Telemetry Options for Small Water Systems

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Executive Summary

At present, information on cost-effectiveness and risks involved in integrating telemetry into small water systems is scarce. The overall goal of the telemetry research at Virginia Tech is to develop procedures for evaluating cost-effectiveness and risk assessment for small water systems. The goal of this report, as a component of the overall project, is to provide guidelines for telemetry selection and the costs involved.

This report builds on a previous study conducted by the U.S. EPA (Remote Sensing/Control for Small Water Systems: Literature Review/Assessment, 1998). The EPA report is complete in describing the four basic types of telemetry links but lacks details or supporting data from which its conclusions were drawn. This report expands on the EPA report and includes details of each type of system, its basic operation, and the associated cost. The end product of this report is a matrix of physical links and their parameters as associated with Supervisory Control and Data Acquisition (SCADA) to aid the small water systems in selecting the appropriate telemetry for their needs.

Keywords: small water systems, telemetry, remote monitoring, SCADA

1. Introduction

At present, there is little information on cost-effectiveness and risks involved in integrating a telemetry system. The overall goal of this project is to develop procedures for evaluating cost-effectiveness and risk assessment of telemetry for small drinking water systems and to apply the procedures to the design of a proposed telemetry system in Virginia. The specific objective of this report was to investigate all possible physical links and associated costs for transferring data from remote sites (i.e. water tanks) to a central location. A physical link consists of either a wired line or some other form of radio frequency channel. The technical term used to describe this system is “Supervisory Control and Data Acquisition” (SCADA). The main function of a SCADA system is to report data and control remote processes or events. It is not intended for rapid data transfer or real-time closed-loop control.

To understand this type of system, all possible physical links should be determined. A 1998 literature review and assessment report on remote sensing/controls for small water systems prepared for the U.S. EPA (Moore and Goodrich, 1998) covers a full range of topics regarding water quality, control devices, data acquisition units, sensors and remote telemetry systems. A modified and expanded version of the report was included in a book by Pollack et al. (1999). Section 8 of the report, "Commercial-Off-the Shelf (COTS) Data Transmission Options" and section 10.4, "Remote Telemetry Options" were of interest for this study. The general conclusion of the report is that, if phone lines are available, using telephone system and a COTS modem is the first choice for small water system telemetry. If phone lines are not available, a radio frequency (RF) or cellular link is suggested to transfer the data to an existing phone service. Phone lines would then be used to complete the data transfer. An RF infrastructure (private radio system) is preferred over a cellular infrastructure if one is already in place. For very remote locations, a satellite link may be the only option. The EPA report is complete on the four basic types of telemetry links, but lacks any details or supporting data from which its conclusions were drawn. This study expands the EPA report with details of each type of system, its basic operation, and associated cost. The expected end product of this study is a matrix of physical links and their parameters as associated with SCADA to aid the Public Service Authority (PSA) or other water system owners in selecting the appropriate system for their needs.

2. SCADA Physical Links

The physical link for a SCADA system can be put into one of four general categories, phone, RF, cellular, and satellite. It was decided that a more detailed list of links be investigated in this study.

The following telemetry links were analyzed:

- Telephone
- Radios operating at unlicensed Industrial Scientific and Medical (ISM) frequencies

- Radios operating at licensed very high and ultra high frequencies (VHF and UHF)
- Cellular radio system
- Satellite system
- Packet Data Services
- Local Multi-point Distribution Service (LMDS)
- Unlicensed Personal Communication Services (PCS) radios

In addition to the physical link, there are three ways in which the system can be owned and/or operated.

1. PSA owns the hardware and operates the system over a licensed or unlicensed RF link
2. PSA owns the equipment and operates the system over a link provided by a service provider
3. PSA contracts the complete task to an external provider

Service providers are cellular, satellite, or paging systems that charge for access according to either time or data transmitted.

3. Telemetry Costs Comparison

In order to compare costs of each type of system, two parameters were used: hardware costs and service costs. Hardware costs were limited to the physical modem (wired or wireless), which is the greatest hardware cost variable between the systems. Costs variances are due to the type of technology, frequency and output power used for the wireless link. Other hardware costs, such as sensors and water quality monitors, should be approximately the same for similar units from different manufactures or vendors. The main service costs consist of monthly connection fees and/or fees for the transmission of data through the network. Other fees may be applied at the discretion of the service provider

The physical modem for a wired telephone based-system consists of either an internal or external computer modem and does not include the computer itself. For a radio modem, the concept is similar in that it is simply the hardware required for transmitting or receiving the data and does not include data acquisition hardware or software.

Radio modems can be purchased as either OEM (original equipment manufacture) or in a ruggedized enclosure ready for use by the end-user. OEM units contain only the necessary hardware for the RF section and are designed to be a component in the completely enclosed modem with standard interface connectors to the outside world. Since most PSA’s are not in the business of building end-user RF modems, OEM units do not lend themselves as well to small water systems, but the costs are included in this report for comparison purposes.

3.1 Telephone

Using the telephone system for SCADA incorporates two one-time hardware and two monthly service costs. Hardware costs include service installation and a computer modem. If the telephone company has classified the installation as "typical", the cost is about $50, which is the same as the average modem cost. In this situation both hardware and software are inexpensive. If the installation is atypical, then the cost falls under the Special Construction section of the Tariff. Special construction costs are based on each individual site and what is required to bring service to that site. Depending on the site's location, these costs can be several thousand dollars or more. These costs cannot be accurately estimated because they vary from case to case. Service costs include monthly access fees and long distance charges where applicable. These costs vary with the type of plan and service provider; therefore, each PSA must set up the service to suit its needs.

3.2 Unlicensed ISM Frequencies

A license from the Federal Communications Commission (FCC) is not required to operate in the unlicensed industrial and medical (ISM) frequency bands. However, the user must follow the FCC Code of Federal Regulations (CFR) 47 Part 15 rules. Under those rules, a radio must accept any existing or new interference since others are free to operate radios on the same frequencies. Using these bands can reduce costs, since users do not have to apply for and purchase a license from the FCC to operate the radios. Table 1 lists the unlicensed ISM frequencies as determined by the FCC Spectrum Allocation Chart.

Table 1. ISM Frequencies

Frequency Band
6.765 MHz-6.795 MHz
13.553 MHz-13.567 MHz
26.957 MHz-27.283 MHz
40.66 MHz-40.70 MHz
902 MHz-928 MHz
2400 MHz-2500 MHz
5.725 GHz-5.875 GHz
24 GHz-24.25 GHz
61 GHz-61.5 GHz
122 GHz-123 GHz
244 GHz-246 GHz

Although there are many frequency bands available, a review of SCADA hardware vendors produced the most used ISM frequencies available from COTS equipment (Table 2). These two frequencies commonly have the most off-the-shelf components available for low-cost radio link construction under FCC CFR 47 Part 15 rules.

Table 2. Commonly Used ISM Frequencies

Frequency Band
902 MHz-928 MHz
2400 MHz-2483.5 MHz

One major cost associated with an unlicensed system is the necessary radio modem. Table 3 shows a number of ISM hardware vendors' products and prices. Comparing the 900 and 2400MHz equipment, the data rate is essentially the same while the average cost for the 2400MHz equipment is $400.00 higher. A general rule is as a radio's operating frequency increases, the cost for that radio's components increase as well. Additional costs include antenna towers and installation, which will be addressed later in the report.

