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USE OF THE DIGITAL MOBILE RADIO TECHNOLOGY STANDARD FOR EMERGENCY PUBLIC INFORMATION PROVISION THROUGH ELECTRONIC WARNING ENDPOINTS

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Research article

Abstract: This paper describes experiments and results of evaluation of the intelligibility of verbal information within the population protection. Direct remote announcements to warning endpoints would mean a substantial improvement in the quality of the unified public warning and notification system of the Czech Republic. Through announcements it would be possible to provide up-to-date information about impending dangers and operational instructions that would improve measures to protect lives, health and assets of the population in the Czech Republic.

Keywords: Wireless public address system, Digitalization of transmission, Electronic siren, Text-to-Speech synthesis, DMR technology standard.

Introduction

Timely and reliable public warnings are a fundamental civil population protection measure. To implement this measure, the FRS CR operates a unified warning and notification system (hereinafter the "UWNS") (act 239/2000, 2000; act 380/2002, 2002). The broadening array of potential threats to the public puts new demands on the warning system and its functionality. Siren warnings are acoustically robust but provide low informational value. In contrast, emergency information is more subtle acoustically, but can provide more details about a current situation and needed public responses, i.e. it can be more effective. Warning signals can be an effective means of initiating an information campaign, but the campaign implementation relies on verbal forms of communication to a considerable extent (Šimek, 2016).

New warning endpoints (electronic sirens and local information systems) are capable of providing emergency information. However, only verbal pre-recorded information stored in endpoint memory can be dispatched remotely from notification centres, or by attaching another modulation source. The standard source is an FM radio receiver, which is part of the standard equipment of electronic warning endpoints. In some areas, other external modulation sources can be used as part of autonomous systems.

Up-to-date emergency information can be provided through the UWNS only on a local level, through local dispatching directly from the given endpoint, i.e. from the lowest-level crisis management authority. Provision of up-to-date emergency information from higher crisis management levels is essentially possible only through mass communication means. Emergency information provision tends to be overlooked by the competent bodies, partially because this functionality is not fully supported by the existing UWNS transmission infrastructure. The possibility of providing up-to-date emergency information from higher crisis management levels is one of the key requirements for an upgrade of the UWNS transmission infrastructure.

The feasibility of using Digital Mobile Radio technology (hereinafter the "DMR") (Digital mobile Radio, 2007) was tested under the research of critical state information structures with a focus on a unified public warning and information system (hereinafter the "UWIS"). The goal of the industrial research was to develop a secure UWIS grounded in modern principles and the possibilities offered by contemporary and future ICT. The research aim is to propose a method for using modern UWIS infrastructure employed in the CR to transmit information between dispatchers (Integrated Rescue System (IRS) units, crisis units, other persons responsible for dealing with emergencies) and UWIS endpoints (public warning and information, monitoring and data collection equipment). The purpose of this comprehensive system is to increase the security of the population and secure infrastructure for communication with warning endpoints for use of IRS units and others.

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The research coordinator is Colsys s.r.o. Partners include the Faculty of Biomedical Engineering at the Czech Technical University in Prague and the Population Protection Institute of the Directorate General of the FRS CR of the Ministry of the Interior.

Hereinafter the term UWIS will be used to denote the new system as it more clearly captures the actual designation of the public warning and emergency information system. Notification of the public, which was a heavily used functionality at the time when the existing system was introduced, is now accomplished through other, more modern technology and procedures. The term notification is thus no longer relevant in relation to the warning system.

During the previous phases of the research, the method of existing infrastructure and warning endpoint use was analysed and the basic requirements for technical parameters and utility properties of the UWIS communication infrastructure equipment and endpoints were determined.

Subsequently the technical and economic aspects of potential UWIS communication infrastructure technologies were evaluated. The main technologies standardized by the European Telecommunications Standards Institute (ETSI) were assessed to ensure that the new system would not be restricted by proprietary solutions.

