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Evaluation of smartphone ultrasonic airborne communication as regards acoustic environment

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ABSTRACT

Ultrasonic airborne communication has attracted a renewed interest in the past few years, thanks to the capability of mobile devices to emit and receive acoustic signals above the limit of the audible frequency range. One of the main applications under concern is the short-range data transmission. The aim of this work is to set up a general methodology making it possible to evaluate the performances of ultrasonic airborne communication, particularly as regards the characteristics of a given acoustic environment. The proposed methodology based on impulse responses and noise measurements can be implemented easily on any device and does not need a long measurement campaign. Once the application is loaded, a collection of impulse responses and noise samples can be recorded in-situ. The performances of any modulation scheme can be studied afterwards using real noises and impulse responses. The robustness of the transmission can thus be evaluated a priori with realistic use conditions, taking into account both the electroacoustic response of the smartphone and the acoustic environment.

1. INTRODUCTION

Most mobile phones can acquire and process digital audio signals sampled at 44100 Hz or higher [1]. These high sampling levels allow development of inter-device communication systems at near-ultrasonic frequencies (NUSC), and different NUSC implementations for chat applications, wireless payment or file transfer systems are already functional [2-6]. In this paper, an evaluation protocol for NUSC efficiency is proposed. This protocol is based on the convolution of impulse responses with original signals and the addition of background noise recordings. The proposed method provides analysis tools for the study of NUSC alterations due to the acoustic environment.

The “material and method” part presents the modulation process used and the mobile devices audio set up and characteristics. The “experiments” and “results” parts present the study of the robustness of the communication protocol according to its parametrization, environmental parameters and devices relative positions. Observations and results presented in the first three parts are discussed in a fourth part.

2. MATERIAL AND METHOD

2.1 Modulation scheme

The modulation technique implemented for this study is a multi-band On-Off Keying (MOOK) scheme [7] over 8 frequency bands from 18260 Hz to 20069 Hz. Each individual signal (i.e. one-bit coding over one frequency band) has a level of -27 dB(FS). The modulation/demodulation technique implements also a state transition encoding/decoding [8] consisting of having the signal of one coding byte followed by its complementary byte. A start indication signal and an end indication signal are added (Fig. 1).

The demodulation process is based on a spectral analysis by time windows, comparing the energy at the coding frequencies between two successive windows (state transition coding/decoding). The detection of the start and end signals carried out from an analysis by successive windows allows to adjust the signal readout clock.

2.2 Mobile device: acoustic & audio characterisation

Two phones of the SM-A520F model (Samsung Galaxy A5(2017)) were used with the Android 7.0 (API Level 24) operating system. The audio signals were processed with a 16 bit PCM encoding at 44100 Hz. The overall level of the smartphone for broadcasting media content has been set to 80%.

Pre-tests carried out on reception over the entire width of the available frequency band (0 Hz to 22050 Hz) ensured that there was few pre-processing and sufficient relative sensitivity over the near-ultrasonic band (18.2 kHz to 20.1 kHz). Emission tests revealed that different audio effects are post-processed by the device. However, for a controlled configuration and levels below -18 dB(FS) these effects are not detrimental to NUSC and the convolution process assumptions are still met.

3. EXPERIMENTS

3.1 USC signals

For this study three test signals have been built, an exponential sine sweep signal (ESS) [9] and two signals encoding “Hello World!” with the MOOK scheme (HW_a, HW_b) which differs from the presence of a silence gap between each octet in the HW_b signal (Fig. 1).

Device-to-device impulse responses were measured from the ESS signal with the transmitter and receiver unit arrange as shown in Fig. 2. The unit was placed in the centre of a room and isolated from structure-borne noise by a suspension system. Four impulse responses were

measured by varying the distance between the transmitter and receiver (10 cm/50 cm) and the nature of the surface positioned under the transmitter/receiver system (absorbent: melamine foam / reflective: glass). Each of these impulse responses was convoluted by the “HW_a” or “HW_b” test signal resulting in a set of 8 signals to study the efficiency of the modulation/demodulation protocol.