Table 3. ISM Modem Cost

		Data Rate in Kbps		Power	Price		
Company	**Model**	**900 MHz**	**2400 MHz**	**Watts**	**900 MHz**	**2400 MHz**	**Unit Type**
YDI	910	78.6		20mW	$ 528.00		Enclosed
	2400		250.0	10/100mW		$ 1,175.00	Enclosed
Xetron	Hummingbird	128.0			$ 850.00		OEM
	Hornet		115.2			$ 150.00	OEM
Utilicom	LR2030	57.6			$ 1,249.00		Enclosed
			57.6			$ 1,299.00	
GRE America							
	6000N-5	128.0			$ 1,049.00		Enclosed
	6000NV-5	128.0			$ 1,129.00		Enclosed
	6000N	128.0			$ 1,149.00		Enclosed
	6000NV	128.0			$ 1,229.00		Enclosed
	8000N-5		128.0			$ 1,449.00	Enclosed
	8000NV-5		128.0			$ 1,529.00	Enclosed
	8000N		128.0			$ 1,549.00	Enclosed
	8000NV		128.0			$ 1,629.00	Enclosed
	2000-64K		186.0			$ 2,129.00	Enclosed
FreeWave	DGR 115H	115.0			$ 1,300.00		Enclosed
	DGMR 115W		115.0			$ 1,750.00	Enclosed
		Data Rate in Kbps			Average Price		
Average		**900 MHz**	**2400 MHz**		**900 MHz**	**2400 MHz**	
		111.4	137.3		$ 1,060.38	$ 1,406.56	

3.3 Licensed VHF and UHF Frequencies

The licensed frequencies of interest for the SCADA application are in the very high frequency (VHF/30-300MHz) and ultra high frequency (UHF/300-3000MHz) bands. However, the FCC requires an operating license to use these bands which adds an additional cost. Users of these bands benefit by not having the interference from other radios. In addition, the allowed output power of the transmitter is higher than ISM, which translates into longer distances between the central and remote location. Table 4 lists the most commonly used VHF and UHF frequencies as determined by SCADA hardware vendors.

Table 4. Commonly used VHF/UHF Frequencies

Frequency Band
66 MHz-79 MHz
132 MHz-174 MHz
216 MHZ-266 MHz
380 MHz-512 MHz
928 MHz-960 MHz

In addition to the costs for using the frequency, the user must also purchase RF hardware. Table 5 lists a number of vendors and their products and prices. Data rates stated in the table are the same as standard telephone modems; thus they are referred to as RF modems. A higher data rate can be obtained from the ISM modems for about the same cost. However, for this SCADA application, distance is more important and a lower data rate is acceptable. The higher cost of the VHF/UHF modems is primarily due to higher transmitter power.

Table 5. VHF/UHF Modem Cost (All units are enclosed)

Company	Model	Frequency(MHz)	Data Rate(Kbps)	Power(W)	Price		
YDI	192CM	216-226	19.2	5	$ 675.00		
		430-470	19.2	5	$ 675.00		
	192MM	136-175	9.6	5	$ 695.00		
		390-470	9.6	5	$ 695.00		
	192RR	450-480	19.2	8	$ 2,235.00		
Teledesign	TS4000	132-174	19.2	5	$ 1,160.00		
		380-512	19.2	5	$ 1,160.00		
		928-960	19.2	5	$ 1,160.00		
Esteem	95	66-79	9.6	1	$ 1,695.00		
	192V	66-79	19.2	1	$ 1,895.00		
	192M	150-174	19.2	4	$ 2,395.00		
	192C	450-470	19.2	4	$ 2,395.00		
	192F	400-420	19.2	4	$ 2,395.00		
			Average Price				
66-79MHz		**132-174MHz**		**216-226MHz**	**380-512MHz**		**928-960MHz**
9.6Kbps	**19.2Kbps**	**9.6Kbps**	**19.2Kbps**	**19.2Kbps**	**9.6Kbps**	**19.2Kbps**	**19.2Kbps**
$ 1,695.00	$ 1,895.00	$ 695.00	$ 1,777.50	$ 675.00	$ 695.00	$ 1,772.00	$ 1,160.00

3.4 Cellular

Similar to the phone system, the cellular infrastructure was originally designed for voice communication. Also similar to the phone system, procedures were developed to use the cellular system for data transmission in addition to voice. Circuit switched data was first to break into the cellular data market. Circuit switched cellular is based on the same concept as a telephone modem, but uses the wireless cellular network. Next to evolve was the Cellular Digital Packet Data (CDPD) that still uses the voice channel, but sends data packets addressed to the receiver. The transmitter must be an active node (connected) to the network to send the data packet, but the receiver is not required to be active to receive the packet. If the receiver is an active node then the data packet is delivered immediately, if not, the system stores the data until the user is connected and the data sent. The most recent usage of the cellular infrastructure has been to use the control channel to send packets of data. Cellemetry and Aeris Microburst are the service providers for this type of service in the U.S. The data service providers maintain hubs to which the cellular service provider forwards the data packet. The customer can then access the data using one of several standard network protocols (interfaces).

Circuit Switched Cellular

Circuit Switched Cellular is the wireless equivalent of the telephone modem. A connection is established between the two parties and the data is passed. Since this type of service requires a connection to be established and held for the duration of the data transmission, the data costs are based on time and not the amount of data sent. To determine data service costs, users must contact the local provider to check for special rates or packages. The RF hardware for circuit switched cellular is around $300.00 for an OEM unit with an average cost of $700.00 to include a weatherproof enclosure.

Cellular Digital Packet Data (CDPD)

CDPD is a recently developed technology for sending and receiving data over the existing cellular infrastructure. Cellular RF voice channels are not in use 100 percent of the time, and CDPD makes use of the unused channel time to send packets of data. The user becomes an active node in the network once the mobile user (in a cellular system the base station is in a fixed location but phones are not in a fixed location and are mobile) is registered on the system. This means that a registered user's data sent to or from the mobile will be delivered immediately. Since CDPD is a packet-switched network sharing the radio channel, there is no connection time charge. CDPD usage is measured in terms of the amount of data transferred, rather than how long the user is registered on the network. This contrasts with Circuit Switched Data where the customer is billed for connect time whether or not data is being transferred. Like the telephone system, the CDPD user only needs to buy a modem and establish an account with the provider to use the existing system. The system operator handles maintaining and upgrading the infrastructure while the customer is responsible for the modem. Tables 6 details the CDPD hardware costs.

Table 6. CDPD Modem Cost

Company	Model	Data Rate Kbps	Qty	Price Ea	Unit Type
Standard Communications	CRM4100		1 to 99	$ 250.00	OEM
			100 to 999	$ 195.00	
			1000 to 5000	$ 172.00	
			5001 to 10000	$ 150.00	
DataRemote	CDS-8800		1 to 2	$ 595.00	OEM
			1 to 2	$ 695.00	Enclosed
Sierra Wireless					
Circuit Switched with options	Dart 200	19.2	1	$ 595.00	Enclosed
CDPD and Circuit Switched	MP200	19.2	1	$ 995.00	Enclosed

The CDPD service is dependent on existing cellular coverage and the provider having the additional equipment required for the CDPD. The user cost for CDPD covers the hardware and fees to use the system. Fees are split into a one-time connection fee and the monthly cost for sending data. Data costs are based on the amount of data sent in a month's time; if the limit set by the contract is exceeded, then an additional cost is incurred. Table 7 details the CDPD service costs.