Based on the analyses and with regard to the status of solutions of similar systems in other countries, the following recommendations were made:

- Retain the existing transmission infrastructure of the UWNS based on POCSAG technology (Codes and Formats for Radio Paging, 1997) for basic management of warning endpoints. The advantage of this technology is its simplicity and resultant reliability, which also means it is easy to sustain in tense emergencies;
- Focus on developing DMR technology for new UWIS communication infrastructure to ensure provision of newly required functionalities, including checking the condition of warning endpoints and connecting to environmental monitoring systems. Also consider LTE technology in relation to the NAKIT strategy for securing mobile communication services for IRS (Long Term Evolution, n.d.).

In early 2017, DMR technologies for existing warning endpoint control were tested and the possibility of transitioning from analogue transmission to digital was verified in the laboratories of Colsys s.r.o. and the CTU. A reference set was determined and the power consumption of the various technologies was measured.

Material and methods

Use of DMR technology for the given purposes was further tested in late summer 2018 on a test range at the Research and Experimental Centre of the Lázně Bohdaneč Population Protection Institute. A series of experiments was conducted there to verify that the DMR technology is capable of transmitting speech modulation in a quality ensuring sufficient intelligibility of verbal information when reproduced by high-power electronic warning endpoints.

DMR transmission equipment (transducers and transceivers) from two different manufacturers in different combinations was tested. DMR technologies were tested in a setup that simulated operation of the UWIS in real-life conditions, i.e. transmissions were dispatched to the terminal equipment via a converter and the transmission chain consisted of at least two radio links.

The DMR technology on the transmission path uses 4FSK frequency shift keying with a bitrate of 3,600 bps. The solution codes individual sounds of speech with a length of 20 ms. A AMBE2+ vocoder is used for digitization (AMBE+2TM Vocoder, n.d.).

Both main types of electronic warning endpoints - local information systems and electronic sirens - were tested during the experiments. Experiments were carried out on two types of digital wireless local information systems (hereinafter referred to as “WLIS”), which use different modulations on the transmission path between the system control panel and endpoint loudspeakers (warning devices) and different codecs for signal digitization. One WLIS uses DRM+ modulation on the transmission path (Digital Radio Mondiale, 2014) while the other uses quadrature phase modulation (QAM) (Qudrature Amplitude Modulation, 1989). To compare the effect of transmission digitalization, identical experiments were also performed with an analogue local information system (hereinafter referred to as “LIS”) with a 100 V line connection to horn loudspeakers. To reproduce the audio signal, four 30W horn loudspeakers were used on all endpoints.

Two types of electronic sirens were also tested. Control electronics of both tested sirens are shown in Fig. 1. Sirens representing the portfolio currently used in the existing UWNS were selected for the tests. The selection criterion was to enable verification of the impact of DMR modulation on speech intelligibility when reproduced by endpoint equipment that uses low frequency amplifiers of different classes. One siren uses a Class AB amplifier and the other a Class D wideband amplifier (Kesl, 2004). Sirens in the power range of 250-300 W were

used. Two 150 W acoustic units were used for both sirens.

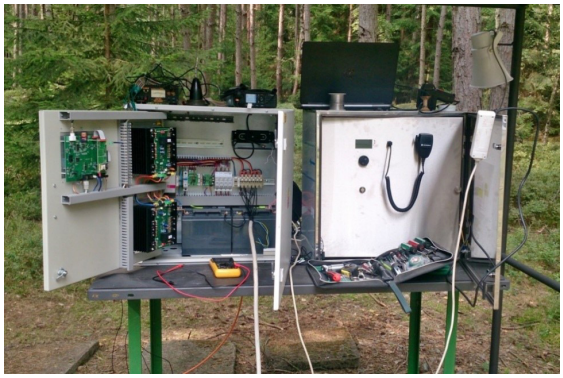

Fig. 1 Electronic sirens with DMR radios

In the experiments, the influence of DMR technology, which was incorporated into the test transmission chain, on speech intelligibility was investigated. To evaluate the tests, results obtained in the same test chain without DMR were used for comparison.

The experiments were carried out outdoors on a test range, where measurements of acoustic parameters of warning endpoints are made.