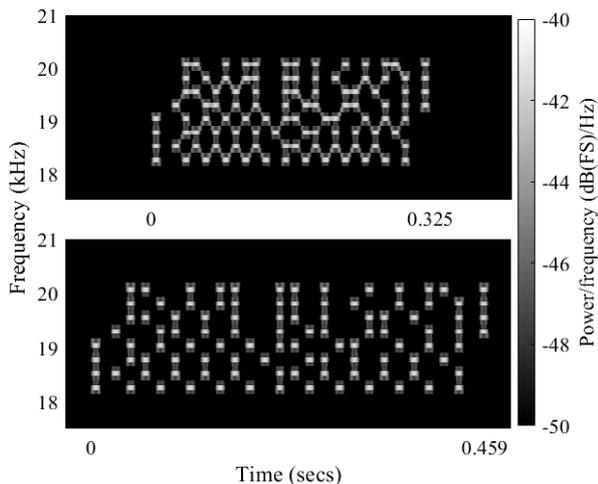


Figure 1. Spectrograms of modulated signals encoding "Hello World!" (UTF-8) with the start and the end indication signals (top: test signal “HW_a”; bottom: test signal “HW_b” i.e. including a silence samples between each byte).

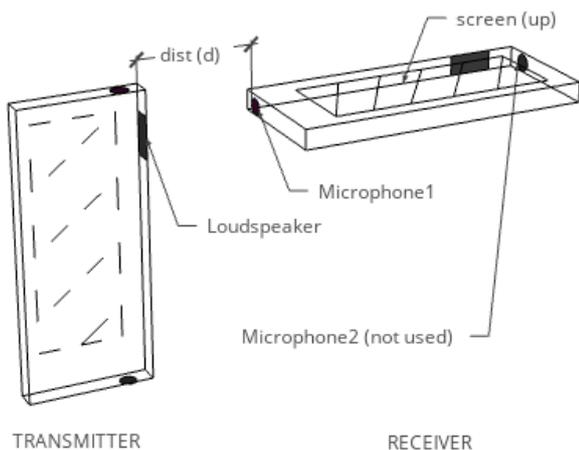


Figure 2. Arrangements of the two devices when measuring impulse responses. Microphone 1 of the receiver and the transmitter loudspeaker were positioned 20 cm above an absorbent or reflective surface.

3.2 Background noises

The first experiment on the efficiency of the modulation/demodulation protocol was carried out by superimposing the test signals on a white Gaussian noise of variable level. For the second experiment, two 5-minute background noise signals were recorded from the receiving smartphone, one on the platform of a station during the arrival of a train and the other in a running subway train.

3.3 Efficiency assessment

The background signal was split into one-second segments with a 97% recovery rate. Each of the 13230 segments obtained was added to the signal obtained by convolution between the impulse response and test signal “HW_a” or “HW_b”. The success (i.e. exact decoding of "Hello World!") or failure of the demodulation was collected for each sample.

4. RESULTS

4.1 Experiment 1: white noise as background noise

The evolutions of the demodulation success rates as a function of the SNR (18kHz to 20.1kHz) take the form of generalized logistic functions [10] (Fig. 3). The use of test signals obtained from the two impulse responses measured for a source/receiver distance of 10 cm leads to the highest efficiency of the demodulation process. For a source/receiver distance of 50 cm the efficiency is lowest when using an absorbent surface. For a source/receiver distance of 50 cm and the use of a reflective surface, the performance of the modulation/demodulation process is intermediate and differs according to the modulation signal used (HW_b or HW_a) signal.

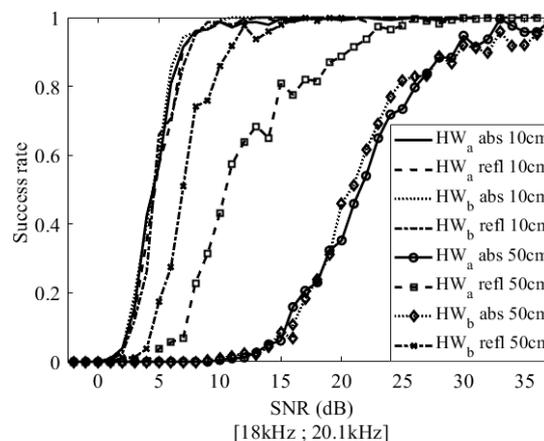


Figure 3. Effect of white Gaussian noise on modulation/demodulation efficiency as a function of SNR.

