6.14 Russian Federation: Use of cellular networks to transmit information on detection from control points up the chain of command

[2.3-4C]

Challenge

The nuclear detection system in the Russian Federation includes autonomous radiation monitors that must transmit detection data from control checkpoints up the chain of command. The data transmission system is designed to operate over a wide variety of communication channels. Different options for mobile communications were studied to determine whether these networks could support transmission of data from remotely located radiation monitors. This case study defines the key criteria used to determine the suitability of potential communication channels, discusses the different options for mobile communications, and describes typical technical specifications for each option.

Context

A key criterion for evaluating communications channels is the rate at which data can be transmitted through the channel. Typically, this is measured in bits per second (b/s), with kilobit-per-second (Kb/s) or megabit-per-second (Mb/s) speeds being common. (1 Kb/s = 1,000 b/s; 1 Mb/s = 1,000,000 b/s.)

To determine the data rates that are necessary for a given application, it is necessary to understand both the amount of data that must be transmitted and the timeframe over which that transmission must occur. For the Russian detection systems, the maximum event response time is specified at 2 minutes. The message about an event recorded by a stationary radiation monitor includes the following elements:

- 2-3 frames of visual data (90-140 KB each);
- an array of radiation measurements (up to 1 KB for each sensor);
- a radio frequency identifier (a few bytes);
- housekeeping information (up to 1 KB).[1]

Thus, the size of the message is determined primarily by the visual data. The amount of the remaining event data is less than the difference between the lowest and highest estimates for the size of the frames of visual data, which is determined by the particulars of the algorithm used to compress them. Therefore, the amount of data in a message is taken to be triple the size of the largest frame, e.g. 3 x 140 KB = 420 KB. The amount of housekeeping information, which is used to organize the transmission of a message, may reach 15-20% of the transmitted data, so the size of an event message including housekeeping information is taken to be 500 KB or 4,000 Kb.

Conservatively doubling this estimate to 1 MB and combining it with the two-minute time window for responding to an event suggests that the effective data transmission speed in the nuclear detection system must be at least 70 Kb/s. However, some portion of the two-minute window must be reserved

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[1] The data sizes are measured in bytes (B), where one byte is equivalent to eight bits of information. A kilobyte (KB) is equal to 1,024 B. (Note the use of uppercase "B" to refer to bytes and lowercase "b" to refer to bits.)

for data processing in the radiation monitor. Since the transmission of data from a radiation monitor to a control center over a mobile network is likely to be the most time-consuming step, the radiation monitors must be capable of promptly processing data.

The required processing time was tested in a pilot project of the Russian nuclear detection system, which showed that generating a message at the radiation monitor takes less than 1 second, recognizing the vehicle's license plate number in a single frame takes less than 1 second, and classifying the event and displaying the information on the screen takes 1-2 seconds. If a message has 3 frames, the maximum total processing time is 6 seconds.

In addition to receiving event information from the radiation monitors, it is also necessary to send a small amount of control information to them. The radiation monitors are autonomous, programmed systems that do not require external management to operate. The volume of control data sent between a stationary radiation monitor and a mobile radiation monitor is minimal, consisting of control data about the radiation monitor's technical condition and arrays of identifiers for authorized shipments. The daily volume of control data does not exceed 1 MB and is comparable with the data in one or two event messages.

Actions Taken

To better understand which methods would be appropriate for transmitting data to and from the remote detectors, a variety of communications channels were studied. In general, communications channels can be divided into two broad classes:

- data transmission through cables or other media, including telephone networks and specially placed cable lines, and
- data transmission through free space, including satellite communications systems, cellular communications systems, wireless data transmission networks, and specially-formed radio or optical links.

The first class, consisting of communication channels using dedicated media, are more reliable, higher-performance, and cheaper. However, they are not available in all regions. Therefore, when designing and implementing nuclear detection systems, a provision must be made for radio communications or mobile communications (e.g., for communicating between two mobile subscribers). These technologies are significantly more effective in sparsely populated regions, and in uninhabited areas they are often the only option.

For communicating with remote detectors, mobile communications appeared to be the best option, and several different systems were examined:

- radio relay communications,
- satellite communications,
- cellular communications, and
- wireless local area networks (LAN).

