Near-Ultrasonic Communications for IoT Applications using Android Smartphone

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***Abstract*—Conventional wireless communication means for Internet of Things (IoT) devices and smartphones mostly rely on electromagnetic waves as the carrier of the information. Typical wireless communication protocols for IoT devices and smartphones include Wi-Fi, Bluetooth, NFC and other radio frequency enabled technologies, which may require additional dedicated transceivers and/or a dedicated router to establish the communication. An alternative method to communicate between two IoT devices is by establishing data transmission through acoustic waves. By utilizing ultrasound or near ultrasound acoustic waves for wireless communications, it allows data transmission between nearby devices without the need of a router or a coordinator. In this study, we explore and seek alternative solutions for IoT devices to communicate using near-ultrasonic waves between two typical Android smartphones. This paper focuses on presenting the feasibility of such a system with Android smartphones as transceivers for near-ultrasonic data communication using their built-in microphones and speakers. Different techniques on encoding, transmitting, receiving and decoding basic text messages are presented by verifying the frequency response of the devices and achieving the communication via Amplitude-Shift Keying (ASK) and Frequency-Shift Keying (FSK) modulation methods.**

Keywords—Near-Ultrasound Communication, Internet of Things (IoT), Android Smartphones

I. Introduction

Modern communications typically use electromagnetic waves as the medium to carry information. Electromagnetic signals have advanced properties compared to other information carriers. For instance, these waves are invisible nor audible, and travel at the speed of light. Also, these waves carry a lot of energy which is beneficial for long-distance communications as the data can be transmitted far away without too much of data losses and without using any physical medium. However, recent studies have shown that these types of electromagnetic waves could be related to the bad impact on human health, such as favoring the apparition of cancers [1]. As an alternative solution, ultrasonic or near-ultrasonic signals can be used as the carrier of information [2] [3] [4]. Using the technology already embedded in any typical smartphone, it is possible to utilize the microphone and the speaker as an ultrasonic or near-ultrasonic sender and receiver, where the ultrasonic frequencies are above the audible frequency at approximately 20 kHz [5] [6]. However, some considerations need to be accounted for concerning the range of frequencies that such devices can operate with. For example, the specification of the smartphone must be known in advance. In this paper, we explore and show that ultrasonic/near-ultrasonic waves could be used as an alternative to the traditional means of wireless communications in terms of the signal carrier, providing efficiency for nearby transmissions, without being invasive as these waves do not carry a lot of energy compared to the conventional electromagnetic waves.

In this paper, we explore the possibility of the ultrasonic/near-ultrasonic data transmission using two typical Android smartphones to provide a cross-platform API for Internet of Things (IoT) devices. Experimental implementations were achieved for sending simple text messages between two Android smartphones. Also, we achieve ultrasonic/near-ultrasonic data transmission by utilizing ASK and FSK modulations in order to compare their performances.

II. Android Application Design

Our customized Android application consists of two parts: Frequency Response Analyzer and Near-Ultrasonic Chat Messenger. In order to have any typical Android smartphone to be capable of performing near-ultrasonic data communication, it is important to determine its current smartphone's capability and finding the optimal frequency range for communication. This is because individual Android smartphones are equipped with different microphones and speakers, and their optimal frequency ranges for data communication may differ. Our Near-Ultrasonic Chat Messenger is a customized Android application, capable of being installed and executed in Android operating systems higher than Android 4.0 to increase the application's compatibility.

A. Frequency Response Analyzer

The purpose of this customized Android application is to find the best range of usable frequencies to communicate through near-ultrasonic waves between Android smartphones. Frequency Response Analyzer can either execute in manual or automatic mode to conduct tests that will sweep user-specified frequency ranges. This method is achieved by one of the Android smartphones (sender) playing these frequencies while the other Android smartphone (receiver) records each frequency. In the automatic mode, we use configurable timers to play a series of frequencies on one device while the other one listens. For obscure reasons, waiting time can vary depending on the device, therefore, different waiting times can be set on each device for the timer in order to achieve the best setting for synchronization. Test results are then displayed on a Bode plot describing the frequency response of the whole system formed by the speaker of the sender, the air and the microphone of the receiver. To analyze the test results, users can define the frequency range for the Bode plot, setting up starting and ending frequencies, as well as the number of

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points for the plot. Our customized application provides the user which frequencies are valid and which are invalid for the data transmission by analyzing the recorded data and the expected data. Users can also save the results that are directly stored in the internal storage of the device and can be used afterward for further analysis. Users have also access to the temporal plots for each frequency and can compare temporal plots between the sender and the receiver.

B. *Near-Ultrasonic Chat Messenger*

Our design approach for ultrasonic/near-ultrasonic data transmission is to use a modulation technique; for this study, we experimented with two modulation techniques: Amplitude-Shift Keying (ASK) and Frequency-Shift Keying (FSK) [7] [8]. Regardless of the used modulation techniques, text messages are first encoded into their binary value using ASCII codes.