A laptop computer was used as the source of the audio signal. The audio signal was sent to the audio input of the electronic system controlling the warning endpoints, or to the input of the DMR radio. Sets of texts recorded in professional quality by trained announcers were used. The following text sets were used:

- Individual words articulated by female and male voices. Recordings used for testing the acoustic parameters of the warning endpoints were used;
- Verbal information pronounced by male and female voices. Recordings of verbal information used for testing electronic warning endpoints were used;
- Text read aloud. Audiobooks read by both male and female voices were used and
- Text-to-speech conversion using Text-To-Speech synthesis (TTS) (Acoustic speech synthesis, n.d.). Only a synthesized male voice was used.

The quality of the speech signal was subjectively evaluated by a panel of listeners who moved along the axis away from the source (a LIS endpoint loudspeaker or an acoustic head of electronic siren - Fig. 2) and recorded the distance over which they could still reliably understand the reproduced text (hereinafter the intelligibility distance).

Subjective evaluation of speech signal quality was used because it is independent of the type of speech signal degradation, be it frame loss, noise, transmission error rate, echo or nonlinear distortion due to use of low bitrate codecs. As the experiments were conducted outdoors, the ACR (Absolute Category Rating) (Aksamit, 2007) listening method was used in order to achieve the highest possible informative value. The listening quality was assessed using a five-point evaluation scale:

5 - Excellent,

4 - Good,

3 - Fair,

2 - Poor and

1 - Bad.

The distance of reliable intelligibility was determined as the distance that scored 3 to 5 on the listening quality scale.

Fig. 2 Endpoint loudspeakers in experiments

Information systems testing results

Analogue local information system

In these experiments, only the effects of the 4FSK modulation and an AMBE2+ vocoder, which are used by DMR technology, were tested. The setup of the test chains with an analogue LIS, which uses a 100 V line, is shown in Fig. 3.

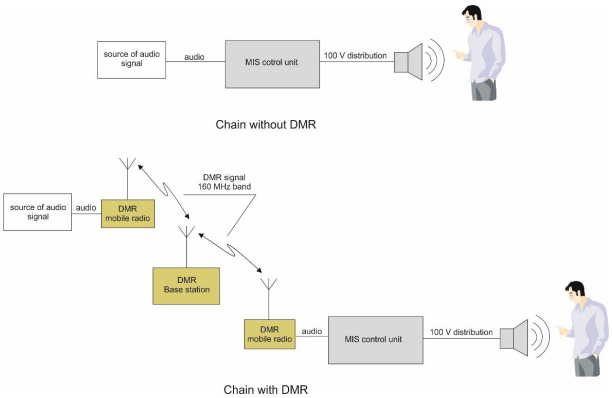

Fig. 3 Test chain for testing analogue LIS

The results are listed in Table 1 and also depicted in chart form below (Chart 1).

Tab. 1 Intelligibility distance of an analogue local information system

Test text set	Intelligibility distance [m]	
	Without DMR	With DMR
Test words - male	227.5	225
Test words - female	240	240
Verbal information - male	227.5	230
Verbal information - female	255	255
Text read aloud - male	160	160
Text read aloud - female	162.5	160
TTS synthesis	150	150

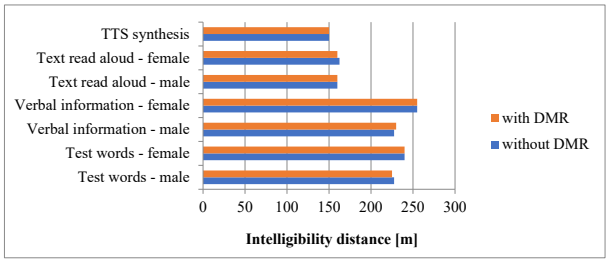

Chart 1 Intelligibility distance of an analogue local information system

The results from all text sets in both chains were almost identical. Minor differences in the order of a few percentage points can be attributed to the influence of weather conditions at the specific time of each of the intelligibility assessments. Weather conditions, in particular short-term changes in wind speed and direction, significantly influence the propagation of the desired signal as well as the background noise level.

The tests showed that DMR technology did not affect the intelligibility of the transmitted spoken word.