Radio relay technologies provide “point-to-point” communications and are in fact not communications system technologies; rather they are one way to create a communication line. The communication range is up to 15 km with direct line of sight between the participants. The bandwidth of radio-relay communications systems reaches 100 Mb/s, and the average world price of two half-set radio-relay stations is approximately $10,000. The radio-relay line itself does not provide any service (it is only a way to connect to a resource), so no access fee is charged for its use.

Satellite communications can also be divided into several subclasses:

- communications for stationary subscribers and
- communications for mobile subscribers.

Communications for stationary subscribers usually implies using either geostationary satellites or satellites with a highly elliptical orbit. A ground station has the information required to correctly point the system's antenna at the appropriate satellite. Such a link can also be created for “quasi-stationary” subscribers (e.g., ships), if they on their own solve the accompanying problems with pointing the system's antenna. The traditional method of providing satellite communications services is to connect several ground stations through a satellite relay in a “point-to-point” or “point-to-multipoint” scheme. The data transmission speed is up to 8 Mb/s. A ground station costs up to $100,000 or more. In Russia, the cost of leasing a satellite channel is very high and may reach $14,000 a month for an 8 Mb/s channel. In this case, the satellite communication system itself does not provide any service other than data transmission between the ground stations (i.e., it does not provide output to external systems).

VSAT solutions are a special case of a satellite communications system. In this case, the client receives a VSAT terminal that provides a satellite link to a service provider, and the service provider provides the connection between the satellite channel and public networks (the Internet). In this case, the client receives access to Internet resources, including data transmission resources, at any point within the operator's coverage zone. The cost of a VSAT terminal, including installation and permit filing, starts at $4,500-$5,000. For a 2 Mb/s uplink, 1 Mb/s downlink, and an “unlimited” connection, the monthly access fee in Russia is approximately $3,000-$3,500. A VSAT terminal is a server.

As it pertains to data transmission, satellite communication for mobile subscribers is based on satellite phone systems. The data speed in such systems is limited to values on the order of 33.6 b/s and is not of interest for the creation of data transmission channels in nuclear detection systems.

Cellular communications technologies are presently being more actively developed than the technologies mentioned above. Cellular communications systems' coverage zone presently includes virtually all areas that are more or less regularly inhabited by people. Cellular communications within Russia are provided using the GSM and CDMA standards. Both of these standards are inherently digital and transmit voice information as a data stream. In its initial form, the GSM standard supports data transmission at 14.4 Kb/s. The voice stream in CDMA is 9.6 Kb/s.

The GSM standard has been augmented by GPRS extensions that enable data transmission at speeds up to 171.2 Kb/s (the theoretical maximum). EDGE (EGPRS) technology was a subsequent development of

GPRS with a theoretical limit of 474 Kb/s, but in practice transmission speeds have proven to be substantially lower. The actual data transmission speed using GPRS channels depends on the network load and may fall to zero in unfavorable periods.

The data transmission speed for GPRS and EDGE in free networks is given in Table 1.

Table 1: Data transmission speed under various GPRS and EDGE coding schemes

Standard	GPRS				EDGE								
Name	CS-1	CS-2	CS-3	CS-4	MCS-1	MCS-2	MCS-3	MCS-4	MCS-5	MCS-6	MCS-7	MCS-8	MCS-9
Max speed, kb/s	9.05	13.4	15.6	21.4	8.4	11.2	14.8	17.6	22.4	29.6	44.8	54.4	59.2

GPRS and EDGE modems of up to Class 12 are currently being manufactured. With a total of 5 timeslots, Class 12 supports allocation of up to 4 timeslots (a timeslot is 0.577 ms in GSM) for sending and receiving. Table 2 shows the maximum and minimum data transmission speeds when Class-12 GPRS and EDGE modems use various numbers of timeslots.

Table 2: Limiting data transmission speeds in GSM networks

Standard	GPRS		EDGE	
Timeslots	1	4	1	4
Minimum speed, kb/s	9.05	36.2	8.4	25.6
Maximum speed, kb/s	21.4	85.6	59.2	236.8

The following minimum data transmission speeds are supported in 3G networks:

- for subscribers with high mobility (up to 120 km/h) — at least 144 Kb/s;
- for subscribers with low mobility (up to 3 km/h) — 384 Kb/s; and
- for stationary objects — 2 Mb/s.

Data transmission speeds can reach 7 Mb/s in currently existing 3G networks.

Equipment to connect to GSM and CDMA networks is quite inexpensive (approximately $50 in Russia). Connection plans based on data usage have virtually disappeared from the market. Service providers are moving to unlimited plans that cost approximately $30/month.