In the ASK modulation technique, we utilize two different levels of amplitudes for the transmitted signal to represent either '0' or '1'. Due to different scattering and reverberating effects, sounds can be easily distorted and attenuated in the air, particularly affecting the amplitude of the signals; for these reasons, the ASK technique is less reliable to send messages. To overcome the generated errors after decoding the text messages on the receiver part due to the attenuation of the signals in the air, a correction scheme is implemented for the ASK modulation technique, based on the Hamming distance. In the FSK technique, we utilize two different frequencies in the near-ultrasound/ultrasound range to represent binary data, where the range is selected from the Frequency Response Analyzer test result. In this technique, we use a common implementation of fast Fourier transform (FFT) to achieve the demodulation of each bit by identifying each frequency used.

For both versions of the application, the user can access the settings to modify the amplitude in the ASK version, and the frequency modulation for each bit in the FSK version as well as the bitrate. The user can also plot and compare the graphs of the transmitted and received signals.

Our customized Android applications were tested using two different Android smartphones: a Samsung Galaxy Nexus running Android 4.0 and a Samsung Galaxy S8+ running Android 9.0. To test the data communication between these two devices, we placed them in the same alignment in a quiet room and conducted experiments at various distances.

III. Experimental Results

The first experiment conducted is the Frequency Response Analyzer as described in Section II, where this Android application determines the optimal frequency range for data communication. Fig. 1 shows the results in the Bode plot format from the Frequency Response Analyzer application, where the two Android smartphones were aligned and facing each other in a quiet room at a distance as close as approximately 5 centimeters apart, and as far as 10 meters apart at the maximum bitrate of 33 bits per second.

As shown in Fig. 1, the result shows good and constant frequency responses up to approximately 16.8 kHz. Beyond this frequency, a rapid drop can be observed on the plot. It entails that the tested device is not suitable for higher frequencies due to the limitation of the built-in microphone and the attenuation of the sound wave which cannot be detected by the microphone. Even though the frequencies beyond 17 kHz are not well suited for Android devices to detect sound waves through the microphone, we were able to achieve transmitting and receiving correct data up to 19.7 kHz.

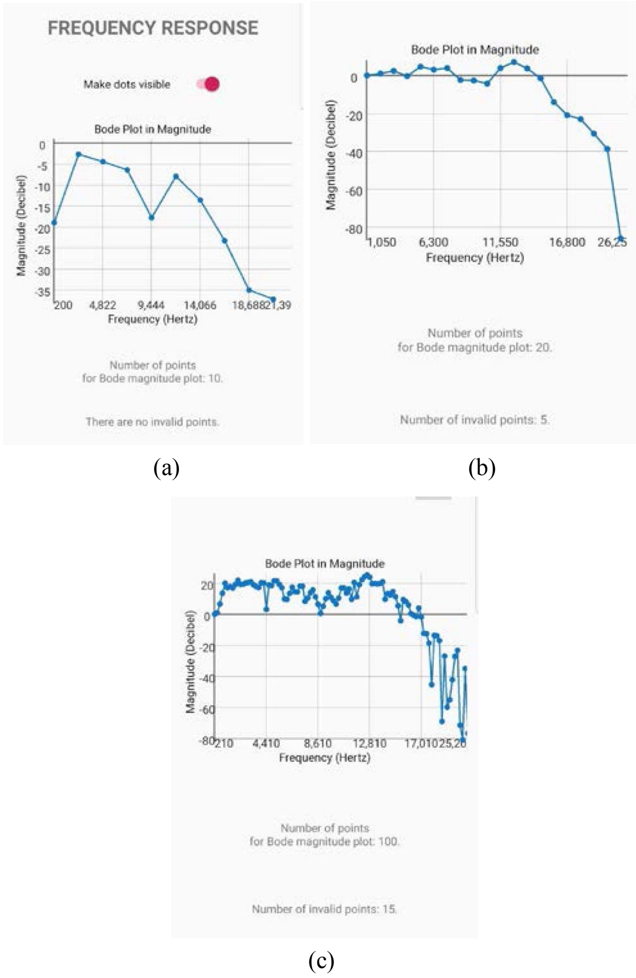
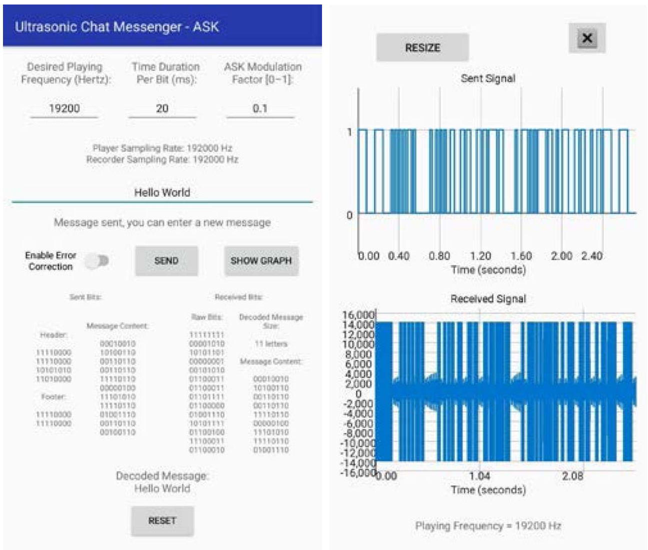


