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Analysis of analog data transmission of dose rate measurements over the HAM amateur radio network in the event of an emergency and possible failure of other communication channels

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ABSTRACT

Use of radioactive materials (Hazard Class 7) [1] is a dynamic process subject to changing conditions and unpredictable events. In industry and medicine, it represents a major challenge worldwide. In case of an emergency event the released radioactive substances (gases, aerosols, deposits) pose a social and health threat to the local population and present a significant challenge to professional rescue and other intervention teams in the measured data transfer. The question itself is thus a prelude to verifying the adequacy of the existing state of the APRS (Automatic Package Report System) [2] for transmitting ARON-ELME (Ecological Unit Mobile Unit) data at a national state level. In case of an emergency event arising and probable failure of other digital communication channels for sending and receiving from HAM (Amateur Radio Network), we will present the process and final results of the analysis of the current situation of the stationary network parameters and coverage of the existing HAM system. Based on the collected data a GAP Analysis of the information system will follow that will examine the strengths and weaknesses of the system and identify the necessary steps to move from the existing status quo to the desired situation.

1 INTRODUCTION

In a small area, Slovenia combines diverse geographical features and urban areas with industries using chemical, biological, and nuclear technology (i.e., Krško Nuclear Power Plant, Reactor Centre of the Jožef Stefan Institute in Podgorica). In major natural and other disasters, this also includes radiological emergency events related to radioactivity, one of the first tasks is to set up an efficient radio communication network to transmit data and shape it into meaningful models. For efficient communication, the right information must be delivered to the right people at the right place, in the correct format, and at the right time. Different forms of smart information systems – governmental and private – for crisis management are the consequence of the need for information. However, communication in emergency event situations is difficult because of unpredictable situations and human nature [3], [4] and due to the possible breakdown of the digital systems. Efficient analog radio communications therefore represent a crucial backup in case of a total general digital communication channel failure. To achieve this, different forms of information and telecommunication technology are inserted in the course of communication between subjects of crisis management. Due to the further development and the improved implementation of the SAR operations, our basic idea was to develop an independent system that would be useful to send dose rate measurement data in the case of a radiological emergency event when all the digital mobile networks would go down and our ELME mobile unit will still be able to send and report them. For this reason, our team at JSI came up with the idea to develop and modify a system already established in the world called the Automatic Packet Reporting System APRS [5].

2 EFFICIENT RADIO COMMUNICATION SYSTEM

With an efficient radio communication system, it is possible to establish a local mobile network in the field, either via the existing infrastructure or in direct mode with mobile radio units. This will primarily allow radiological emergency field teams to send the data collected to the central computer on an ongoing basis and secondly ensure a real-time and accurate record of the situation on the ground. In the past, only classical analog technology was used, but in recent years digital technology has been used increasingly, especially TETRA (Terrestrial Trunked Radio) [6] or terrestrial beam radio and, more recently, DMR (ETSI - Digital Mobile Radio). TETRA is basically an emerging standard for professional digital radio communications, originally intended as a European radio system, but with the success of GSM, it was soon realized that it could become a worldwide radio system (Tavčar 1999, 308) [7], [8]. The frequency band for operation extends between 380 and 400 MHz. The main purpose of the TETRA standard was to create a series of open interfaces, as well as services and utilities, which will allow users to build infrastructure and products capable of interoperating and meeting the needs of organizations still using traditional analog (TETRA standard) professional mobile radio communications. The TETRA system can operate in three ways. The first is a basic bundle, which is optimized for simultaneous transmission of voice and data over a base station infrastructure. The second, direct mode, involves transmitting data and speech directly between radio stations. The third packet data mode involves only packet data transmission over the APRS base station infrastructure.
Slovenia uses a unified and autonomous radio communications system, called ZARE for short. The system is designed for communication by means of wireless communications for the needs of the units and services in search and rescue plans (SAR). The advantage of the system is that it is independent of public telecommunication systems, easy to use, and operates even in emergency situations. In terms of volume, the ZARE system is the largest single professional radio system in the country. Its technical integrity and smooth operation are ensured by the Slovenian Protection and Rescue Administration. The network system currently consists of 35 base and 60 repeater stations in the upper transmitter network and 73 digital repeater stations in the lower transmitter network. Each base station has two logical channels: one is used to control the public alarm system, and the other is free. The second channel is used for voice and in our case data transmission on a test basis.

