BIOGRAPHICAL INFORMATION

Phil A. Graniero
Assistant Professor
University of Windsor, Department of Earth Sciences

Specific Responsibilities

Dr. Graniero joined the University of Windsor in 2000. He created MEMF Lab (Multi-purpose Environmental Modelling Facility), and is responsible for its continued growth and development through his research program. He teaches undergraduate and graduate courses in GIS, spatial problem solving, environmental modeling, and watershed hydrology. Dr. Graniero helped develop the University's new B.Sc. Geoinformatics program, and is the program counselor. He is also a Researcher at the University's Great Lakes Institute for Environmental Research.

Past Experience

Dr. Graniero has over 10 years' experience in GIS-related research and software development in the academic and private sectors. His research focuses on integrating GIS, data acquisition technologies, and environmental models into innovative tools that maximize information effectiveness in resource management decisions. Recent projects include: development of mobile, wireless geospatial data acquisition systems for real-time GIS updating; development and assessment of adaptive spatial sampling methods; evaluation of GPS and radio transmission reliability in urban environments; a spatial simulation modeling framework; integration of real-time environmental sensor data with risk assessment models; and spatially detailed surface water/soil structure dynamic studies in wetlands and riparian zones.

Educational Information

B.E.S. – Geography, University of Waterloo
M.E.S. – Geography, University of Waterloo
Ph.D. – Geography, University of Toronto

Professional Memberships

AGU (American Geophysical Union)
CGU (Canadian Geophysical Union) Hydrology Section
CIG (Canadian Institute of Geomatics)
GLRC (Great Lakes Research Consortium)

BIOGRAPHICAL INFORMATION

Harold S. Miller
Manager, GIS Services
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Specific Responsibilities

Mr. Miller joined Conestoga-Rovers & Associates (CRA) in 2001. He is responsible for developing CRA's GIS and geospatial services strategy and overseeing a rapidly growing team of GIS and application development specialists in the eSolutions Group. Mr. Miller works with utilities, municipalities, and other clients in Canada, the United States, and the United Kingdom to create Web-based geospatial technology solutions that increase the effectiveness of the organizations' business operation and monitoring activities.

Past Experience

Mr. Miller has over 15 years' experience in the use, development and integration of GIS in the public and private sectors, focusing on management of municipal infrastructure and utilities. He has overseen the implementation of full GIS solutions at a number of Canadian Cities and Electric Distribution Companies, including effective centralized Web-GIS tools. Prior to joining CRA Mr. Miller was a Senior Consultant and Utilities Industry Manager at ESRI Canada Limited. He has taught several ESRI Certified Courses on ArcInfo, ArcFM, and GIS management, as well as several undergraduate courses for the GIS Certificate Program at Ryerson Polytechnic University.

Educational Information

B.A.A. – Applied Geography, Ryerson Polytechnic University

Professional Memberships

GITA (Geospatial Information Technology Association)
MEA (Municipal Electric Association)
URISA (Urban & Regional Information Systems Association) Ontario Chapter
MISA (Municipal Information Systems Association)

REAL-TIME, WIRELESS GIS UPDATING: CLOSING THE WORKFLOW LOOP

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ABSTRACT

Using conventional data acquisition methods, a GIS provides a view of what *was*, as opposed to what *is*. However, many monitoring activities including real time condition assessment and emergency management require knowledge of what *is*, to enable proper response actions. Mobile, wireless geospatial applications using GIS and field computers are growing, but most focus on data *access*; wireless data *acquisition* has lagged behind. Emerging systems, however, will rapidly collect and integrate spatially referenced data from a broad range of mobile sensors, reliably update spatial data warehouses wirelessly, and make the data available to client applications in real time. This will essentially "close the loop" for effective workflow in mobile geospatial monitoring applications. Although the new technology opens possibilities for managing our geospatial resources in novel ways, there are many technical issues that must still be resolved, particularly with respect to wireless networking. This paper outlines some of the challenges in creating a mobile, real-time GIS updating system, including component configurations and fluctuating communication reliability. We then discuss design considerations for the data collection, routing, and communication problems associated with acquiring data from a complex, mobile configuration of data acquisition components distributed over a large spatial extent.

