FROM ANALOG VOICE RADIO TO ICT: DATA COMMUNICATION AND DATA MODELING FOR THE GERMAN NBC RECONNAISSANCE VEHICLE

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Abstract: In Germany, the public safety system is largely organized by the German Federal States, which operate, among other equipment, a fleet of Nuclear, Biological and Chemical Reconnaissance Vehicles (NBC RVs) to take measurements in contaminated areas. Currently, the NBC RVs, which have been centrally designed and procured by the German Center for Civil Defense, verbally report measured values to a Central Control Unit (CCU) over the assigned Public Safety Organization (PSO) analog voice radio channel. This procedure has several disadvantages. The channel is not secure, puts a natural limit on the achievable throughput and thus on the number of NBC RVs that can be operational simultaneously. Also, while data is being reported, other PSO members are blocked from sending. Finally, a proprietary model is used to structure the NBC RV data, so the data can only be aggregated and evaluated at the CCU but not by any other PSO unit. To overcome these problems, we propose in this paper a heterogeneous and flexible communication platform that complies with reliability and coverage requirements for PSO. More specifically, our proposed system is designed to replace current ways of communicating between NBC RVs and the CCU. We also propose to standardize data structures for data exchange to enable PSO cooperation. A drastically higher number of measured values can then be transmitted to the CCU, and the data can be processed in a much more effective manner in the CCU as well as in cooperating PSO task forces. Ultimately, this will improve NBC RV missions and consequently shorten PSO response time when dealing with NBC disasters.

1 INTRODUCTION

In the recent years, the German Federal Government designed, procured and deployed an advanced Nuclear, Biological and Chemical Reconnaissance Vehicle (NBC RV) [1] model that allows fire departments operating the vehicle across the country to detect and report various kinds of nuclear and chemical threats. The measured values have to be reported to a Control Center Unit (CCU), where experts record and analyze the incoming measured values from several NBC RVs in near real time. Currently, even though the measured values are digitally available in the vehicle's PC, analog voice radio transmission is used to report readings to the CCU. Unfortunately, this is time consuming and error-prone, and as one simple voice message occupies the radio channel for several seconds, the number of NBC RVs to report to one CCU has to be limited to approximately five in order to avoid channel overload. Another drawback is that the channel is also blocked for other (possibly mission critical) messages, and no channel encryption is available. Basing on a recent study we conducted on behalf of the German Center for Civil Defense, we present new ways for data communication and data exchange, intended to replace the traditional voice radio transmission of display readings with a more efficient and reliable digital data exchange solution for NBC RVs and CCUs. In order to ensure interoperability of the NBC RVs in case of large-scale cross-border disaster response operations involving several units, the solution is designed to be extensible for adoption by all German Federal States. Traditionally they have come up with individual solutions in the area of emergency management due to their constitutional responsibilities.

In the remainder of the paper, we will first summarize in Section 2 what kind of operations NBC RVs are deployed in, and to which limitations the current equipment yields. Following, in Section 3 we propose new communication strategies and data exchange models for more effective NBC RV operations. Finally, in Section 4 we conclude our findings and give an outlook.

2 NBC RV OPERATIONS

The NBC Reconnaissance Vehicle is used for measuring, detecting and reporting radioactive and/or chemical as well as for recognizing and reporting biological contamination. Other missions include the search for scattered radioactive fragments, the marking of contaminated areas also off paved roads and their monitoring using measuring techniques, ground, water and air sampling as well as the acquisition and reporting of meteorological data.

2.1 NBC RV Equipment

Figure 1: NBC RV

The NBC RV (see Figure 1) conducts its measuring operations with the aid of the following equipment: Besides the instrumentation container which accommodates the radiological and chemical measuring systems, the NBC RV contains a Public Safety Organization (PSO) analog radio set, a set for solid, liquid or gas sampling, a meteorological measurement set, a location system, a marking set, an ambient air dependent and independent respiratory protective equipment as well as a gas-tight and semi-permeable NBC protection system.