Table 7. CDPD Service Cost

Service Provider/ Services	Activation Fee	Price/ Month	Data KB Month	Additional $/Kb
Bell Atlantic	$25.00			
Unlimited		$54.95	Unlimited	
AT & T	$45.00			
Base Plan		$8.00	0	$0.055
Mobile I		$19.00	200	$0.050
Mobile II		$49.00	1000	$0.050
Local Unlimited		$54.99		
National Unlimited		$64.99		
GTE	$45.00			
Bronze Plan		$15.00	125	$0.120
Silver Plan		$49.95	1000	$0.080
Gold Plan		$99.95	3000	$0.060

Cellemetry

Cellemetry also uses the existing AMPS cellular infrastructure. Cellemetry is similar to CDPD except that it uses the control channels instead of the voice channels. At the present time, Cellemetry has 90%-95% coverage in the United States. That coverage is growing constantly as new cellular systems offer the service. Adding the Cellemetry service to an existing cellular system requires an upgrade to the Mobile Switching Center (MSC) instead of each individual base station. This makes it easy to offer the service, which is one reason why most cellular systems have upgraded.

Cellemetry is a packet data service that can send a 32-bit packet to or from a remote transceiver to the Cellemetry Service Bureau. The Service Bureau acts as the interface between the usres' central location(s) and remote monitoring transceivers. The data received at the MSC from the remote transceiver has an electronic serial number (ESN) which commands the MSC to forward the data to the Cellemetry Service Bureau. Other information in the data packet commands the Service Bureau which customer should receive the data. The end customer can access the data by the Intranet, Internet, or dial-up modem. Sending data to a remote transceiver follows the reverse path; the customer sends the data packet to the Service Bureau, which sends the packet to the proper MSC to be forwarded to the remote transceiver.

Cellemetry hardware costs are listed in Table 8. The AutoSoft unit comes complete with input for alarm monitoring while the Standard Communications company offers OEM units. To date, Autosoft is offering alarm monitoring with its Water Sentinal for $15.00/month and plans to add daily monitoring for $20.00/month in the near future.

Table 8. Cellemetry Modem Costs

Company	Model	Data Rate Kbps	Qty	Price Ea	Unit Type
Standard	CMM7600	19.2	1 to 99	$ 146.00	OEM
Communications			100 to 999	$ 135.00	
			1000 to 5000	$ 126.00	
			5001 to 10000	$ 113.00	
Ericsson	AM-10				OEM
AutoSoft	Water Sentinal	19.2	1	$ 700.00	Enclosed

Aeris Microburst

Aeris Microburst uses the same control channel technology as Cellemetry and is, therefore, a direct competitor. The main differences are that Aeris uses a 55-bit data packet and refers to the "Cellemetry Service Bureau" as the Aeris Hub. Cellular systems that wish to offer this service simply need to update their MSC switch translation tables to add the Destination Point Code (DPC) of the Aeris hub system that receives the data. Coverage is approaching 90% of the cellular service area with new cellular providers being added daily. Hardware costs are listed in Table 9, but service costs are still being determined due to the newness of the Aeris Microburst service.

Table 9. Aeris Microburst Modem Costs

Company	Model	Data Rate Kbps	Qty	Price Ea	Unit Type
Wireless Link Corp					
	CVDM-3	19.2	1 to 9	$ 199.00	OEM
			10 to 99	$ 169.00	
			100 to 999	$ 144.00	
			1000 to 9999	$ 123.00	
			10000+	$ 111.00	
Standard Communications	CMM8600		1 to 99	$ 146.00	OEM
			100 to 999	$ 135.00	
			1000 to 5000	$ 126.00	
			5001 to 10000	$ 113.00	
PGI Inernational	APM4		1	$ 500.00	Enclosed
	AMR6		1	$ 500.00	Enclosed
	APC10		1	$ 500.00	Enclosed

3.5 Satellite

There are three main types of satellite systems that offer SCADA type applications: Low-Earth Orbit (LEO), Geosynchronous Orbit (GEO), and Very Small Aperture Terminal (VSAT). Companies investigated in the LEO group are ARGOS, Orbcomm, and Globalstar. Inmarsat is a GEO satellite, and VSAT companies are GE Americom and Hughes Network System. The cost given by these companies is representative of what one would expect from other companies offering similar services. LEO, GEO and VSAT operate on the principle of a shared hub or earth station. The hub station is responsible for receiving data from and sending data to the remote terminals, and it is shared with the other satellite system customers. The system works by transmitting data from a remote site to a satellite and then from the satellite transponder to one of several hubs on the earth. For the user to obtain data, a terrestrial connection to the hub must be established and the data downloaded. To send data to a remote terminal (outbound link), the user sends the data to the hub (via the terrestrial link) and the hub transmits the data to the remote terminal.

Low Earth Orbit and Geosynchronous Orbit

Orbcomm, Inmarsat, and Qualcomm offer two-way data transfer while Argos offers data collection only. In addition, Argos is a store and forward system with the satellite in view ten to fifteen times a day to allow the data to be transmitted from the remote terminal and stored on the satellite. When the satellite passes over the designated hub, the data is transmitted from the satellite to the hub where the customer retrieves it. A satellite system of this type is not capable of providing real or near real-time data for the customer. Orbcomm, Comsat-C, and Qualcomm systems are designed to have a satellite in view at all times, thus allowing data to be transmitted or received anytime. As with CDPD, the customer needs to purchase a hardware RF modem and subscribe for service from the respective system. Hardware modem costs are shown in Tables 10 and 11 along with data transmission costs that require a quote from the service provider. Quoted data pricing is addressed later in the report.

Table 10. LEO Satellite Services

Satellite	Service Provider	Hardware Provider	Model	Price	Data services Price
Orbcomm					
	Sat-Ex	Sat-Ex	Panasonic KX-G7000	$ 999.95	Requires a Quote
			Stellar SC	$ 1,099.95	Requires a Quote
	Scientific Atlanta	Scientific Atlanta	FSC1000-AC-1	$ 440.00	Requires a Quote
	Spatia	Spatia		$ 1,350.00	Requires a Quote
Inmarsat	Comsat				$0.20 per 1/4 Kb or 256 bits or 32 bytes/character
		Trimble Navigation		$ 3,685.00	Requires a Quote
		Raytheon Marine	1500-C no computer	$ 3,000.00	Requires a Quote
NOAA	**Agros**				
	(one way data)	Sutron	8210	$ 3,110.00	5$ day per transmitter
					for 10 tx per day
Qualcomm	Qualcomm	Qualcomm		$ 4,500.00	Requires a Quote
	Omni Tracs				
Iridium	Sevenseas Comm			$ 3,000.00	$1.99/minute with a 1 minute minimum, voice only

Table 11. VSAT Services

Satellite	Service Provider	Hardware Price
GE Americom		
	Spacenet	$ 3,500.00
HNS		
	HNS	$ 3,500.00

VSAT

Satellites used for VSAT services have limited data rate capacity. Satellite owners sell large chunks of this capacity to service providers. Service providers then resell the capacity in smaller chunks to individual VSAT customers. The portion of capacity sold to the user is referred to as the space segment. To determine the amount of space segment that a user requires, a service provider looks at the proposed VSAT system and determines the maximum data throughput for the whole system. The service provider then allocates the space segment for the customer based on the data needs. The space segment is shared between all of the sites for that particular user. For example, if a user has 50 sites and the space segment was determined to be 200Kbps at a cost of $5000 per month then the cost per site/month is $5000/50, which is $100/month per site. More sites can be added using the allocated space segment as long as the data requirement does not exceed 200Kbps. If the data needs change, the space segment can be adjusted to reflect the increase or decrease in data. Estimated data costs for several scenarios are investigated later in the report.