The system's communication centres are located in the Regional Communications Centres (ReCOs), where they manage radio traffic and ensure the connection of users to the public and other functional telecommunications systems [10].

- Analog FM network cca. 11.000 users, mostly firefighters)
- System ZARE + (UHF trunking MPT 1327 with 35 base stations)
- System ZARE DMR (under construction, in use for public alert system sirens)

The ZARE communication system provides approximately 95 % coverage of the terrain with a terrain coverage radio signal when a fixed repeater network is implemented and 100 % when mobile repeater stations are used. The limitations of the system are similar to those of all radio communication systems (interference, grey spots, limited number of channels, natural obstacles that weaken the signal) and incorrect use and ignorance in the use of radio resources.

3 GENERAL OVERVIEW OF THE TACTICAL APRS SYSTEM

APRS is a real-time tactical digital communication protocol (TDCP) for exchanging information between a large number of stations covering a large local area that uses (ham) amateur packet radio technology. It is the brainchild of Bob Bruninga, a senior research engineer at the United States Naval Academy, and first came into use during the late 1980s due to the falling cost of GPS hardware. A tactical digital communication protocol (TDCP) is a communication system that utilizes a particular message format and a protocol to transmit data via wireless channels in an instant, automatic, and secure way. APRS turns packet radio into a real-time tactical communications and display system for emergencies and public service applications (and global communications). Normal packet radio is useful in passing bulk message traffic (Email) from point to point, but it does not do well at real-time events where information has a very short lifetime and needs to get to everyone quickly. Bulk messaging is a legacy description for application-to-person messaging services. It refers specifically to the sending of a large number of text messages to the predetermined group of recipients. Unlike packet radio, where stations connect to each other to exchange information, APRS operates in an unconnected fashion, rather than using connected data streams where stations connect to each other and packets are acknowledged and retransmitted if lost. All stations use a single frequency. On the VHF 2m band - the most commonly used band for APRS is 144.800MHz in Europe and 144.390MHz in the USA. HF is also used, with many HF stations acting as gateways between HF and VHF creating the potential for a worldwide radio-based network.

APRS provides universal connectivity to all stations in the net by avoiding the complexity and limitations of a connected network. A network is defined to be “connected” if there exists a path from every end-point source node to every end-point destination node. All relevant information is transmitted immediately to everyone on the net and every station captures that information for consistent and standard display to all participants. It permits any number of stations to exchange data just like voice users would on a voice net. Any station that has information to contribute simply sends it, and all stations receive it and log it. Secondly, APRS recognizes that one of the greatest real-time needs at any special event or emergency is the tracking of key assets. Where are the emergency vehicles? What are the weather conditions? What are the dose rate values at various points in the county? etc.

In addition, all such data are typically ingested into the APRS Internet System (APRS-IS) via an Internet-connected receiver (IGate) and distributed globally for ubiquitous and immediate access. APRS-IS servers collect information received from APRS stations via iGATE, filter out duplicates (where packets have been received by more than one gateway station), and distribute them to the other servers in the network. So, an APRS user anywhere in the world can see APRS activity anywhere else, not just their local traffic. With the widespread availability of 24/7 home broadband connections, most home-based APRS stations that are connected to a radio transceiver operate as internet gateways and the internet now plays a major role in integrating the worldwide APRS network. Much of the information sent by APRS stations - beacons, position reports, objects, telemetry, and bulletin messages - is not addressed to anyone in particular. Other information such as text messages are addressed to a specific station, which transmits an acknowledgment when it receives it. To try to guarantee reception, an APRS station will retransmit a message several times with an increasing delay between each attempt until an acknowledgment is received from the recipient station. However, after several failed attempts retransmission will stop.