The radiological and chemical measurement systems are computer-assisted. The system is capable of archiving acquired measured values, representing them graphically or in tables or visualizing and printing them on a geographic map. Moreover, the instrumentation container is fitted with a location tracking system for positioning purposes. The measured values are always linked with data from the location system. Assisted by satellite-borne navigation (GPS system) and supported by the differential GPS system (DGPS system) a location error of less than 5 m is obtained.

In addition, the location system is equipped with a dead-reckoning navigation component (self-sufficient navigation). It is only used when no GPS information is available. This may be due to nearby high buildings, tunnel passages, satellite breakdowns or the like.

To protect the operating personnel, the system generates visual and audible alarm whenever measured values exceed adjustable thresholds.

2.2 Measuring and Data Communication Operations

The various measuring systems onboard the NBC RV produce a large amount of data. For example, the radiological device typically generates one readout per second. These values are collected, visualized, and stored by the NBC RV installed software. The staff of the NBC vehicles analyze the measured values only for self-protection purposes to avoid stays in contaminated areas. Since it is the responsibility of the staff at the CCU to evaluate the overall situation, it requires continuous updates on all deployed NBC RVs' measured values. Currently, this information is sent via the onboard PSO analog voice radio system from the NBC vehicles to the CCU. Additionally, operation process and coordination communication, such as messages sent from the CCU to NBC RVs to start or modify an ongoing operation, are also sent via voice radio commands.

2.3 Current Problems

The current solution has several drawbacks: The German Federal States have developed individual emergency management solutions to handle operations with a single NBC RV. There are several proposals regarding middle- to large-scale operations, i.e., multiple NBC RV operations, optionally with dynamic processes (e.g., cross-States cooperation, responsibility handover from one Federal State to another, etc). However, currently there are no established standardized work processes and protocols for larger operations.

Another problem is the data communication bottleneck due to the usage of analog voice radio. A large amount of data is collected during the measuring process (e.g., the radiological system generates one readout per second),. As this is a time-consuming task and since the channel is "blocked" for other PSO usage during a radio message, only few selected measured values are transmitted to the CCU. Existing alternative communication technologies like GSM or GPRS are either not reliable enough or have too bad coverage for PSO purposes. TETRA or other digital PSO communication systems can be expected to be suitable, but unfortunately such a technology is still to be deployed in Germany, and due to cost reasons, it is not even sure that 100% coverage will be attainable.

To overcome these problems, we propose to use existing communication infrastructure by integrating various communication technologies into one platform and by using them flexibly and interchangeably according to prevailing radio conditions. In this way, the various communication alternatives can complement each other, and an acceptable level of reliability and coverage can be guaranteed. We also evaluate the suitability of using standardized data exchange models, enabling large-scale operations with cooperation over the Federal State borders to be realized independently of software systems. Finally, we evaluate how our proposed solution could improve the organization and coordination (i.e. the workflow) of NBC RV operations.

3 TOWARDS A NEW NBC VEHICLE ICT SYSTEM

Based on the analyzed problems, this section addresses the following issues:

First, none of the existing data communication technologies fulfill all requirements. The challenge is then to integrate various alternatives in a “fallback” arrangement, so that at least a low level, but reliable communication between the NBC RVs and the CCU is enabled. The solution should replace or complement the currently used analog voice radio transmissions, have high reliability and coverage, and be inexpensive.

Second, only a small subset of measured values is (currently) transmitted to the CCU. To provide a better overview about potentially critical situations to the staff at the CCU, as much measured data as possible should be transmitted to the CCU, while critical data must obtain priority if the communication channel suddenly deteriorates.

Third, workflow communication is also done via voice radio, so it suffers from the same inefficiencies as data communication. Workflow communication specifies e.g., the start, eventual modifications, and the termination of operations. There is no suitable operation workflow model defined that specifies message exchange between NBC RVs and CCU for small-, medium-, and large-sized operations. Such a model must also be adaptable to varying communication channel restrictions (e.g., bandwidth, latency, etc.).