4.0 Packet Data Services

RAM Mobile Data (MOBITEX)

RAM Mobile Data is a BellSouth Wireless Data (BSWD) company that provides a packet switched data only service, called MOBITEX, through their own private UHF radio system deployed throughout the world. In the Unite States the system operates in the 900MHz-frequency band. Coverage is generally limited to metropolitan areas such as Washington D.C., Los Angeles, and Dallas, Texas, but the service can extend into the surrounding areas. A BSWD representative should be contacted to find out if an area is covered.

The service is provided by BSWD and the hardware to access the system is purchased from various companies. MOBITEX has an open system architecture that allows any manufacture to design and build communications equipment as long as it complies with the publicly available specifications. Service costs are kept low by charging the customer only for successfully transmitted data packets. Costs for service are application based and therefore BSWD will need specific information on the number of sites and data requirements before a cost can be determined.

MOBITEX has a data rate of 8Kbps with a maximum data packet size of 12 bytes. The system operates using addressed data packets transmitted to the closest base station, which then forwards the data to the appropriate address. If the address is within the range of the base station, the message is sent directly to the receiver; if not the data packet is sent to the MOBITEX network for distribution. If the receiver is connected to the network the message is forwarded, but if it is not connected the data can be stored for up to 72 hours and retrieved at a later time. Connections to the network can be either wireless or one of several standard network protocols (leased line, ISDN, Internet, dial-up, or X.25)

Table 12. Mobitex Modem Costs

Company	Model	Data Rate Kbps	Qty	Price Ea	Unit Type
Motorola	MRM660	19.2	1	$ 995.00	Enclosed
RIM (Research In Motion)	900		1	$ 995.00	OEM
			additional	$ 395.00	

ARDIS

ARDIS, at present owned by American Mobile Satellite, is a two-way packet data communications network using the Motorola 800MHz DataTAC system deployed throughout the United States. The system architecture is the same as MOBITEX except the DataTAC system offers data rates at up to 19.2Kbps and a packet size of 240 characters (bytes). The system covers most of the top metropolitan areas in the U.S. and extends to other countries (which may operate on different carrier frequencies). A potential user must contact ARDIS to determine if service is available in a particular area.

Table 13. ARDIS Modem Costs

Company	Model	Data Rate Kbps	Qty	Price Ea	Unit Type
Specialized Control Systems	Datapac		1	$ 649.00	Enclosed
			50	$ 595.00	
			100	$ 575.00	
			Over 100	$ 552.00	
RIM (Research In Motion)	801D		1	$ 995.00	OEM
			additional	$ 395.00	

Local Multipoint Distribution Service (LMDS)

The FCC allocated the 27.5-31.3GHz-frequency band for Local Multipoint Distribution Service (LMDS). At these frequencies, the transmission is purely line-of-sight (LOS) and does not lend itself well to remote monitoring. The wide channel bandwidth is designed for high data rate applications, which is not desirable for water resources monitoring. Since LMDS is a new application in the frequency spectrum, equipment will remain costly (5K-10K per unit) until the market is better established and the demand for hardware increases. Without a detailed investigation, it can be concluded that LMDS has no application to Water Resources SCADA at the present time.

Unlicensed Personal Communication Services (PCS)

Operating in the 1910-1930MHz and 2390-2400MHz frequency bands, PCS allows for SCADA telemetry type of applications under FCC CFR 47 Part 15.301. This frequency band was previously designated for Private Operational-Fixed Microwave Service (OFS) under FCC CFR 47 Part 101 and is still in use by these operators. Use of a PCS service must be coordinated with the OFS user in the geographic region of interest through the FCC. Details of the limitations and procedures for implementing a PCS system are explained in FCC CFR 47 Part 15.301-15.323. Although this is a viable solution for SCADA telemetry, hardware for this unlicensed band has been slow to come onto the market due to the limitations set by the FCC rules, and therefore, no associated cost could be obtained.

5.0 Transmission Distance for RF Telemetry Links

The maximum distance that a RF link will pass valid data depends upon several factors:

- distance between transmitter and receiver
- antenna height
- radiated power
- receiver sensitivity
- carrier frequency
- the terrain
- the earth's horizon
- data error correction

For SCADA systems the end-user has some control over the frequency, antenna height, and the radiated power. The radio design, FCC, and the terrain on which the system is deployed set the other parameters.

Figure 1 shows that the curvature of the earth poses a problem with the line of sight (LOS) transmission due to the optical horizon. The horizon sets the limit on how far apart two antennas can be placed before the path is no longer LOS. For a terrestrial RF link placing the antennas at a higher elevation can increase the LOS distance. The relationship between the maximum distance in miles and the antenna heights in feet is stated in the equation below where ht and hr are the transmitting and receiving antenna heights and the distance D_{max} is d_1 plus d_2.

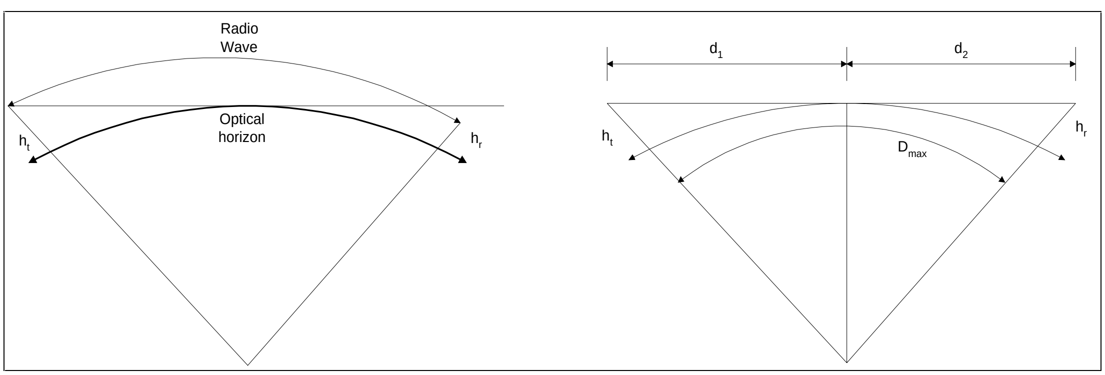

Figure 1. Radio Horizon

(Adapted from Dennis Roddy, Microwave Technology, 1986)

$$D_{\max}(miles) = \sqrt{2h_t(ft)} + \sqrt{2h_r(ft)}$$

This equation puts a pessimistic limit on the maximum transmission distance, because in reality the radio waves can and will propagate further depending on the frequency. As a general rule, VHF (30-300MHz) frequencies are capable of distances beyond line of sight propagation and are less limited by the earth's horizon, while UHF (300-3000MHz) frequencies are mainly applicable to line of sight and are limited by the horizon. By setting the transit and receive antennas to the same height in the equation, a plot of antenna height versus LOS distance can be created (Figure 2).