INTRODUCTION

The use of spatially referenced data for facilities, environmental and resource management is becoming increasingly mobile, and wireless data access technologies are growing. There are numerous examples of mobile wireless applications that remotely access geospatial databases for effective display and decision-making in the field. However, development of real-time mobile data *acquisition* technology is lagging. Although the speed at which data are collected in the field has improved, its arrival in the enterprise database has not. To date, most field-based geospatial data acquisition systems require the modified data to be uploaded to the GIS upon return from the field. The trip to the office at the beginning and the end of the day simply to transfer data can place a significant upper bound on the daily efficiency of field crews.

When the data are finally compiled into the GIS, in some applications it produces a view of what *was*, as opposed to what *is*. The lag time may be acceptable for regular update and maintenance of asset databases; we don't expect things to change significantly overnight in many cases. However, many monitoring activities including real time condition monitoring and assessment require the operator to view what *is*, to enable proper response actions. If acquisition systems do incorporate a real-time update component, fleet management applications being a good example, then usually the applications are highly customized for specific purposes, have static data structures, and follow strict, automated data acquisition rules. The GIS community has identified that many exciting new applications will emerge as the technical challenges of Location Based Services (LBS) and real-time spatial systems are overcome (Batty, 2003). In the near future, systems currently under development will allow field workers to rapidly collect and integrate spatially referenced data from a broad range of mobile environmental sensors in highly configurable data formats and structures and reliably update flexible spatial data warehouses using wireless methods (Graniero and Miller, 2003). This will essentially "close the loop" for effective spatial data acquisition and analysis workflow in field-based, mobile environmental monitoring applications.

In the next few sections, we will describe some of the technical options for creating a wireless, real-time infrastructure as well as some of the decision trade-offs that should be considered. Each class of equipment has its own set of characteristics, which can be considered as strengths or weaknesses depending on the application needs. We place our emphasis on the wireless services and data transmission methods, since the other components of mobile field mapping systems such as GPS, rugged field computers, and database integrity and quality control are well treated on a regular basis in trade magazines such as *GEO World*[*] (GeoTec Media) and *Geospatial Solutions* (Advanstar).

DATA TRANSMISSION METHODS

There are several different wireless networking options readily available on the market that can play appropriate roles in our real-time system, depending on application requirements. They can be broadly grouped into WiFi services, digital cellular services, and other transmission methods like use of satellite and RF radio modems.

WiFi Services

Wireless Internet connectivity via 802.11x and Bluetooth are available at very little cost on mobile field computers, and they are emerging as powerful access methods in office and contained, campus-like environments. However, their very short transmission ranges (up to tens of meters) require a dense network of access 'hot spots' to maintain connectivity. From a data acquisition perspective, these methods can have some limited utility in highly urbanized areas, but current infrastructure growth likely won't make it a viable method for real-time GIS update for quite some time.

Digital Cellular Services

Currently, the most readily available and popular wireless approach uses digital cellular services operating in the 800 MHz and 1.9 GHz bands. The Global System for Mobile Communication

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[*] All products named in this paper are common illustrative examples only; other products may provide comparable characteristics. Mention of a product name does not necessarily imply an endorsement by the authors. Many product names are claimed as trademarks; all trademark ownership and rights lie with the respective manufacturers or their authorized agents.

(GSM) is a standard for digital cellular communication infrastructure used by more than 110 countries worldwide. Many voice, fax, and data services operate on the GSM system, but two of the most popular packet-based services for data transmission are the General Packet Radio Service (GPRS) and the Short Message Service (SMS). GSM data modems may be purchased for around $200*, but many users find it useful to have a GSM voice phone with data capabilities, connected to their field computer by cable or wirelessly via Bluetooth or some other wireless method. Monthly subscription fees are highly variable, but they typically range between $12 and $30 per month depending on the bundle of services included in the subscription.

General Packet Radio Service (GPRS)

Data transmissions are broken into short packets and transmitted over an IP-based network. GPRS has fast session set up, which effectively gives an "always on" or continuous connection service. This allows mobile networked applications to behave in a manner that is consistent with 'wired' network applications. Although the service gives continuous connection, pricing is based on the volume of data transferred. Pricing is quite variable depending on service provider and subscription package, but $0.004 to $0.012 per kilobyte is a typical price range. With its IP-based structure, field data acquisition developers must consider the full range of network issues such as how to discover, identify and select a message recipient, as well as select an appropriate network architecture for the overall acquisition system.