3.1 Communication Infrastructure

There are several requirements on the communication infrastructure. To begin with, the CCU should receive data from the NBC RV in near real time, or at the latest 5 seconds after taking the measurement. Therefore, the *latency* and *connection setup time* for each communication technology is interesting to compare. Regarding the *data rate*, the current proprietary data structure used for the measurement data is relatively compact, so that no more than ca. 4 kbit/s is needed (on average). Additionally, the workflow messages will require some small capacity, bringing the total data rate up to ca. 6 kbit/s.

Operations over long distances (here, “*roaming*”) are currently problematic, since each Federal State follows its own PSO frequency allotment plan. Consequently, a moving sender must bring and consult a radio frequency table in order to switch to the correct PSO frequency when entering a new county area. At that point, direct communication with the HQ “at home” is no longer possible over the PSO radio channel. To solve this problem, any alternative communication technology should support seamless roaming, i.e. operations over Federal State boarders should be possible without user action. More generally, long-distance operations should be supported by very good outdoor *coverage*, if possible even within tunnels etc.

An at least rudimentary level of *encryption* is important to ensure confidentiality of sensitive PSO data. TETRA-25, TETRAPOL, GSM-BOS seem promising for PSO purposes, but in this context they are only *operational* in very limited testing areas in Germany (we have refrained from assessing TETRAPOL in this work). Similarly, UMTS has only recently been launched and it will take some time before it is fully operational.

One of the most important questions in this scenario is whether the communication technology is *reliable* or not. Experiences from the floodings in eastern Germany in the summer of 2002, where GSM base stations were rendered inoperable, show that a land-based communication system for PSO purposes must have a support organization that can bring failing equipment back online quickly. Finally, it is interesting to know if the technology has good *prospects* or not, since the investment decision is influenced by the expected lifetime of the technology.

In order to comply with requirements mentioned above, we have evaluated existing and forthcoming wireless WAN (Wide Area Network) alternatives for communication between NBC RVs and CCUs. We focused on the technologies GSM (Global System for Mobile Communications), GPRS (General Packet Radio Service), TETRA (Terrestrial Trunked Radio, more specifically: TETRA-25), GSM-BOS (GSM adapted for PSO requirements, as proposed by Vodafone), data communication over the PSO 4m radio band currently used (mainly) for voice communication, LEO (Low Earth Orbit) and GEO (Geostationary Earth Orbit) satellite systems, and UMTS (Universal Mobile Telecommunications System) (see Table 1).

	GSM	GPRS	TETRA	GSM-BOS	4m-Band	LEO	GEO	UMTS
Latency (s)	1	Netw. dep.	N/A	Netw. dep.	0	1	1	Netw. dep.
Conn. setup time	5 s	2 s	2 s	2 s	0 s	Min-utes	Min-utes	2 s
Data rate (kbit/s)	9,6	111	28,8	111	1,2	10	64	2000
Roaming	EU	EU	DE	DE	No	Glob.	Glob.	EU
Coverage	Bad	Bad	Good	Good	Good	Good	Good	Bad
Encryption	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Operational	Yes	Yes	N/A	N/A	Yes	Yes	Yes	Yes
Reliability	No	No	Yes	Yes	Yes	Yes	No	No
Prospect	Good	Good	N/A	N/A	Bad	Good	Good	Good

Table 1: Evaluation of communication technologies (where applicable, estimated maximum values are given)

TETRA [3] or GSM-BOS [4] are interesting for general PSO needs, since these technologies have additional features like group calling and direct (walkie-talkie type) connectivity. But, in this scenario we are only interested in their data transferring qualities. Besides, it is still to be decided if, when, and to which extent a new PSO digital technology is deployed in Germany. Therefore, in some cases no precise information was available. The PSO analog radio channel on the 4m band is used mainly for voice communication, but experimental modems exist that can achieve a data rate of 1,2 kbit/s over the channel.

