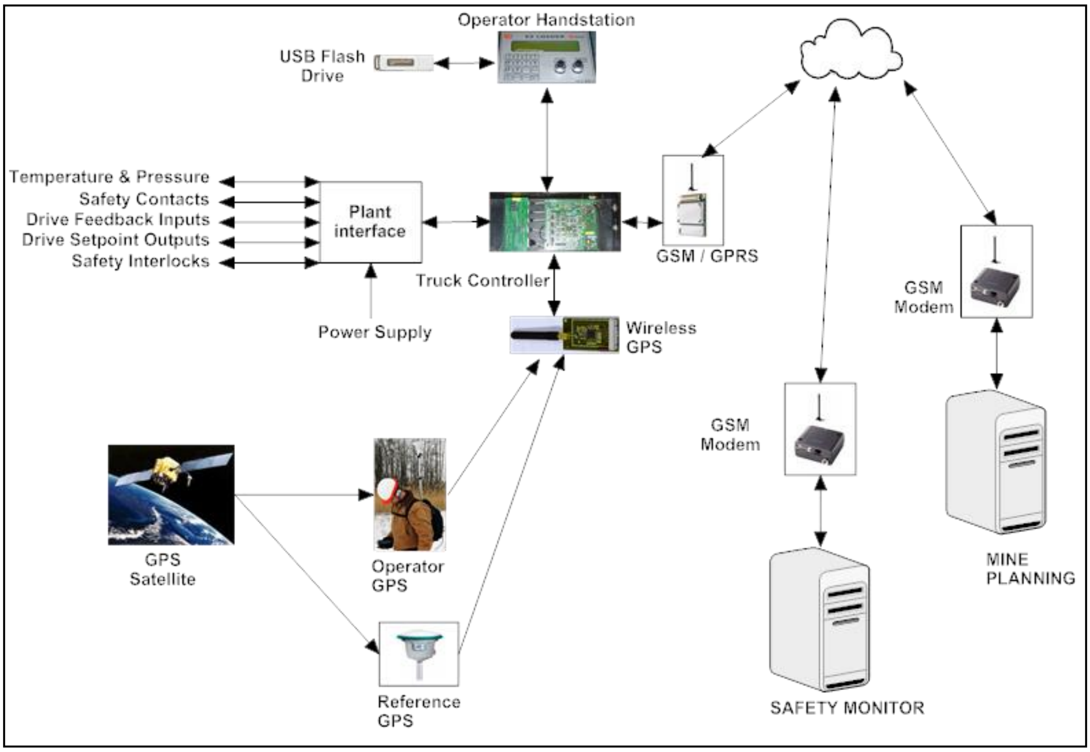

Fig. 4. Block diagram of remote safety monitor

Conclusions

Real-time remote monitoring can improve the availability and reduce the downtime of critical equipment. This reduces the consequent financial losses from production loss and critical plant monitoring equipment typically has very short payback times.

A number of proven wireless communications technologies are available which can provide connectivity to a control room. The choice of technology will depend on the application data requirements and site location.

References

1. Bailey D., Practical Radio Engineering and Telemetry for Industry. Newnes, Oxford, 2003
2. Cousins, T and Valentim, L., Remote Monitoring of Critical Plant Assets. Industrial Automation Conference – IDC Technologies, Johanesburg, May 2012