Wireless local information systems (WLIS)

In these experiments, the effects of DMR on intelligibility were tested together with the effects introduced into the transmission chain by additional digitization of the signal. Additional digitization is introduced by another radio transmission with different modulation and with the use of other vocoders on the path between the control panel and the WLIS endpoint loudspeakers (warning devices).

The setup of the test chains for testing digital wireless local information systems is shown in Fig. 4.

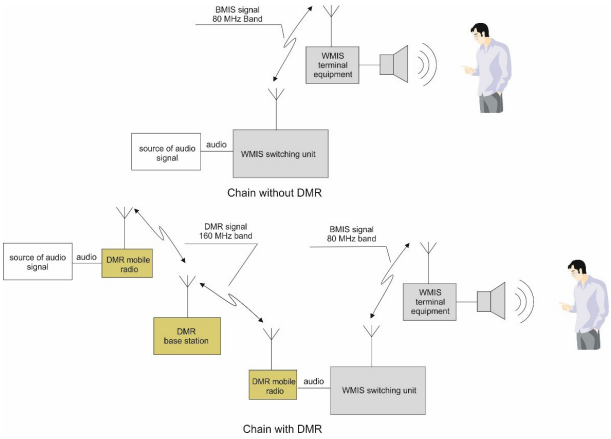

Fig. 4 Test chain for testing wireless local information systems

Results with each type of WLIS are indicated in Tables and Charts 2 and 3.

Tab. 2 Intelligibility distance for WLIS with DRM+ modulation

Test text set	Intelligibility distance [m]	
	Without DMR	With DMR
Test words - male	190	205
Test words - female	180	215
Verbal information - male	215	222
Verbal information - female	230	245
Text read aloud - male	110	75
Text read aloud - female	110	90
TTS synthesis	125	110

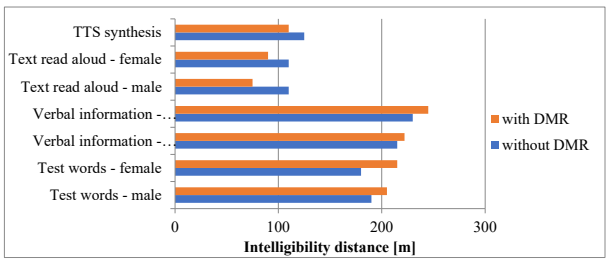

Chart 2 Chart comparing intelligibility distances in WLIS with DRM+ modulation

Tab. 3 Intelligibility distance for WLIS with QAM modulation

Test text set	Intelligibility distance [m]	
	Without DMR	With DMR
Test words - male	220	240
Test words - female	230	240
Verbal information - male	200	255
Verbal information - female	230	255
Text read aloud - male	160	150
Text read aloud - female	170	140
TTS synthesis	150	120

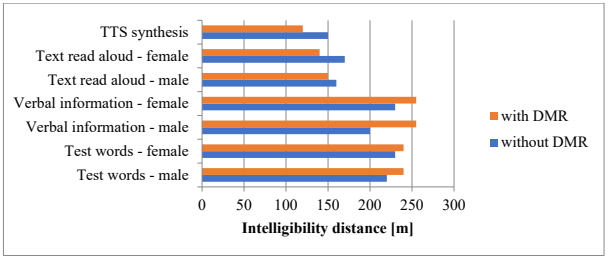

Chart 3 Chart comparing intelligibility distances for WLIS with QAM modulation

By incorporating the DMR technology into the transmission chain, a longer intelligibility distance was achieved for both tested WLISs for test words and verbal information in both voice forms. This can be attributed to the fact that DMR limits the bandwidth of the transmitted signal. The final effect was that the endpoint loudspeakers emitted more acoustic energy in the band that is essential for intelligibility of speech content.

On the other hand, there was a decrease in intelligibility distance for texts read aloud and TTS-synthesized announcements. Digital transmission is influenced by speech source coding technology and by the method used for subsequent transmission of data packets in the radio part of the chain. The extent of this influence is also dependent on quantitative and qualitative parameters of the voice and on the voice technique of the announcer (Frič et al., 2010), which differed significantly between different sets of test texts. Recordings of test words and verbal information contain longer gaps between words than normal speech. These sets of texts also use a slower speech rate and emphasize articulation.