The theoretical maximum transfer speed is 171.2 kilobits per second (kbps), if the sender could take dedicated control of all channels in a shared data frame. Combined with the continuous connection mode and IP-based networking behaviour, it is relatively easy to imagine the mobile field worker operating with the same types of enterprise applications and the same degree of efficiency as if they were at a desktop with a dial-up modem connection to the network. Small airphotos, satellite images, and raster data could be downloaded to act as a backdrop for the data that the field worker is adding or updating, and a seamless movement of new data between the mobile unit and the central spatial data warehouse could occur. In reality, transfer speeds are more in the range of 30 to 40 kbps since there is heavy sharing of the cellular resources. Considering protocol inefficiencies and software delays at both ends, this translates to about 10 minutes to transfer one megabyte of data. Clearly, there is a great advantage to design real-time applications to use bursts of compact data. If there is enough computational power on the mobile unit, in many cases it is more time- (and cost-) effective to transmit vector data and allow the mobile unit to construct a rasterized version rather than to transmit a raster graphic.

Short Message Service (SMS)

Messages of up to 160 characters in length are routed via an SMS gateway or Short Message Service Center (SMSC) which acts a secure store-and-forward server. The message from the sending mobile is stored on the gateway and is forwarded to the destination mobile; if the destination mobile is not available, the message is stored until it can be delivered. If desired, SMS can also provide a return receipt message to the sender to notify that the message reached its destination. The constrained communication pathway can simplify application development, since each node in the system must communicate via a single gateway. Some SMS providers

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* All prices are given in U.S. dollars.

offer additional services, such as offering web-based message retrieval services or hosting the switching portion of a mobile enterprise data application. In those cases, the SMS provider typically requires that their customers' applications go through a testing and acceptance process conducted by the SMS provider, so that they may ensure secure and stable service to all of their customers. Since messages are small they are transmitted in a very short time period, and therefore the cost per packet is very low. Pricing varies by service provider, value-added services, and subscription bundling, but $0.04 per message is typical, which includes the store-and-forward and return receipt services.

SMS messages are limited to a maximum of 160 characters. For mobile geospatial applications, typical GPS position information such as latitude, longitude, bearing, and altitude takes approximately 60 characters, but addition of other fields for attribute data and other metadata can quickly reach the maximum message size. It is possible to break a longer record into multiple messages, but the total cost per record will quickly exceed the cost of other services like GPRS. A more attractive alternative is to encode the data using an abbreviated form of some kind. For instance, if the movement is within a relatively consistent and known geographic region, some of the most significant digits may be dropped from the spatial coordinates. Short codes can be used to represent common data occurrences. Multiple attribute values may be combined into single state codes which may be expanded at the destination by using a lookup table. These strategies allow a large amount of information to be communicated in a small number of characters.

Non-Cellular Transmission Methods

Subscription to a wide choice of digital cellular services is becoming quite easy, and the prices for equipment and network usage are steadily dropping as the consumer market grows and the many service providers compete for their business. GPRS services provide their data via an IP-based network structure, which allows easy transition of current Web-based enterprise applications to a wireless setting. Both of these factors make cellular transmission an attractive alternative. However, there are limitations to using cellular that should be considered.

Cellular services rely on a series of ground-based relay stations, which restricts service coverage to the geographic range in which infrastructure has been constructed. Service is generally available in all urban areas and along all major transportation corridors between them, serving over 90% of the population in most countries with cellular infrastructure. This is certainly adequate for many mobile geospatial applications including fleet management, municipal asset tracking and updating, utilities management, and urban environmental monitoring. However, cellular-based wireless geospatial applications in rural or remote locales are often not feasible because there is no cellular coverage. In many applications the roving unit and the base station may be widely separated, since cellular transmission range is effectively unlimited within the coverage area. However, there may be cost constraints on the full geographic range. Additional roaming charges usually apply if the roving unit moves from its home Mobile service Switching Center (MSC) to a distant MSC, or if the unit moves from one service provider's coverage to another's. This can substantially increase the cost of operating the real-time GIS infrastructure.