4 BUILDING OUR OWN SYSTEM

The *Go-Kit* (or Radio-Ready-Kit) enables communications personnel to connect anywhere, anytime with flexible and agile *communications* and interoperability. Our general idea was to build a first Go-Kit communication case that should suit the needs of the Ecological Laboratory Mobile Unit (ELME) when performing on-route real time dose rate measurement or can quickly be assembled to respond to a "Call To Service" in a case of emergency situation. Equipped to serve, enables rapid deployment! These communication cases should be ready to receive the serial signals sent by the Automess 6150 AD6 detector (Geigher-Muller dose rate probe). This has led us to build a Go-Kit which is capable of enough transmitter power. The additional transmit power does not have to be utilized, but if needed, it is there. Another feature this radio provides is the ability to transmit and receive encoded, digital data via a direct connection to a computer/laptop.

4.1 Arduino microcontroller

We chose the Arduino open-source electronic prototyping platform as it enables users to create interactive electronic objects. The advantage of an Arduino microcontroller board is that contains the central process unit (CPU), random access memory (RAM), and read-only memory (ROM) on the chip. The additional devices on the Arduino board are to connect the power supply and connect input/output devices with the board. Automess 6150AD 6/H meter sends a serial signal of the measured dose rate values every second using an Arduino microcontroller. With the use of the Arduino microcontroller, the signals of the Automess meter are then converted into signals in the form of the RS detector and can thus be transmitted via an external radio antenna attached to the case as can be seen in Figure 1.

Figure 1: ELME - APRS system

4.2 APRS digipeater

The main purpose of digipeater device is receiving and sending APRS data packets via amateur radio transceiver. We choose to use a universal Microsat WX3in1 Plus 2.0 digipeater that is capable of receiving an APRS packet, decoding the sender, recipent, path and information field. WX3in1 Plus 2.0 allows you to generate APRS data packets with information field defined by user and send them in a specified interval. In this way, it is possible to send beacons, objects, weather and telemetry data. Then actions are performed in accordance with the options configured by user:

•Package is digipeated via the APRS network,
•Package is sent to the APRS-IS server,
•Package is ignored if it was corrupted.

4.3 Programming

In programming, we needed knowledge of the serial protocols generated by the Automess 6150 AD6/H detector to write code on the microcontroller. We came to the understanding with the help of the instructions for the device and by observing the signals on the computer. The packets sent by the Automess meter consist of six bytes. Automess meter, always sends signals when it is turned on. The speed at which the Automess sends data (baudrate) is 4800. APRS client software is all very well but it doesn't allow you to do much that you couldn't do using websites like www.aprs.fi. To start using APRS over the radio we

needed additional hardware. We set up an iGATE base station in our server room at Jožef Stefan Institute. This helped us to provide the local APRS infrastructure that we needed to ensure that our position reports and other output packets sent on the move were picked up and relayed to the internet. For our JSI base station, we did not need a GPS, since our position was fixed. APRS client software allows you to enter your position manually so that it appears in the correct place on aprs.fi maps.
For a way to decode APRS packets received over the radio so that our software may process them, and to encode any packets your station wishes to transmit, we used the traditional way and used a packet radio TNC designed specifically for APRS. A terminal node controller (TNC) is a piece of equipment amateur radio operators use to send and receive data on their computers through radio frequency. Some radio mobile transceivers including the Kenwood TM-281 have built-in support for APRS that can be accessed directly from a computer making them much more helpful. The use of one of these transceivers simplifies the setting up of an APRS station. This connected to our PC and client software using a serial interface or Bluetooth and to our radio using a dedicated data interface.

4.4 Performance test

After verifying the correct operation of the microcontroller we assembled all components for mutual communication. For the test performance purpose, we placed the Go-Kit suitcase (Figure 2) with the Automess 6150 AD6 probe at the server room on JSI.

Figure 2: APRS Communication Go-Kit suitcase

We continualy transmitted/received radio signals for about 20 hours and got an average background dose rate of 0.063 μSv/ h. The time interval between two consecutive measurements based on the current system software support of WX3in1 Plus 2.0 digipeater rated between 6-8 minutes. The time course of the measurements and the average value are shown on the following graphs (Figure 3).