The texts read aloud, for which audiobooks were used, were characterized by much higher dynamics (Jirka, 2012; Codes and Formats for Radio Paging, 1997) and marked changes in the speed of verbal expression. A number of passages were accompanied by background music and other sound effects. These are all elements intended to give the listener the best aesthetic experience possible. They are not essential for conveying the actual content of the message and when using endpoints with a high acoustic power output, they may even have a degrading effect in some respects. Audiobooks are meant to be listened to mainly in an undisturbed indoor environment or using headphones. This means that they are typically reproduced at a lower volume, with limited background noise and in an environment with limited reverberations and echoes caused by reflections of acoustic energy from obstacles. Reverberations and echoes are significant accompanying phenomena of sound propagation from high-power loudspeakers in an outdoor setting.

For TTS synthesis, the rate of verbal communication had the strongest effect on the results. The software did not allow adjustments to the speed of text reading, and it corresponded to the speed of normal speech.

For WLIS, which uses DRM+ modulation for transmission to acoustic warning devices, better results were achieved in the DMR chain with female voice test texts. WLIS with QAM modulation showed comparable results for both voice forms.

Electronic sirens

The composition of test chains with electronic sirens is shown in Figure 5. These experiments were designed to verify the potential impact of DMR on speech intelligibility when using warning endpoints with low-frequency amplifiers of different classes.

Due to time constraints, a full set of tests with both types of electronic sirens could not be performed. Full tests were performed only with a siren with a Class AB low-frequency amplifier (Tab. 4, Chart 4). For Class D sirens, tests of a transmission chain without DMR were not performed.

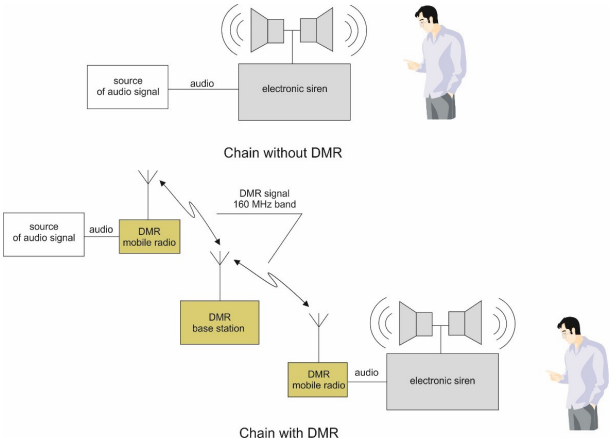

Fig. 5 Test chain for testing electronic sirens

Tab. 4 Intelligibility distance for electronic sirens with Class AB amplifier

Test text set	Intelligibility distance [m]	
	Without DMR	With DMR
Test words - male	165	140
Test words - female	195	170
Verbal information - male	190	182.5
Verbal information - female	190	200
Text read aloud - male	55	52.5
Text read aloud - female	55	50
TTS synthesis	120	100

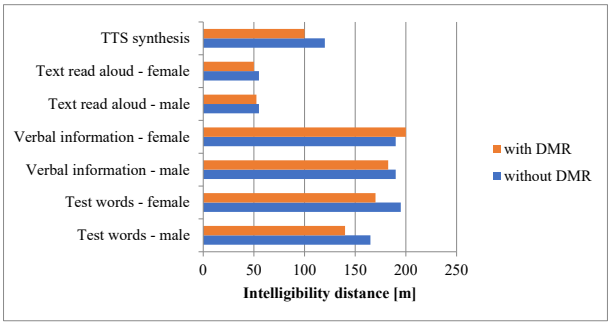

Chart 4 Chart comparing intelligibility distances for an electronic siren with Class AB class amplifier

Class AB amplifier siren tests were the only tests where transmission chains with DMR technology showed poorer results in comparison to transmission chains without DMR. The exception were tests with a set of verbal information in a female voice variant.

In general, electronic sirens performed better with female voice tests. However, there were significant differences in the intelligibility distance between sirens of similar power output in the DMR chain. This is evident from Tab. 5 and Chart 5.