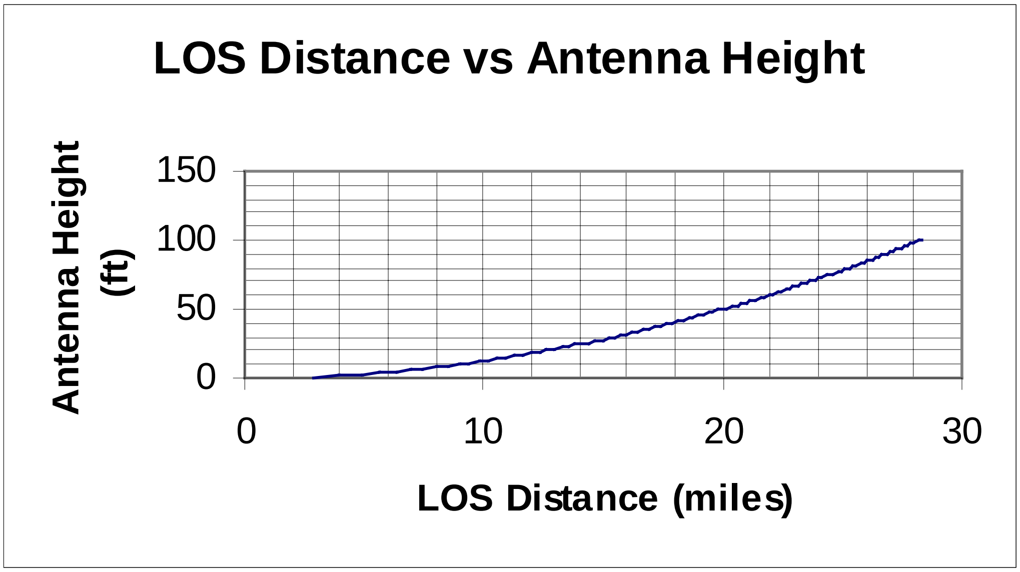

Figure 2. LOS Distance vs Antenna Height

The frequency selection occurs as a parameter of the type of system selected for the data transmission network. Using the free space path loss equation given below, the maximum distance, D, can be calculated for fixed receiver sensitivity. The wavelength, lambda (λ) is indirectly proportional to frequency. Therefore, as the frequency increases lambda decreases and the free-space path loss L_{FS} increases reducing the received power for a fixed transmitter power.

Thus

$$L_{FS} = 21.98 + 20\log\left(\frac{D}{\lambda}\right)dB$$

since,

$$L_{FS} = \left[\Pr(dBm) - Pt(dBm)\right]dB$$

it can be shown that

$$D(meters) = \frac{\lambda 10^{\left(\frac{|\Pr - Pt|}{20}\right)}}{4\pi}$$

where, the powers P_t and P_r are expressed in dBm.

When the received power is below the receiver sensitivity the receiver can no longer discern the desired signal power from the received noise power. Typical receiver sensitivity for these types of radios is –90dBm. The distance versus radiated power, for the frequencies of interest, were plotted by setting the received power (Pr) equal to –90dBm and assuming an isotropic receiving antenna. In the graph the LOS distance limitation due to the earth for antenna heights of 100 feet has been plotted. The curves on the graph are in order represented in the legend. 70 MHz is the …….. line next is the 150 MHz and the last is the 2400MHz line (------)

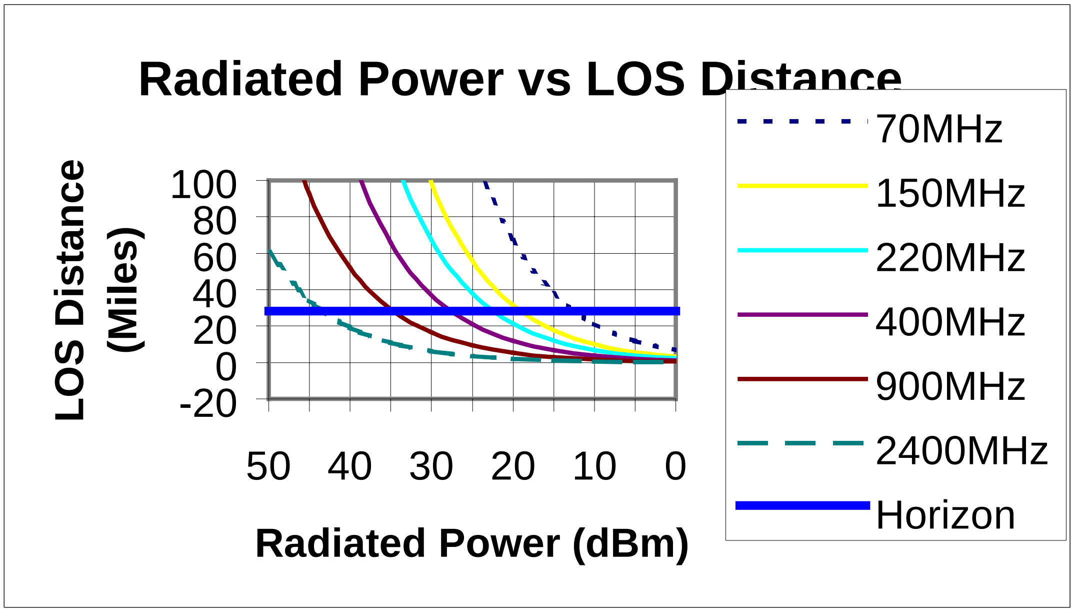

Figure 3. Radiated Power vs LOS Distance

The maximum LOS distance for each frequency can be determined by finding the transmitter power in Table 14 and the antenna gain from the specification sheet for the selected antenna. To calculate the radiated power, add the antenna gain in dB or dBi to the transmitter power in dB. If no antenna has been selected, then assume a gain of 0dB to calculate the radiated power. For example, if the antenna has 0dB of gain and the transmitter power is 10dBm, then the radiated power is the 10dBm plus 0dB, i.e. 0dBm (the transmitter power). Using the same transmitter (10dBm) and an antenna gain of 6dB, the radiated power is now 10dBm plus 6dB, i.e. 16dBm. By using the selected frequency and calculated radiated power, the maximum LOS distance can be determined from Figure 3. A detailed example on how to use the chart should help clarify this process. For a frequency of 915MHz, the transmitter power is 30dBm (Table 14) and selected antenna gain is 5dB making the radiated power 30dBm plus 5dB, i.e. 35dBm. Locating 35dBm on the X-axis of Figure 3 and moving up that line until the 900MHz curve is intersected (this curve is closest to 915MHz), the LOS distance can then be read from the Y-axis. For this example the LOS distance is about 30 miles. These graphs are not intended to be a design tool for the RF link, but are intended to give the user a general overview of how antenna height and frequency affect the distance between the transmitter and receiver for a usable link.