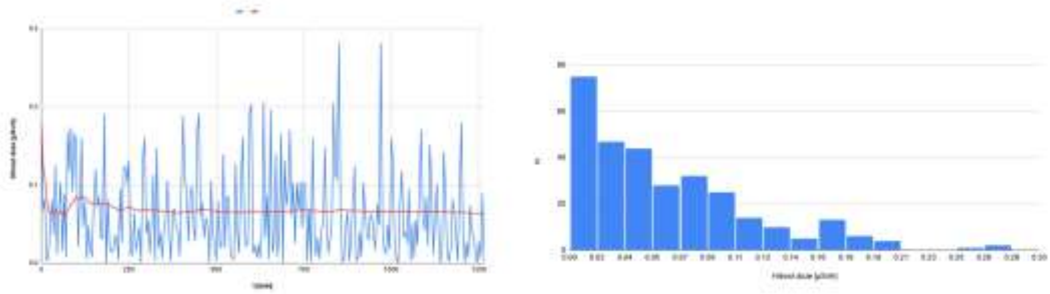

Figure 3: left: A 24h dose rate histogram ; right: Dose rate average value

A few days later, we measured again for an additional 4 hours and with all these measurements together (that is, after about 24 hours) we drew a final histogram of the dose rate which is shown in Figure 3 (on the right).

After that, we analyzed all of the total dose rate data gathered via our web page server domain www.hikaru.ijs.si. This domain automatically when turned on and signed in by the admin right collects information and shows real-time information collected from the APRS-IS. Then we made an additional QC test of the equipment and concluded that our Go-Kit is ready to be tested in vivo dose rate mapping.

5 ON ROUTE APRS.FI MEASUREMENTS

Our objective goal was to perform measurements of dose rate during driving and continuous dose rate mapping by ELME team. And secondly an operational test in the vicinity of NEK power plant in the framework of the regular annual exercise. During our performance on route dose rate measurements we used already mentioned the aprs.fi web service which automatically when signed in collects information from the APRS data of the ELME-ARON probes. In principle, a vehicle equipped with a GPS receiver, a VHF transmitter or HF transceiver and a small computer device called a tracker transmits it's location, speed and course in a small data packet, which is then received by a nearby iGate receiving site which forwards the packet on the Internet. Packets are also retransmitted on the radio channel by digipeater such as to enhance the coverage of the system. Systems connected to the Internet can send information on the APRS-IS without a radio transmitter, or collect and display information transmitted anywhere in the world.

We have selected the main A2 motorway connecting route between Ljubljana – Krško, and additional wider connecting area of the circular route within the Krško field, the Cerklje ob Krki Air Base and the highest hill above Krško (Trška gora). The speed of movement , i.e. driving was 130 km/h on the A2 motorway, while on local roads within the Krško and Brežice area the maximum speed was limited to 50 km/h. However, at the main selected measurement points, the vehicle was stopped for 10 minutes due to the data transmission (GPS position, outside temperature, and dose rate). This ensured that the data packages were definitely transmitted to APRS-IS due to the current minimal interval capacity of the WX3in1 Plus 2.0 digipeater being 5 minutes in the current configuration. Unfortunately, we did not have any live feedback information on this in the field with the current configuration of the Go-Kit case and equipment. Therefore we had to manually record and measure the time interval until the signal was transmitted using a stopwatch.

5.1 Test fire brigade Krško 2022 (fixed measurement points)

In addition to the on-route measurement test, fixed in-vivo measurements were comparatively performed in the vicinity of the selected PGE (Fire Brigade) Krško. Our tasks has to be carried out in cooperation with URSZ and PGE Krško within the most exposed and densely populated locations Krško and Brežice. This is a broad, mainly flat terrain (with the exception of Trška Gora, which is in the radio shadow) that would be most exposed in the event of a radiological emergency and therefore most suitable for testing. During the test we placed a Go-Kit case on the roof of the unit's gravel area of the PGD Krško to perform a continuous, 24-hour measurement of dose rate at fixed measurement points.