Tab. 5 Intelligibility distance for electronic sirens in a DMR chain

Test text set	Intelligibility distance [m]	
	Class AB amplifier	Class D amplifier
Test words - male	140	255
Test words - female	170	265
Verbal information - male	182.5	300
Verbal information - female	200	350
Text read aloud - male	52.5	130
Text read aloud - female	50	100
TTS synthesis	100	140

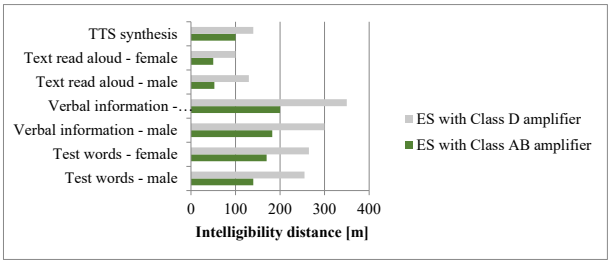

Chart 5 Chart comparing intelligibility distances for electronic sirens in a DMR chain

The results with a siren with a Class AB amplifier were significantly worse in comparison to a siren with a Class D wideband amplifier. This can be attributed to the fact that in a siren with a Class AB class amplifier the amplifier is optimized to achieve maximum acoustic output for the warning signal, i.e. a narrower frequency band is used.

The results could also be influenced by insufficient adaptation of the external audio input in the siren with the Class AB amplifier. After removing the isolation transformer from the input for the external modulation source, significantly better intelligibility was achieved than in the first tests during which the isolation transformer was connected. However, due to time constraints, it was not possible to further optimize the external audio input. In this paper, only the results of tests without the isolation transformer are presented. There was no need to make any adjustments to the external audio input for the Class D amplifier.

Conclusion

The experiments proved the usability of the DMR technology for spoken word transmission to the warning endpoints. The use of DMR did not significantly affect the intelligibility of the spoken word transmitted under the given conditions. When using pre-recorded emergency announcements recorded in sufficient quality and in compliance with the appropriate verbal expression principles, the intelligibility was in fact even better. Although the AMBE2+ codec used in DMR is relatively lossy (lower sound quality), it is very robust, since it uses low bitrates of 3.6 kbps and auto-correction algorithms. This means that even with the assumed relatively high transmission error rate, intelligible voice information can be transmitted. In addition, noise cancellation algorithms are used, which achieve very robust transmission resistance to background noise.

No problems with using DMR equipment from different manufacturers in one transmission chain were observed during the experiments.

The use of DMR would extend the utility features of the UWIS by adding functionalities that cannot be provided by the existing UWIS transmission infrastructure. This would make full use of the potential that modern electronic warning endpoints offer.

If direct announcements are introduced to the UWIS, it would be desirable to focus on announcement skill training for the shift personnel at the operating and dispatching centres from which the warnings and emergency information are disseminated to the population. When broadcasting emergency information, announcers must take into account the above-mentioned effects, which impact the intelligibility of speech in outdoor sound propagation conditions. Thus, announcers should have practical experience in this area or be adequately trained. Lack of experience or nervousness can significantly influence announcers' verbal expression. It can be expected that in tense crisis situations nervousness will play a more significant role.

Therefore, beyond the research objectives, the possibility of using a TTS system was also experimentally verified. The fundamental advantage of machine conversion of written text into voice form is that it eliminates announcer nervousness. A TTS system would make it possible to optimize the emergency information in writing in advance and to dispatch it in sufficient quality when needed. It is therefore advisable to further verify the usability of TTS applications for broadcasting emergency information. In doing so, focus should be put primarily on optimum parameter settings to achieve adequate intelligibility of information in an outdoor setting.

The experiments confirmed that the intelligibility of information when reproduced by high-power acoustic devices is significantly affected by quantitative voice parameters (voice intensity and pitch, phonation time), qualitative voice parameters (voice clarity, voice sonority and voice technique) and separation of individual words with reasonably long gaps, which eliminates the effects of disruptive reverberations, echoes and multiplied reception signals.

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