Table 14. Typical Transmitter Power

Frequency	Transmitter Power (dBm)
70MHz	30.0
150MHz	37.0
220MHz	37.0
400MHz	37.0
950MHz	37.0
915MHz	30.0
2400MHz	30.0

6.0 SCADA Telemetry Link Costs Matrix

Several factors can affect the cost of a telemetry link. These include but are not limited to modulation type, carrier to noise ratio (C/N), transmitter power, receiver sensitivity, and antenna gain. These parameters are important in a detailed link analysis, but hold no relevance as a selection tool for the general consumer. A matrix needs to be devised that can be used by any PSA to determine what type of SCADA telemetry system is best suited for their application. Developing such a matrix requires a few select parameters. The main concerns for a first cut at the telemetry link comparison were determined to be cost and range. Costs that should be determined for the scope of this study are RF hardware and commercial service. RF hardware costs are for the radio portion only and do not include data processing unless it is sold as part of the radio modem. Commercial service costs are those costs incurred to access or send data over a commercial system. As with any listed or quoted price, the prices are subject to change. Once the RF hardware costs and transmission distance are determined, the data transmission costs must be estimated to complete the matrix.

Commercial services charge either per data packet and/or by the total amount of data passed through the network over a month's period, or by the amount of time users are connected to the network. These costs are dependent upon transmittal repetition rate (how often data is sent) and/or number of bytes in each transmission. The repetition rate is a variable that the PSA determines depending upon the need for information. The bits-per-transmission is dependent on the data acquisition unit (DAQ) and modulation scheme used in the transmitter. A DAQ is needed to convert the analog signals from the monitoring devices into digital data and store the information until transmission time. A device inside the DAQ known as an analog to digital converter (ADC) is used for this task. ADCs convert the analog signal to a digital signal of N bits in length depending on the ADC. For the analysis, a DAQ with a 16-bit ADC (N=16) and some form of binary modulation is assumed. Binary modulation results from sending all 16 bits in the transmission instead of a lesser number with a more complex modulation scheme.

Estimating data service costs requires several pieces of information:

- number of bytes per transmission
- number of transceivers (remote locations to be monitored)
- number of transmissions per day for each transceiver
- services available to each remote location

The first three items are easily determined from a system diagram showing the remote locations, what data is required, and how often it is to be monitored. The fourth item requires the knowledge of the type of wireless data service that is available at each remote location. Once all of these items are determined cost comparisons can be made.

To obtain costs for comparison, a scenario consisting of 25 remote locations was chosen. Twenty-five units were thought to represent a reasonable number of units that may be utilized for each type of system for SCADA telemetry links. Transmission repetition rates were chosen for a maximum (one transmission per minute), minimum (one transmission per day), and several median rates to allow for a wide variance. A 2-byte data transmission was chosen to represent a single measurement from a DAQ with a 16-bit DAC, which may be a tank level, water pressure, oxygen content, or some other water parameter. Where possible, costs were directly determined from information on hand. For the others, service providers were given the scenario information and asked to quote prices for data transmission. Service providers were asked that the quoted prices include all possible scenarios without regard to cost. The final link required is the link used to transfer data from the service provider to the PSA for display and evaluation. Of all the available options, the lowest cost connection, Internet, was chosen.

The RF hardware costs and estimates for every type of data link using 25 remote data transmitters at various intervals are summarized in Table 15. The prices quoted in Table 15 are representative of what a PSA could expect using a particular system. It must be noted that prices change over time and pricing on any data service is negotiable. For several services, the price per month is excessive and has only been included for comparison. Although the life span for hardware could be ten to twenty years, from an accounting standpoint it will depreciate to a less than marketable value in five to ten years. Cost per year for the investigated systems is calculated for a five- and ten-year life span (Tables 16 and 17). For the cost-per-year calculation the one-time hardware cost is spread over the life span (5 or 10 years) and any monthly data costs (multiplied by twelve) are added. The ISM/VHF/UHF systems do not include the required infrastructure (antennas, towers, etc.). These costs must be added in to get a more accurate cost estimate. These cost estimates should give the PSA a more realistic cost basis for comparing different systems.

A PSA could use this type of table in the initial pricing for data services to reduce the number of candidates and then could further reduce the pool, as more details of the system requirements are determined. To obtain an estimate of the data requirements, determine the total transmissions per day for the service of interest, assume each transmission is one 16-bit sample and multiply the number of transmissions by 16 bits to obtain total number of bits per day. The service providers can use this number to estimate data transmission costs for their system. The next sections give a brief summary of each type of system documented in Table 15 and describe how the costs were determined.

ISM/VHF/UHF

ISM, VHF and UHF offer the advantages of no direct monthly data costs, in addition to good range. The PSA would require an engineering firm to do a propagation study to determine the configuration for the system and determine if additional repeater sites are required. In addition, the PSA must implement and maintain the infrastructure that could incur capital expenditures for antenna towers and repeater sites. Since there are a large number of factors affecting tower costs that are specific to the system and the individual PSA, exact costs are beyond the scope of this report. However, discussions with a few companies revealed that the cost for an installed antenna tower range from $1000 to more than $250,000 per site. However, for this type of application, a lower end tower, with costs around $1000-$3000 per site, is more realistic.

Cellular (CDPD)

Costs were determined from Table 7 (CDPD Service Costs) that listed the allowed Kbytes for a fixed cost. Hardware costs are inexpensive and more companies are beginning to develop equipment for this application. On average, data costs tend to be low with GTE taking the lead. GTE offers the advantage of being able to spread the data limits for a month across several units, whereas AT&T and Bell Atlantic cannot. Bell Atlantic previously offered several rate plans, but recently developed a single price, unlimited data plan for all CDPD service. CDPD offers great ease of adding an additional unit to a remote location, as long as the service is available.

Cellular (Microburst)

Cellemetry and AERIS offer data service using the existing cellular network control channels. Using the control channels will limit the transmission to no less than once per hour. This is done to prevent overloading the channel and cause cellular phone users to suffer extended delays in connecting to the system. One advantage over CDPD is that control channels operate at a higher power than voice channels, and therefore offer a greater range. The monthly data costs are fixed and not dependent on the number of transmissions in a month. The $20 per month is an estimated cost derived by slightly increasing the costs quoted from the service provider. Microburst is a new offering of cellular systems and it is expected that the price per unit will decrease as usage increases.

Satellite (Orbcomm)

Orbcomm was not designed to handle transmissions at the rate of one-per-minute shown in Table 15. Only Sat-Ex quoted a price for this scenario. The cost is excessive and is shown simply for comparison. One transmission every 30 minutes or even one-per-hour still results in excessive monthly data costs. Orbcomm becomes more cost effective when the transmissions are twice a day or less. For the scenario of a two-byte transmission, the system is not being utilized for optimum performance. Sending larger data packets consisting of multiple measurements makes better utilization of the system since there is a connection charge for every packet transmitted to the satellite. The larger the data packet, the lower the cost per byte for the connection charge. Costs for the Orbcomm service were arrived at through quotes from service providers.

Satellite (LEO/GEO)

In this group of satellite services, only one is actually designed for the small data packets that can be used in the SCADA system. Comsat-C was designed with this application in mind and charges only for data transmitted over the system. Pricing for Comsat is calculated from the total number of Kbytes per month for all units combined, multiplied by the rate of $0.80 per Kbyte (Table 10). The other services tend to be expensive, with Iriduim ($1.99/minute with a one-minute minimum) being extremely excessive since it is not designed to provide data service (voice only). Iridium is included for comparison only.