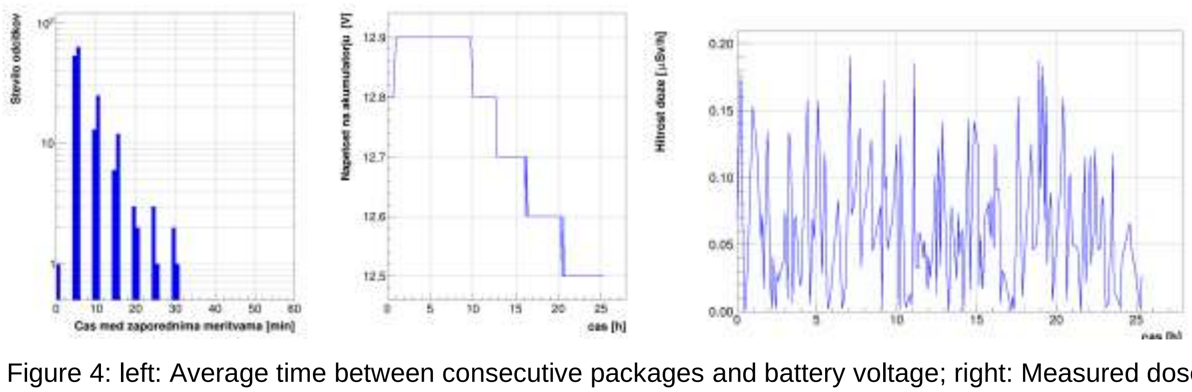

Figure 4: left: Average time between consecutive packages and battery voltage; right: Measured dose rates in Krško.

After the 24 hour period we gathered the measured data as shown in Figure 4. Further gap analysis gave us the outcome findings:

- There is a significant negative impact of the surrounding hills (radio shadow) - problems coincide with the difficult communication via the ZARE system.
- The system enables monitoring of the situation / hazard level in the city.
- The average time between consecutive packets is too long (8 minutes).

5.2 Test fire brigade Brežice 2022 (fixed measurement points)

After the first test in Krško, we made a comparable test carried out in cooperation with the URSZ Brežice. In comparison to the first test we now placed our Go-Kit case located in the parking lot between the two buildings of the administration to perform a continuous, 24-hour outer temperature measurement at fixed measurement points.

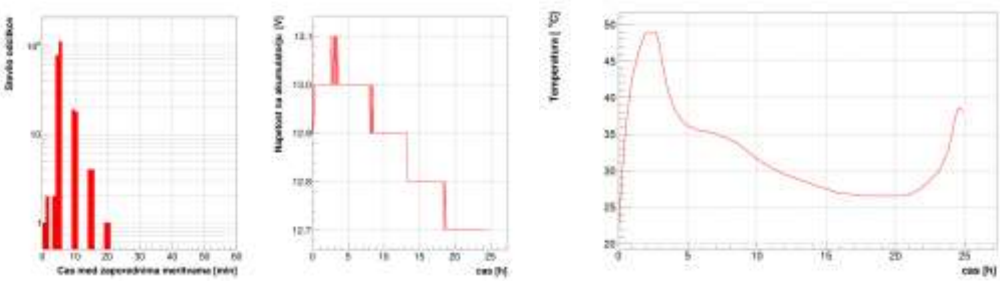

Figure 5: The average time between consecutive packages and battery voltage (left) and Measured temperature inside the measuring case in Brežice (right).

After the 24 hour period we gathered the measured data as shown in Figure 5. Further gap anaysis gave us the outcome findings:

- Better transmitter and receiver connectivity due to more open terrain.
- The system enables monitoring of the situation/hazard level in the city.
- The average time between consecutive packets is still too long (6 minutes)

6 DISCUSSION

During the measurements, it has been confirmed that natural and artificial barriers significantly disrupt or can completely obstruct the transmission of radio signals from station to station. In general, only main internet gateways and digipiters are visible. In the flat terrain of the Krško field and a hillside terrain on the AC Ljubljana - Krško route, which was carried out with dose rate mapping in a practical field test showed a typical shadow in the reception of transmitters (Figure 6). Artificial obstacles (tall buildings) can also obstruct the transmission of signals between stations and reduce intelligibility [12].