The remaining alternatives do unfortunately not meet the reliability and coverage requirements. High elevation angle systems like Low Earth Orbit (LEO) satellite systems (e.g., Iridium) have very good outdoor coverage and are not affected by local disasters, but have poor indoor (e.g., tunnels) coverage. LEO satellite signals can be picked up with small omnidirectional antennas, but the data rate is very limited. Geostationary Earth Orbit (GEO) satellite systems like Inmarsat, offer ISDN-type data rates, but bigger antennas must be used, since the distance to the satellite is much longer. Also, the antenna must be precisely aimed at the satellite at all times, which makes it impractical for this scenario, since NBC RVs must be able to stay online even while on the move. Recently, Inmarsat antennas that address this problem have appeared on the market (see e.g., [5]), but they are rather expensive. Promising research indicates that a solution for vehicular satellite-based mobile applications can be expected in a near future, where the antenna not only automatically adjusts for best signal reception, but is also able to utilize both LEO and GEO satellite systems [2].

Commercial systems like GSM/GPRS/UMTS position their infrastructure according to cost-benefit calculations and not PSO considerations, i.e. good coverage in all areas cannot be guaranteed. However, some major tunnels do have GSM and GPRS coverage. The technical support organization around PSO-based technologies is also expected to be much better, so that for example mobile base stations are deployed on-site within short time when needed for an operation. This translates into higher reliability for the system, since there is a lower probability of communication failure.

For a survey of technologies and initiatives for disaster response communication in areas with underdeveloped or non-existing infrastructure, we refer to [8], where, in particular, ad-hoc technology is discussed. Rapidly deployable networks, which might be considered for NBC RV operations in a very limited geographical area, are investigated in [9].

As mentioned, we propose to use multiple communication options simultaneously (see Figure 2) in a fallback solution setup. When one option is unavailable, the system can switch to communicate over another technology, as proposed in [10] where vertical handoffs are discussed. If no communication technology is available, the last option is to send a messenger with mission critical data. As an example, PSO radio data communication, GPRS and satellite communication are shown in the figure. In the end, it is up to the system designer/customer to decide which and how many fallback technologies should be used. Each option adds coverage and reliability but increases the costs.

The system therefore needs to monitor and control the transmission so that it fits the underlying communication technology that is being used. Also the data stream generated from the onboard sensors must be adapted to the circumstances. For example, if only PSO 4m band data communication is available, the data rate is too low to send all data. In this case, only the most essential data is sent to the

CCU, according to some preset filter. Also, feedback from the CCU (i.e. workflow messaging) is automatically managed by the system. Besides from TCP and UDP, proprietary transport protocols should be supported for greater flexibility.

In any case, all generated data is stored in the NBC RV even if it is not sent to the CCU during an operation. In this way, the data can be used for later simulations and personnel training. For the same reasons, operation events are logged in a protocol in the NBC RV and in the CCU.

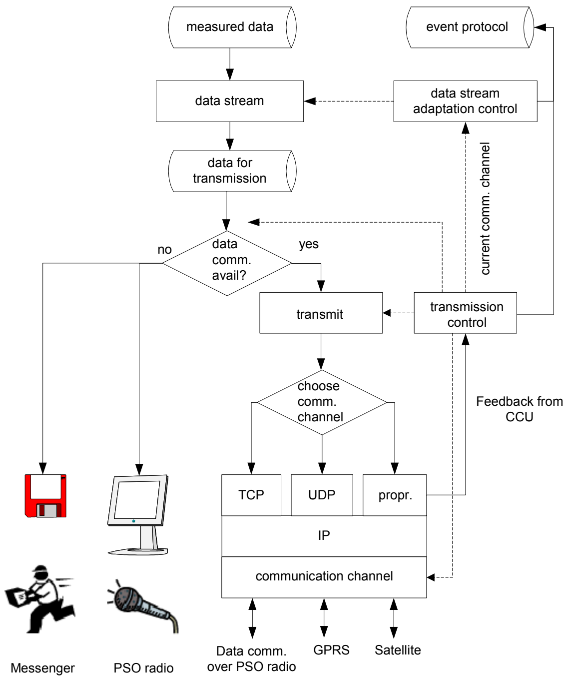

Figure 2: Proposed communication architecture

Obvious advantages of our proposed architecture are increased reliability and coverage while using existing infrastructure. Also, the system is flexible both during operation and with regard to communication technology development. If, for example, a PSO TETRA system were deployed in Germany, it would not be difficult to integrate it in the system described above. The drawbacks are increased system complexity and cost.