Although cellular service is highly reliable under normal conditions, it is dependent on the proper operation of the electrical power grid. If there is major power loss in a region, the cellular base stations and switching centers can become inoperable until emergency backup power sources are activated. Once the cellular system has its power restored, the system becomes heavily congested with caller traffic as system subscribers place many voice phone calls to check on the safety of family and friends. The congestion can considerably slow down data transfer rates or create frequent delays or pauses in local cell availability. These factors make the public wireless network vulnerable to uncontrollable overloading and failure in emergencies and disasters, as observed during several emergency events (Moore et al., 2002). The widespread power blackout in August 2003 that affected an estimated 50 million people in Ontario and the northeastern United States for up to two days provided a potent example of service failure.

There are two alternative approaches to get around the use of cellular services and their associated problems. First, the transmission service can use base stations and relays that are not tied to the ground-based infrastructure, such as with satellite-based data services. Second, an autonomous wireless network can be established that is independent of the cellular network, such as with radio modems.

Satellite Services

Packet-based satellite data services are available in the 1.5 to 1.7 GHz band. Packets are routed through a constellation of orbiting communication satellites rather than ground-based towers. The broad field of view available to each satellite eliminates the need for dense installation of relaying infrastructure. Service coverage is at the continental or global scale, with no restrictions to just populated areas. However, the data rates are quite slow, on the order of 9.6 kbps. The cost of a satellite phone and associated packet data equipment can approach $2,000 and the hardware is relatively bulky, limiting range of personal mobility for data acquisition. There are also vehicle-mounted solutions in the same price range. Airtime is typically in the range of $1.50 to $2.00 per minute (approximately $0.04 per kilobyte at 9.6 kbps), and SMS-style messages can cost $1.00 per message. Services offering 64 kbps such as Inmarsat are available, but they are even more expensive and aimed towards fixed-location data transmission. Satellite data transmissions are much costlier than cellular transmissions by a factor of 5 to 10 for volume data transfer costs and a factor of 20 for short message costs. In addition, the monthly subscriber fees tend to be more expensive by a factor of 2 to 3.

The main justification for using satellite transmission is if data acquisition is required in a remote region well away from cellular coverage. There are no roaming fees associated with satellite services, so there is a small possibility that the increased transmission costs could outweigh the additional cost of extensive cellular roaming service if the mobile units were required to cover extremely large geographic areas. In geographically extensive applications such as fleet management, movement is typically constrained to major transportation corridors where cellular coverage is well established. In those cases, cellular-based services like MicroBurst by Aeris.net would likely be more attractive. MicroBurst utilizes very small segments of bandwidth that are idle even under heavy load to move 50-byte messages in a manner similar to SMS, but at a smaller per-message cost. Usage agreements negotiated with all of the major cellular systems make the service available through Canada, the United States, and Mexico with no roaming fees. If the required data can fit into such a short message by using the strategies described for SMS above, then MicroBurst would be a far more cost-effective solution over satellite transmission.

Radio Modems

Radio (RF) modems typically operate in the 300 MHz to 1 GHz band. They are highly portable: they may be mounted to portable masts, vehicle rooftops, range poles, or GPS backpacks, and

12-volt camcorder batteries or automotive batteries can provide long-lasting power for all components of the radio network. A temporary packet-switched, peer-to-peer radio network can be established very quickly, with one or more base stations placed in mobile command centers or other strategic locations in the study area. Mobile field units can then communicate with the base stations to send new or updated data records, or to query the existing spatial database. The geometry of the base stations can be adjusted while the network is operational in order to adjust any 'holes' in the network coverage.

A 2-Watt radio modem with hardware-level peer-to-peer addressing, a data packet protocol, error detection and correction, and transmission management, may be purchased with a small selection of antennas and a portable power supply for around $800. Less expensive options are available, but they require the user to develop software that manages the packet assembly, addressing, routing, and verification. For most organizations' in-house programming capability, purchasing the built-in capability is well worth it; development effort can then focus on system architecture and application software. Radio modems must be licensed by Industry Canada, or by the Federal Communications Commission (FCC) in the United States. Licensing fees are very modest; our collection of Pacific Crest 2-Watt RFM, PDL and EDL radio modems are licensed at $38 per year per modem through Industry Canada. FCC fees are $100 per year per call sign. There are no additional volume- or message-based costs for data transmission. Data transfer rates are typically around 9.6 kpbs, which is slower than cellular services by a factor of 3 or 4, so compact message data structures must be designed. However, total fixed equipment costs, subscription costs, and usage costs make the transfer price per kilobyte for radio becomes much smaller than the cellular rate over extended periods, particularly for large data volumes.