4.2 Experiment 2: in-situ recorded noises as background noises

For station recording (Fig. 4), whatever the test signal, demodulation has a lower success rate when there is a strong background noise in the transmission frequency band. The arrival of the train at the station and the isolated impulse noises reduce the success rates. Signals built from an impulse response for a source/receiver distance of 10 cm give the best performances. The HW_a signal obtained from an impulse response for a source/receiver distance of 50 cm above a reflective surface gives the poorest success rates. The HW_b signal obtained from the same impulse response produces intermediate success rates.

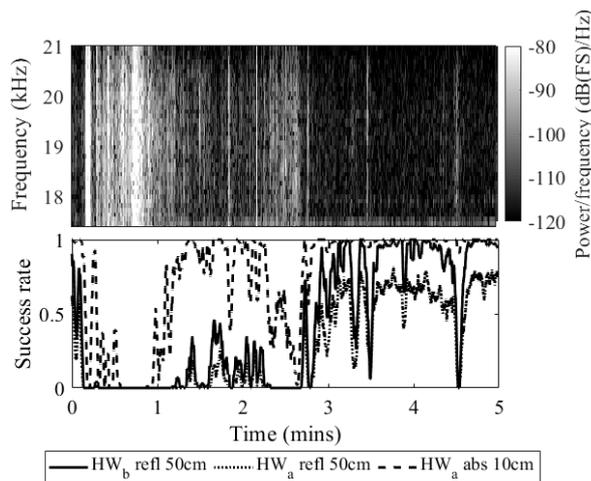


Figure 4. Near-ultrasound spectrogram of the recording made on a station platform (top) and average success rate of the demodulation process (average over 10 analysis windows and sliding over the whole background signal) (bottom).

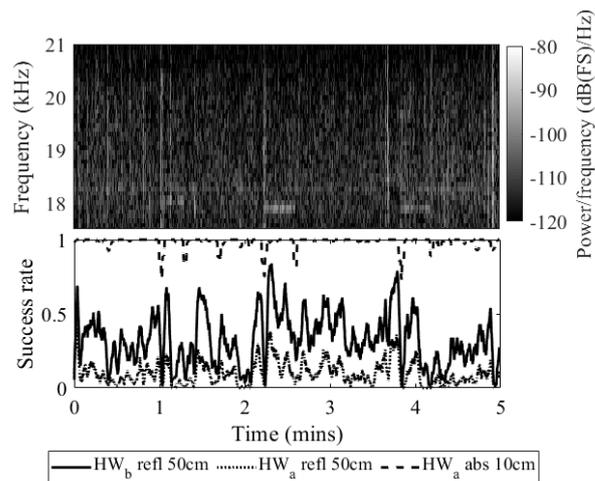


Figure 6. Near-ultrasound spectrogram of the recording made in a running subway train (top) and average success rate of the demodulation process (over 10 analysis windows) (bottom).

The effect of background noise level on demodulation efficiency is shown in Fig. 5. When the dynamic range is sufficient the overall form of the demodulation performance curves as a function of SNR is close to that of a generalized logistic regression but with the presence of very different point values (SNR around -10 dB).

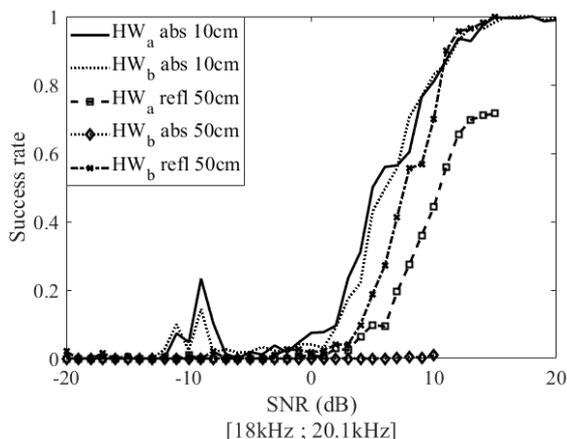


Figure 5. Effect of station platform ambient noise on the efficiency of demodulation according to SNR.

For the recording of noise in a subway train (Fig. 6), the results on the relative efficiency of the different signals are close to those obtain for the train station noise (Fig. 7). Here too, the success rate vs SNR curves with sufficient success rate dynamics seem to be close to generalized logistics functions with some values deviating significantly from them. In the case of the best and worst performing configurations, the lack of dynamic success rate values does not allow for the visualization of an inflection zone.