Wireless LAN technologies are currently only beginning to be deployed as a commercially available service. Up until now they have been used only as internal technologies for corporate LANs. These technologies include:

- Wi-Fi technologies;
- WiMAX technologies.

At present, Wi-Fi communication lines can extend up to 10 km while providing a data transmission speed of up to 11 Mb/s. Considering the relatively high cost of equipment and antenna systems (approximately $1,700-$2,000 in total in Russia), such a solution is somewhat competitive with radio relay lines. DSRC technology is a kind of Wi-Fi technology for use on moving vehicles. This technology enables immediate data transmission between motor vehicles and transportation infrastructure facilities while simultaneously minimizing data center costs, without the creation of an expensive infrastructure and involvement of global communication channels. DSRC technology's maximum capabilities provide:

- virtually instantaneous (less than ¼ second) connection,
- data transmission at speeds of up to 100 Mb/s at a distance of 1.5 km, and
- stable operation on vehicles moving at up to 250 km/h.

WiMAX technologies provide a data transmission range of up to 80 km at up to 75 Mb/s for stationary subscribers and up to 5 km at up to 40 Mb/s for mobile subscribers.

The basic general characteristics of wireless (mobile) communications systems are shown in Table 3.

Table 3: Characteristics of wireless (mobile) communications systems

Communications system	Frequency	Range	Data transmission speeds
GSM/GPRS	850, 900, 1800, and 1900 MHz	60–70 km	up to 384 kb/s
Wi-Fi	5795–5805 MHz	Up to 1 km	25 Mb/s
DSRC	5805–5815 MHz	Up to 1 km	25 Mb/s
WiMAX	2.3–2.5, 2.5–2.7, and 3.4–3.8 GHz	6–10 km	up to 75 Mb/s

Result(s) and Lessons Learned

Based on these results, it is reasonable to use GSM/GPRS, WiMAX, or DSRC wireless (mobile) communications systems in places where it is impossible or difficult to use wired communications systems. GSM/GPRS has the largest radius of operation (up to 70 km) and data transmission speeds up to 384 Kb/s. GSM/GPRS towers cover more than 80% of Russia. WiMAX has a radius of operation of up to 10 km, and only major cities are covered by WiMAX towers. Therefore, using a GSM/GPRS communications system makes the most sense for the nuclear detection systems. Moreover, to increase the reliability of the communication in the region of each stationary radiation monitor, the services of all available cellular communications providers should be used. To minimize the expense of data transmission over cellular links, the most inexpensive communication lines should be used.

Transmitting event data over a channel on GSM/GPRS networks takes 100 seconds. Therefore, considering the nuclear detection system's maximum response time (120 seconds), the time allocated to data processing is 20 seconds. As discussed above, tests on a pilot system indicate that this is more than sufficient to process the data at both the radiation monitor and the control center, leaving at least 14 seconds to spare. This leads to the conclusion that the requirements for prompt collection and processing of event data are satisfied, even when using the slowest data transmission channels between the region of a stationary radiation monitor and a control center. When using a CDMA channel, the system's response time is no more than 33 seconds, with spare time of at least 87 seconds.

In Russia the minimum cost for data transmission (based on published rate information from cellular operators) is approximately $0.15/MB for GSM/GPRS networks and approximately $0.10/MB for CDMA networks. Therefore, the cost of transmitting a message about a recorded event in GSM/GPRS networks is roughly 8 cents, and in CDMA networks the cost is approximately 6 cents.

While GSM/GPRS or CDMA systems promising for long-range transmission, wireless LAN technologies (Wi-Fi) may find use in a radiation monitoring system to join the devices servicing a road junction into a single system.

The short-term prospects for the development of data transmission systems include an increase in the bandwidth capability of cellular communications networks due to the expansion of 3G coverage and the expansion of the coverage zone of wireless LANs on the WiMAX standard. This will make it possible to increase the speed of data transmission from a radiation monitor to a data center using cellular communications networks and, with coverage of radiation monitors by WiMAX networks, to switch to this type of network as the main data transmission channel. In the future, WiMAX networks may also be used to connect to the communications and data transmission networks of control centers at different levels.

In general, the Russian experiment indicates the feasibility and high efficiency of using mobile networks to transmit detection data from control checkpoints (radiation monitors) to control centers higher up in the chain of command, as long as these networks are stable.