Despite the advantages of low cost, infrastructure independence, high flexibility and high portability, the range and reliability of radio networks are subject to many constraints. Maximum transmission range between sender and receiver is limited by direct line-of-sight, or radio horizon. The only way to increase the radio horizon is to increase the height of the transmitter, the receiver, or both relative to the average ground elevation. The radio signal may be degraded (called signal fade) due to absorption or scattering of the signal energy by natural or man-made obstructions along the line-of-sight path. The radio waves may also be reflected off of nearby obstructions (multi-pathing, similar to GPS signals), creating destructive interference and difficult signal processing. Strong signal fade can cause the effective transmission range to be less than the calculated radio horizon. It is also possible that other radio signal sources can interfere with the transmission, increasing the difficulty of signal processing and successful receipt of the transmitted data.

Signal fade and interference interactions are highly variable and site-dependent. We conducted an extensive study in Windsor, Ontario and the surrounding rural areas in Essex County to establish realistic radio ranges and transmission success rates related to surrounding land use and possible obstructions and sources of interference (Graniero and Fan, in prep.). The City of Windsor has a population of 200,000 and includes a compact central business district, some concentrated commercial zones of varying density, and mixed residential and industrial zones. Three large automotive assembly plants and associated manufacturing facilities are interspersed through the city. The surrounding County is dominantly open agriculture with only 3% woodlot coverage and flat topography.

In open field or rural areas, our typical radio range was just over 11 km. This distance is very close to the calculated radio horizon of 12 km for a transmitting antenna at about 185 cm height (mounted on a GPS backpack) and a receiving antenna at about 215 cm height (mounted on the roof of a van). The transmission success rate through most of that range varied between 95% and 99%, dropping to a range of 70% to 75% as the roving unit approached the edge of radio range. In residential, commercial, and light- to medium-density industrial areas, the typical radio range dropped to an average of 2 km. The transmission success rate varied between 95% and 99% close to the receiving base station, but dropped to a range of 60% to 70% once the roving unit was more than 1.2 km away from the base station. These results were fairly consistent across land uses and densities.

No discernible differences in transmission reliability were observed in the vicinity of the 5,000 licensed transmitter locations within the study area, nor in the vicinity of 4.7kV or 27kV electrical transformers or high-tension power lines. Commercial buildings along the transmission line-of-sight created only slight reduction of transmission reliability in the highest density central business district. However, large factory buildings and industrial facilities created strong line-of-sight barriers to transmission success. This is likely due to a high density of material obstruction and generation of stronger interference across a broader range of the electromagnetic spectrum.

GPS AND POSITIONING ISSUES

As part of the radio reliability study we also examined the rate of success in establishing a GPS fix in rural and urban environments. The combined data set, consisting of more than 100,000 data points and collected with various GPS units on foot, on bicycle, or in a car, showed an average 99.5% success rate in open field or rural settings and an average of 98.1% in low- to medium-density residential and commercial areas. It is expected that GPS fix success will be considerably lower in highly localized places within high-density commercial areas and immediately adjacent to built structures due to blockage of satellite line-of-site and complex multipath environments. It is harder to establish an aggregate GPS success rate in forested areas, due to the strong influence of site-specific and species-specific factors. Typically, GPS fixes are either established with a high success rate, often in the 90%+ range, or are generally not obtainable at a particular site.

Positional accuracy of GPS measurements is an important point to consider when acquiring real-time GIS data. The data record typically contains just the resulting spatial coordinates established when the measurement is made, and not the ancillary data required for post-processing differential corrections. It would be possible to update the GIS with the real-time solution, locally log the full set of GPS data, post-process the logged points, match them to the associated real-time records in the GIS, and update the positions with the corrected values. However, establishing the correct data point associations would be a complex task, with a lot of room for processing error. In practical terms, only real-time differential corrections may be used to improve the positional accuracy of the spatial data set. For applications requiring meter accuracy or better, each mobile field worker would require some sort of real-time correction source such as a WAAS-enabled receiver or RTCM corrections received from beacons or radioed from a local base station. This, of course, increases the cost of equipping each worker and in the case of RTCM receivers possibly increases the bulk of the equipment that must be carried.