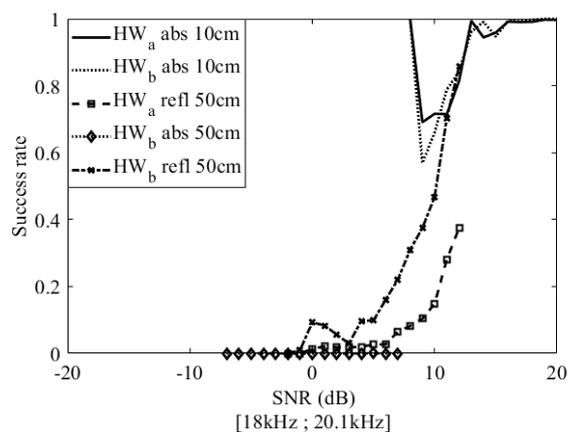


Figure 7. Effect of the indoor ambient noise of the running subway train on the efficiency of the demodulation according to the SNR

5. DISCUSSION

Regardless of the background noise, measurements made for a source/receiver distance of 50 cm always result in lower performances than for a distance of 10 cm even for identical SNR values. This effect is probably due to a decrease in the energy ratio of the early field (0-10 ms) relatively to the reverberated field. The reverberated field induced by sending one byte thus interferes more strongly with the signal of the next byte when the source/receiver distance is large. The relationship between the early and reverberated fields can be assessed according to the measurement configurations based on the time evolution of the energy in the impulse responses. In Fig. 8, it can be seen that the “late” reverberated field strength is limited to a level of about -60 dB(FS) for all measurement configurations. The early field energy, on the other hand, varies according to the measurement configurations between -36 dB(FS) maximum for measurements of

impulse responses at 10 cm source/receiver distance and -46 to -50 dB(FS) for a source/receiver distance of 50 cm. For a measurement distance of 50 cm, compared to the situation where the surface under the measuring device is absorbent, the gain in performance when a reflective surface is present can be explained by a level about 4 dB higher for the first 10 milliseconds of the impulse response. This gain on the early field is probably due to a constructive interference in the transmission frequency band between the direct wave and the first reflection from the reflecting surface. However, it should be pointed out that a small change in the path difference between the direct wave and the first reflection would result in a destructive interference thus decreasing the early field energy useful for an efficient demodulation. For measurements of impulse responses at 10 cm, no surface effect is observed. This is probably due to the absence of a reflected contribution arriving quickly after the direct field. At 10 cm it is assumed that the devices are too close as regards as the directivity of the transducers for a strong specular reflection to exist on the surface and/or be picked up by the microphone.

For a source/receiver distance of 50 cm with a reflective surface the proposed communication system is more efficient for a modulation including a time interval between each byte. This result is probably due to the introduction of silences in the “HW_b” signal that allows the reverberated field of the signal of one byte to have a lower impact on the transmitted useful signal of the next byte (Fig. 9). For impulse response measurements at 10 cm, no effect of these silences is observed. It seems that the early field contributions for this configuration are large enough to neglect the masking effect of the reverberated field compared to the background masking effect.

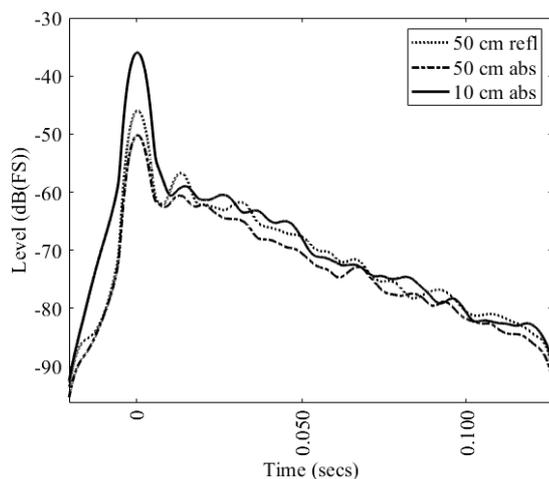


Figure 8. Time evolution of the energy of the source/receiver impulse responses (energy of the impulse responses over sliding windows identical to those used in the demodulation process).