3.2 Operations Workflow

To avoid the error-prone and time-consuming tasks to transmit messages via voice radio, we propose to transmit measured values as well as any messages concerning orders to the NBC vehicles by using the proposed system architecture with its more advanced communication technologies.

To this end, we classify messages to be exchanged between NBC RV and CCU as follows:

- Messages that give the order to an NBC vehicle to examine potentially contaminated areas. This includes also modifications of the ongoing operations, and their termination.
- Messages concerning the transmission of measured values from the NBC vehicle to the CCU. By default, any measured values are transmitted.
- Messages specifying modifications on the default transmission of measured values. These messages are either triggered by the control center or, due to observed communication bottlenecks, by the system (on the basis of a decision to switch to fallback communication solutions, see Fig. 2: data stream adaptation control). In such situations, the data volume is typically reduced, and only a fraction of the measured values are sent to the control center.

We propose to use XML as data exchange format for these messages for the following reasons:

- XML provides a huge set of tools for handling XML data (e.g., parsing, transformation). Thus, XML messages can be easily generated (even when the size of the data stream needs to be adapted to the currently used communication infrastructure) and be interpreted at the receiver (e.g., at the CCU).
- Using XML means that the current industry standard is employed, and not any proprietary formats for data communication, which generally leads to lower costs for the system design. Although XML leads, due to the markup of data, to some data overhead, this overhead can be reduced by an appropriate structuring (e.g., re-structuring of measured values) and by sending larger numbers of measured values in one message.

Furthermore, we propose to use Web Service technology for the implementation of the system infrastructure, as existing technologies and tools (e.g., SOAP, i.e. Simple Object Access Protocols for document exchange) can be used.

3.3 Cost Considerations

Our evaluation, which we can only partially report here, shows that for now, GPRS is the most cost-effective solution, since investment-, operational-, and maintenance costs are all comparably low. PSO systems like TETRA are likely to incur huge investment costs. Sums in the range of 7-7,5 billion euros have been mentioned. This may in the end add to operation expenses, but this is a political issue, of which the outcome is difficult for us to estimate. Satellite technology is interesting but very expensive, at least if GEO systems are used. In the end, the user has the freedom to choose which communication technologies and how many fallback levels are integrated into the system, so costs can be regulated.

4 CONCLUSION AND OUTLOOK

In this paper, we have reviewed the issue of enabling the German NBC Reconnaissance Vehicle for data communication, in order to allow measured values to be transmitted to a Control Center Unit, and to provide a means for sending operational messages to the vehicle. Based on a recent study we carried out, we have reported recommendations for appropriate communication technology, arguing that fallback solutions must be provided in order to ensure reliability in the presence of possible network failures. There are still some uncertainties due to, in particular, the pending decision on the selection of a new country-wide digital radio system for German Public Safety Organizations, and the fact that establishing a "federal" data communication solution for the NBC vehicle stands in some contrast to the German Federal States' constitutional role of making the decisions in the field of fire department equipment and policies.

The use of mobile data communication to support emergency response field operations is still a relatively new concept for German PSOs, and so we feel that our results may have significance beyond the individual case. In fact, some fire departments are now equipping their command vehicles with network-connected laptops, and the CarPC [6] is being introduced for selected police services. However, apart from network connectivity issues, a lot of work remains to be done in order to ensure proper integration of mobile nodes into established back-end PSO information systems [7]. In this context, we have recently suggested the concept of a Mobile Smart Message Board to be linked with headquarter C3I (Command, Control, Communications and Intelligence) systems, providing a means to access and propagate information "anytime, anywhere" during a response operation. Thus, this paper (and the study it is based on) can be seen as a building block for our contributions in the field we refer to as "e-Emergency".

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