WORKFLOW AND DATA QUALITY ISSUES

The same business rules regarding quality control for new data apply in the real-time workflow as they do in the conventional workflow: quality standards must be defined; data must be isolated and/or marked as provisional until reviewed; and the review must be documented. The presence of real-time data flow merely amplifies the need to formally recognize and establish the organization's quality control process. It perhaps enforces the need for automated quality control mechanisms within the organization, since real-time data flow eliminates the possibility of a manual, 'habit-based' process of checking through the new data before merging it with the production database, or handing off an update file to a QC reviewer. If an automated process and data management tools already exist, then properly attributed real-time data records can flow naturally into the existing business practice.

The data acquisition system must be sufficiently flexible to allow the organization to incorporate quality control fields and metadata into the data stream. This can be handled at a session level or at a record level. At the session level, the incoming real-time data are channeled to a 'working' table with identical structure to the production table. After appropriate QC review, the records are transferred from the working table and into the production table. In the meantime, workers for whom the need to have the most recent data outweighs the risk of potential quality problems can be granted access to the working table so that it may be used in conjunction with the production database. At the record level, new data items flow directly into the primary database with appropriate tagging. In this case, the table should include at minimum a flag field indicating that it is a new, non-reviewed record. Additional fields may identify the QC reviewer, the date/time of review, and other quality notes, depending on the organization's documentation needs. The QC reviewer can query the flagged records, establish their validity, and update the QC fields as appropriate. Although the record-level approach can simplify access to and manipulation of both reviewed and non-reviewed data, it does cause some difficulties automatically isolating non-reviewed data under normal use.

IMPLEMENTATION RECOMMENDATIONS AND SUMMARY

Although WiFi services are not usually appropriate for primary data transfer in field mapping situations, they can still play a useful role: they are excellent for eliminating the cables required to integrate all of the field mapping components. Bluetooth can establish wireless interaction between: the field computer; a GPS receiver and possibly a DGPS beacon receiver; a laser range finder for offsets; and in some environmental monitoring cases maybe other environmental sensors or dataloggers. In most cases (thankfully) all of these devices are not needed at the same time. New products are integrating many of these components into single 'boxes', but while we wait for these products to mature or continue to use our existing tools, freedom from cables can be a godsend.

Wireless connectivity between one or more field workers and a network-enabled vehicle parked nearby can be achieved using 802.11x networking protocols. Once the data arrives at the vehicle, it can be forwarded to the remote data warehouse via cell, satellite, or radio modem. This means that the field collection software must allow the user to easily set which network device and protocol should be used for each input and output stream, but some new systems like ProbeFusion are being designed to specifically meet this requirement.

Selection among the 'long-haul' wireless services depends on the data collection application. In mission critical applications like environmental crisis management or emergency response, it may be worthwhile to use longer-range and fast methods like SMS or GPRS under normal conditions. When crisis strikes, a set of radio modems (with a stock of charged batteries!) and a preliminary deployment plan can be quickly used to replace the strained cellular system until it restored. Again, if the field collection tools are designed to handle multiple networking methods, this can be done easily with simple changes to configuration properties within the application software.

The capability to collect spatially referenced environmental data in a highly flexible manner, coupled with the ability to use that data in real time, would be of considerable benefit to a broad range of users in all sectors. In situations where regular monitoring over large regions is required, the field data can be merged at collection time and automatically moved to the final database to reduce post-processing effort and errors. With an effective wireless, real-time spatial data acquisition and update system, new possibilities emerge for streamlining the GIS maintenance workflow.

In crisis management situations, up-to-the-minute updates can be made available at off-site locations, which can greatly speed up and improve the quality of initial assessment, containment planning, progress assessment, and remediation planning. Configuration flexibility means that an organization's everyday mobile monitoring tools may be rapidly reconfigured and re-deployed to aid on-site evaluation. This provides a degree of response beyond most organizations' current capability, for the same cost as normal monitoring. The GIS community hasn't yet arrived at this target – but we are getting close.

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