Satellite (VSAT)

For VSAT service the monthly costs is based on the needed bandwidth for the application. To provide any type of VSAT service, there is a minimum bandwidth the commercial service will provide in order for it to be cost effective. For the SCADA application, the bandwidth required is small compared to what VSAT can provide and therefore, the cost is the minimum available. Even with this bandwidth there is still some room to add more remote units to the system under the current monthly price. VSAT is not cost effective for the user until the number of units exceeds 100. Using the information for Table 15 and setting the units to 100 brings the costs per unit to only $65.00 per month. Users must keep in mind that the bandwidth limit will be exceeded at some point and more bandwidth will have to be purchased

Packet Data

Packet data services can handle the one transmission per-minute rate, but this comes at a high cost. These services do not become economical or competitive until the transmission rate is one-per-hour or less. The scenario of a two-byte transmission does not efficiently use the whole assigned packet length and sending more data per transmission to fill the packet effectively reduces the costs. For Ardis this is $0.06 per message unit plus $0.03 per 100 bytes. A message unit can be up to 240 characters where one character is equal to one byte. Even if you do not send 240 characters the charge is still $0.06 per packet or transmission. Using the scenario of one transmission per minute for 30 days and 2-byte per transmission, the costs per unit per month is calculated by

($0.06/TX*1440 TX/Day*30 Day/Month)+($0.0006/TX*1440 TX/Day*30 Day/Month)

where, the $0.0006/TX is calculated from the $0.03 per 100 bytes to give $0.0006 per 2-bytes (per transmission).

Table 15. SCADA Telemetry Link Matrix

	Number of Units		25									
	Number of Bytes per TX		2									
	Transmission Rate		1 TX/Min		1 TX/ 30 Min		1 TX/Hour		1 TX/12 Hours		1 TX/Day	
	TX per Day/Unit		1440		48		24		2		1	
	Days/Month		30									
			KBytes/Month		KBytes/Month		KBytes/Month		KBytes/Month		KBytes/Month	
			2160		72		36		3		1.5	
N/D=	No data at time of report		KBytes/Unit		KBytes/Unit		KBytes/Unit		KBytes/Unit		KBytes/Unit	
N/A=	Not Applicable		86.4		2.88		1.44		0.12		0.06	
	RF Hardware	Data				Costs						
Type Of Service	Costs	Connection	Unit/Month	Monthly Tot	Unit/Month	Monthly Tot	Unit/Month	Monthly Tot	Unit/Month	Monthly Tot	Unit/Month	Monthly Tot
ISM/VHF/UHF												
ISM900	$1,060.00	Radio Link	Although there are no direct monthly costs to send data over these systems one must keep in mind the infrastructure that will have to be installed.									
ISM2400	$1,406.00	Radio Link	The main components of the infrastructure are antenna towers and cabling.									
VHF (70MHz)	$1,695.00	Radio Link	Cost for these items start as low as $1000 per site and increase from there depending on configuration.									
	$1,895.00		The cost will have to be spread across time, say 10-15 years, to obtain an comparison to the other systems.									
VHF (150MHz)	$695.00	Radio Link	The number of towers required will need to be determined from an propagation study of the proposed system.									
	$1,777.00		All other systems infrastructure was installed by and will be maintained by the service provider/system owner.									
VHF (220MHz)	$695.00	Radio Link										
UHF (400MHz)	$695.00	Radio Link										
	$1,772.00											
UHF (950MHz)	$1,160.00	Radio Link										
Cellular(CDPD)	$577.00											
Bell Atlantic		Internet	$54.95	$1,373.75	$54.95	$1,373.75	$54.95	$1,373.75	$54.95	$1,373.75	$54.95	$1,373.75
AT&T		Internet	$19.00	$475.00	$19.00	$475.00	$19.00	$475.00	$19.00	$475.00	$19.00	$475.00
GTE		Internet	N/A	$99.95	N/A	$49.95	N/A	$15.00	N/A	$15.00	N/A	$15.00
Cellular(Microburst)	$600.00											
Cellemetry		Internet	N/A	N/A	N/A	N/A	$20.00	$500.00	$20.00	$500.00	$20.00	$500.00
Aeris		Internet(fixed IP)	N/A	N/A	N/A	N/A	$20.00	$500.00	$20.00	$500.00	$20.00	$500.00
Satellite(Orbcomm)	$1,000.00											
Sat Ex		Internet	$10,000.00	$250,000.00	$350.00	$8,750.00	$160.00	$4,000.00	$35.00	$875.00	$35.00	$875.00
Sci Atlanta		Internet	N/A	N/A	$670.00	$16,750.00	$335.00	$8,375.00	$30.00	$750.00	$14.00	$350.00
Spatia		Internet	N/A	N/A	$580.00	$14,500.00	$300.00	$7,500.00	$42.00	$1,050.00	$30.00	$750.00
Satellite(LEO/GEO)												
Comsat-C	$3,300.00	Internet	N/A	$1,728.00	N/A	$57.60	N/A	$28.80	N/A	$2.40	N/A	$1.20
NOAA	$3,100.00	Telnet	N/A	N/A	N/A	N/A	N/A	N/A	$150.00	$3,750.00	$150.00	$3,750.00
Qualcomm	$4,500.00	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Iridium	$3,000.00	Included	$85,968.00	2.15E+06	$2,865.60	7.16E+04	$1,432.80	$35,820.00	$119.40	$2,985.00	$59.70	$1,492.50
Satellite(VSAT)												
SpaceNet		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
HNS	$3,500.00	Satellite	$260.00	$6,500.00	$260.00	$6,500.00	$260.00	$6,500.00	$260.00	$6,500.00	$260.00	$6,500.00
Packet Data	$995.00											
ARDIS		Internet(fixed IP)	$2,617.92	$65,448.00	$87.26	$2,181.60	$43.63	$1,090.80	$3.64	$90.90	$1.82	$45.45
Mobitex		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D