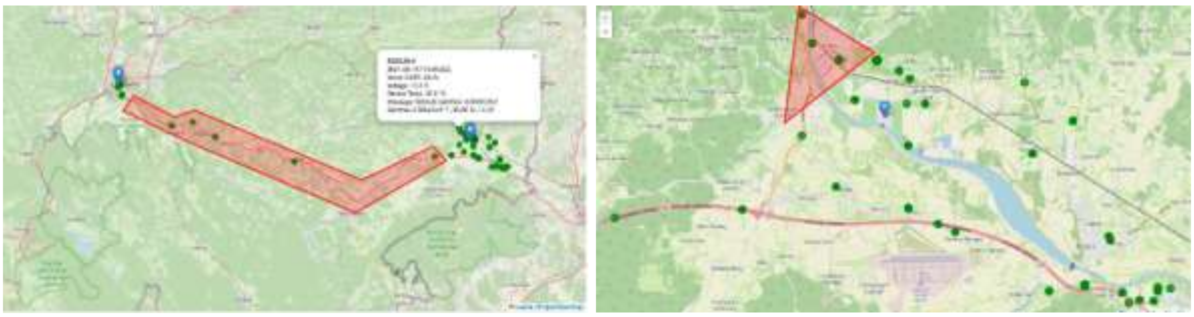

Figure 6: Shadow in the reception of transmitters

In these cases, the use of repeater stations is recommended, if not essential. According to the ZARE – DMR the main digital radio repeater systems are located on Mount Velika Planina and on Mount Janče. We are still waiting for the new tower on Mount Krim which will cover the Ljubljana and middle of Slovenia region and the APRS which should cover the path on AC towards Dolenjska region. Krško and Brežice should then be well covered. Care must be taken in the selection of sites for repeater or base stations, as otherwise interference and instability of the system may occur [13].

7 FINAL CONCLUSIONS AND FURTHER TASKS

The overall conclusions were marked as successful, there were some positive and negative findings. On the basis of the collected data, a brief GAP Analysis was performed of the information system we identified the necessary steps to move from the existing status quo to the desired situation. They gave us motivation for further work.

Positive findings:

- The system is independent of the telephone and mobile networks.
- It takes advantage of the benefits of the Amateur Radio network.
- Does not require an external power supply.
- Long autonomous operation (72h).
- Excellent as a redundant system for fixed site measurements.
- Spatially oriented HD data accessible to all.

Negative findings:

- A 5-minute interval is too long for quality measurements.
- Most of the Ljubljana-Krško route is in "radio shadow" and data transmission was unsuccessful.
- Significant loss of APRS packets also on the northern side of the Krško field, which is in the shadow of Mt. Trška Gora.
- The data from Aprs.fi is not much richer than the one of Hikaru.ijs.si
- No live feedback on packet reception.
- The WX3in1 modem in beacon mode does not allow a higher data transmission frequency.
- Current system performance unsuitable for "dose rate mapping".

ELME mobile units do not have their own system to display the measured data. We use standard aprs.fi and hikaru.ijs.si APRS mapping support. We definitely need our additional autonomous off-grid internet system for the display and storage of spatially oriented data in the field thus enabling us to develop further tasks:

- Adopt a protocol for the installation/use/maintenance of APRS cases, thus enabling simultaneous accessibility to multiple users.
- Incorporate measured data into the decision-making process by storing data in a database.
- Upgrade WX3and1 modems to increase the frequency of measurements and to minimize the send interval to a couple of seconds.
- Complete the system for displaying spatially oriented data in the field using Open Street Map locally.
- Minimal user interface and built-in VHF receiver that acts as a WIFI hotspot.
- The range of TETRA radios can be improved by using DMO repeaters or base stations at a higher and exposed position. This is a feature that some TETRA mobile radios already have and can be used.

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External links:

https://aprs.fi/#!lat=46.0503&lng=14.5046

http://hikaru.ijs

https://vhf.dxview.org/#si/