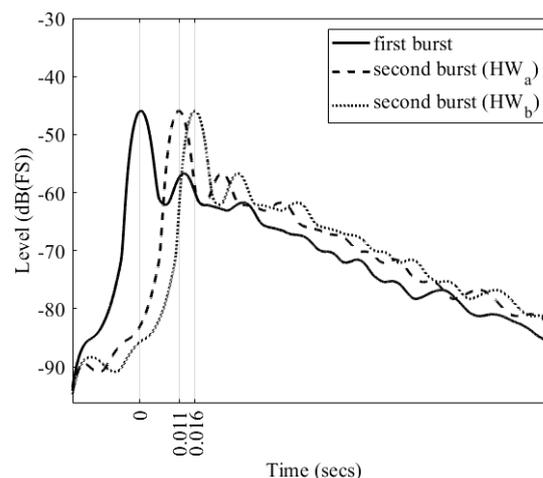


Figure 9. Evolution of the energy of successive impulse responses for a measurement at 50 cm from the source/receiver distance and a reflective surface.

Analysis of the effectiveness of the proposed communication protocol according to the type of ambient noise shows that a simple SNR study on white noise seems to explain the overall performance levels. However, at particular SNR values, it is possible to observe significant deviations of the performance curves when using real background noise compared to artificial white Gaussian noise. These localized differences are due to the particularities of the actual background noise, which during certain periods, corresponding to given SNR levels, deviate significantly from a Gaussian noise.

6. CONCLUSION

The study presented here meant mainly to be a proof of concept of the use of impulse response measurements and background noise recordings for the evaluation and study of a given communication protocol between mobile devices in the near ultrasound environment. The study of the effectiveness of the proposed communication protocol based on these simulations made it possible to highlight the influence of the sound environment on its success using short recordings of sound ambiances. It appears that for a short distance only the relative levels of background noise influence the success rate. For a longer distance, which are more relevant in practice, an effect of the surrounding environment is observed depending on whether it is absorbent or reflective due to the probable creation or not of a marked specular reflection. The introduction of silences between each coding byte can also have a positive influence on the success of the proposed communication process, but only for relatively large distances. Finally, despite some spectrotemporal peculiarities of the background noise, it seems that, overall, the level of performance of USC in noise can be studied according to the measurement configuration from a global SNR.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

- [1] Q. Wang, K. Ren, M. Zhou, T. Lei, D. Koutsonikolas, and L. Su, ‘Messages behind the sound: real-time hidden acoustic signal capture with smartphones’, in *Proceedings of the 22nd Annual International Conference on Mobile Computing and Networking*, 2016, pp. 29–41.
- [2] M. Zeppelzauer, and A. Ringot: SoniTalk: An Open Protocol for Data-Over-Sound Communication, Technical report, 2019.
- [3] ‘CopSonic - Ultrasonic authentication’. <https://www.copsonic.com/> (accessed Jun. 23, 2020).
- [4] P. Getreuer, C. Gnegy, R. F. Lyon, and R. A. Saurous, ‘Ultrasonic communication using consumer hardware’, *IEEE Transactions on Multimedia*, vol. 20, no. 6, pp. 1277–1290, 2017.
- [5] M. Chung, ‘Short distance data transmission method using inaudible high-frequencies between smart devices’, *Telecommunication Systems*, vol. 70, no. 4, pp. 583–594, 2019.
- [6] J. Miegel, P. Branch, and P. Blamey, ‘Wireless communication between personal electronic devices and hearing aids using high frequency audio and ultrasound’, *The Journal of the Acoustical Society of America*, vol. 144, no. 4, pp. 2598–2604, 2018
- [7] D. R. Smith, ‘Digital modulation techniques’, in *Digital Transmission Systems*, Springer, 2004, pp. 363–436.
- [8] R. C. Dorf, *The Electrical Engineering Handbook-Six Volume Set*. CRC press, 2018.
- [9] A. Novak, P. Lotton, and L. Simon, ‘Synchronized swept-sine: Theory, application, and implementation’, *Journal of the Audio Engineering Society*, vol. 63, no. 10, pp. 786–798, 2015.
- [10] J. Nelder, ‘The fitting of a generalization of the logistic curve’, *Biometrics*, vol. 17, no. 1, pp. 89–110, 1961.