Figure 16. Five Year Life Cycle Cost

Number of Units		25									
Number of Bytes per TX		2									
Transmission Rate		**1 TX/Min**		**1 TX/ 30 Min**		**1 TX/Hour**		**1 TX/12 Hours**		**1 TX/Day**	
TX per Day/Unit		1440		48		24		2		1	
Days/Month		30									
		KBytes/Month		**KBytes/Month**		**KBytes/Month**		**KBytes/Month**		**KBytes/Month**	
Life Cycle (Yrs):	**5**	2160		72		36		3		1.5	
Notes:	Costs for 25 sites	**KBytes/Unit**		**KBytes/Unit**		**KBytes/Unit**		**KBytes/Unit**		**KBytes/Unit**	
N/D=	No data at time of report										
N/A=	Not Applicable	86.4		2.88		1.44		0.12		0.06	
	RF Hardware										
Type Of Service	**Costs**	**Monthly Tot**	**Cost/Year**	**Monthly Tot**	**Cost/Year**	**Monthly Tot**	**Cost/Year**	**Monthly Tot**	**Cost/Year**	**Monthly Tot**	**Cost/Year**
ISM/VHF/UHF											
ISM900	$1,060.00		**$212.00**								
ISM2400	$1,406.00		**$281.20**	The Cost per year for these services does not change due to change in the data rate							
VHF (70MHz)	$1,695.00		**$339.00**	Although these costs look low one must also consider any antenna tower cost							
	$1,895.00		**$379.00**								
VHF (150MHz)	$695.00		**$139.00**								
	$1,777.00		**$355.40**								
VHF (220MHz)	$695.00		**$139.00**								
UHF (400MHz)	$695.00		**$139.00**								
	$1,772.00		**$354.40**								
UHF (950MHz)	$1,160.00		**$232.00**								
Cellular(CDPD)	$577.00										
Bell Atlantic		$1,373.75	**$390.15**	$1,373.75	**$390.15**	$1,373.75	**$390.15**	$1,373.75	**$390.15**	$1,373.75	**$390.15**
AT&T		$475.00	**$210.40**	$475.00	**$210.40**	$475.00	**$210.40**	$475.00	**$210.40**	$475.00	**$210.40**
GTE		$99.95	**$135.39**	$49.95	**$125.39**	$15.00	**$118.40**	$15.00	**$118.40**	$15.00	**$118.40**
Cellular(Microburst)	$600.00										
Cellemetry		N/A		N/A		$500.00	**$215.40**	$500.00	**$215.40**	$500.00	**$215.40**
Aeris		N/A		N/A		$500.00	**$215.40**	$500.00	**$215.40**	$500.00	**$215.40**
Satellite(Orbcomm)	$1,000.00										
Sat Ex		$250,000.00	**$50,115.40**	$8,750.00	**$1,865.40**	$4,000.00	**$915.40**	$875.00	**$290.40**	$875.00	**$290.40**
Sci Atlanta		N/A		$16,750.00	**$3,465.40**	$8,375.00	**$1,790.40**	$750.00	**$265.40**	$350.00	**$185.40**
Spatia		N/A		$14,500.00	**$3,015.40**	$7,500.00	**$1,615.40**	$1,050.00	**$325.40**	$750.00	**$265.40**
Satellite(LEO/GEO)											
Comsat-C	$3,300.00	$1,728.00	**$1,005.60**	$57.60	**$671.52**	$28.80	**$665.76**	$2.40	**$660.48**	$1.20	**$660.24**
NOAA	$3,100.00	N/A		N/A		N/A		$3,750.00	**$1,370.00**	$3,750.00	**$1,370.00**
Qualcomm	$4,500.00	N/D		N/D		N/D		N/D		N/D	
Iridium	$3,000.00	2.15E+06	**$430,440.00**	7.16E+04	**$14,928.00**	$35,820.00	**$7,764.00**	$2,985.00	**$1,197.00**	$1,492.50	**$898.50**
Satellite(VSAT)											
SpaceNet		N/D		N/D		N/D		N/D		N/D	
HNS	$3,500.00	$6,500.00	**$1,300.00**	$6,500.00	**$1,300.00**	$6,500.00	**$1,300.00**	$6,500.00	**$1,300.00**	$6,500.00	**$1,300.00**
Packet Data	$995.00										
ARDIS		$65,448.00	**$13,205.00**	$2,181.60	**$551.72**	$1,090.80	**$333.56**	$90.90	**$133.58**	$45.45	**$124.49**
Mobitex		N/D		N/D		N/D		N/D		N/D	

Figure 17. Ten Year Life Cycle Cost

Number of Units		25									
Number of Bytes per TX		2									
Transmission Rate		**1 TX/Min**		**1 TX/ 30 Min**		**1 TX/Hour**		**1 TX/12 Hours**		**1 TX/Day**	
TX per Day/Unit		1440		48		24		2		1	
Days/Month		30									
		KBytes/Month		**KBytes/Month**		**KBytes/Month**		**KBytes/Month**		**KBytes/Month**	
Life Cycle (Yrs):	**10**	2160		72		36		3		1.5	
Notes:	Costs for 25 sites	**KBytes/Unit**		**KBytes/Unit**		**KBytes/Unit**		**KBytes/Unit**		**KBytes/Unit**	
N/D=	No data at time of report										
N/A=	Not Applicable	86.4		2.88		1.44		0.12		0.06	
	RF Hardware										
Type Of Service	**Costs**	**Monthly Tot**	**Cost/Year**	**Monthly Tot**	**Cost/Year**	**Monthly Tot**	**Cost/Year**	**Monthly Tot**	**Cost/Year**	**Monthly Tot**	**Cost/Year**
ISM/VHF/UHF											
ISM900	$1,060.00		**$106.00**								
ISM2400	$1,406.00		**$140.60**	The Cost per year for these services does not change due to change in the data rate							
VHF (70MHz)	$1,695.00		**$169.50**	Although these costs look low one must also consider any antenna tower cost							
	$1,895.00		**$189.50**								
VHF (150MHz)	$695.00		**$69.50**								
	$1,777.00		**$177.70**								
VHF (220MHz)	$695.00		**$69.50**								
UHF (400MHz)	$695.00		**$69.50**								
	$1,772.00		**$177.20**								
UHF (950MHz)	$1,160.00		**$116.00**								
Cellular(CDPD)	$577.00										
Bell Atlantic		$1,373.75	**$195.08**	$1,373.75	**$195.08**	$1,373.75	**$195.08**	$1,373.75	**$195.08**	$1,373.75	**$195.08**
AT&T		$475.00	**$105.20**	$475.00	**$105.20**	$475.00	**$105.20**	$475.00	**$105.20**	$475.00	**$105.20**
GTE		$99.95	**$67.70**	$49.95	**$62.70**	$15.00	**$59.20**	$15.00	**$59.20**	$15.00	**$59.20**
Cellular(Microburst)	$600.00										
Cellemetry		N/A		N/A		$500.00	**$107.70**	$500.00	**$107.70**	$500.00	**$107.70**
Aeris		N/A		N/A		$500.00	**$107.70**	$500.00	**$107.70**	$500.00	**$107.70**
Satellite(Orbcomm)	$1,000.00										
Sat Ex		$250,000.00	**$25,057.70**	$8,750.00	**$932.70**	$4,000.00	**$457.70**	$875.00	**$145.20**	$875.00	**$145.20**
Sci Atlanta		N/A		$16,750.00	**$1,732.70**	$8,375.00	**$895.20**	$750.00	**$132.70**	$350.00	**$92.70**
Spatia		N/A		$14,500.00	**$1,507.70**	$7,500.00	**$807.70**	$1,050.00	**$162.70**	$750.00	**$132.70**
Satellite(LEO/GEO)											
Comsat-C	$3,300.00	$1,728.00	**$502.80**	$57.60	**$335.76**	$28.80	**$332.88**	$2.40	**$330.24**	$1.20	**$330.12**
NOAA	$3,100.00	N/A		N/A		N/A		$3,750.00	**$685.00**	$3,750.00	**$685.00**
Qualcomm	$4,500.00	N/D		N/D		N/D		N/D		N/D	
Iridium	$3,000.00	2.15E+06	**$215,220.00**	7.16E+04	**$7,464.00**	$35,820.00	**$3,882.00**	$2,985.00	**$598.50**	$1,492.50	**$449.25**
Satellite(VSAT)											
SpaceNet		N/D		N/D		N/D		N/D		N/D	
HNS	$3,500.00	$6,500.00	**$650.00**	$6,500.00	**$650.00**	$6,500.00	**$650.00**	$6,500.00	**$650.00**	$6,500.00	**$650.00**
Packet Data	$995.00										
ARDIS		$65,448.00	**$6,602.50**	$2,181.60	**$275.86**	$1,090.80	**$166.78**	$90.90	**$66.79**	$45.45	**$62.25**
Mobitex		N/D		N/D		N/D		N/D		N/D	

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