Fig. 1. Bode Plot Results of Frequency Response Analyzer; (a) 10 data points, (b) 20 data points, (c) 100 data points

The second experiment conducted is the Near-Ultrasonic Chat Messenger as described in Section II, where this Android application sends and receives simple text messages encoded in ASCII codes. There are two types of Android applications as introduced in the previous section, ASK modulation and FSK modulation, to observe and verify the optimal method of near-ultrasonic data communication using the typical Android smartphone.

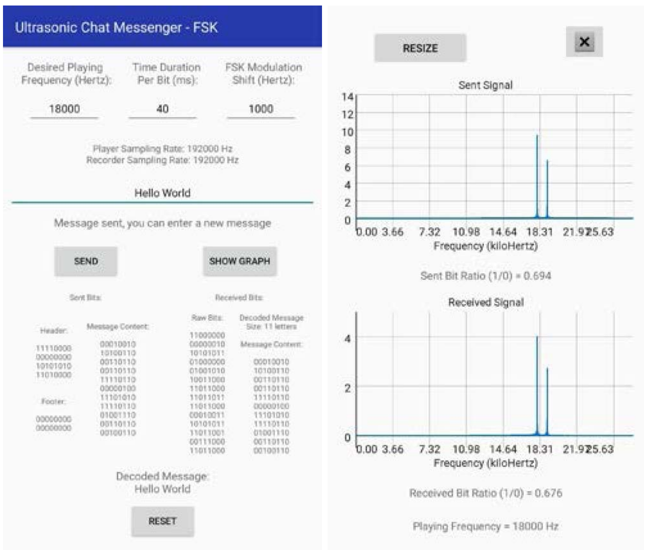
Fig. 2 shows the results of the Android application sending and receiving a sample text message, "Hello World", by utilizing ASK modulation. As shown in Fig. 2(a), the Android application enables users to adjust the frequency range of the data communication, time duration per bit and the desired message along with the encoded and decoded binary text messages. Also, the customized application offers a function to perform the error correction and to show the temporal graphical representation of the transmitted and received signals as shown in Fig. 2(b).

Fig. 3 shows the results of the Android application sending and receiving a sample text message, "Hello World", by utilizing FSK modulation. Similar to the ASK modulation method, Fig. 3(a) illustrates the capability of the Android application to change the desired frequency range for data communication, time duration per bit and the FSK modulation shift amount along with the encoded and decoded binary text messages. Also, the application offers the graphical representation of the transmitted and received signals as shown in Fig. 3(b) where it is the FFT calculation result of the signals that is plotted.



(a) (b)

Fig. 2. Near-Ultrasonic Chat Messenger using ASK Modulation; (a) Transmission Results in Text, (b) Transmission Results in Graph



(a) (b)

Fig. 3. Near-Ultrasonic Chat Messenger using FSK Modulation; (a) Transmission Results in Text, (b) Transmission Results in Graph

As shown in Fig. 2(a) and Fig. 3(a), we added a header and a footer to the desired text messages. The header contains information such as a synchronization signal and the encoded length of the text message following the header. The footer permits to decode the signal properly at the end of the text message.

IV. Evaluation of the Experimental Results

From the results obtained from both ASK and FSK applications, we were able to determine that the typical Android smartphone speaker (transmitter) and microphone (receiver) operate at a maximum sampling rate of 192 kHz. We also observed that the quality of transmitted and received sound waves is device dependent. For example, on the Samsung Galaxy S8+, the maximum frequency at which the signal was correctly recorded was approximately 24 kHz. However, on the Samsung Galaxy Nexus, the maximum frequency to achieve successful transmission was about 20 kHz. This indicates the range of near-ultrasonic frequencies that can be effectively used lies in between 18 kHz to 20 kHz.

From the results obtained, in particular from the Near-Ultrasonic Chat Messenger, we found that the optimal settings for the ASK modulation method relies on a transmission at 19.2 kHz, a one-bit duration of 20 milliseconds, and a ratio of 0.1 for the ASK modulation factor. This means that the amplitude coding for the ‘0’ value is 10 times lower than the coding for the ‘1’ value. With a five-centimeter distance between the two Android smartphones, we were able to achieve successful data transmissions with some errors which were well rectified using the error correction scheme. However, the communication performance dropped significantly after 10 meters of distance apart.

The FSK modulation method delivered more robust results over the ASK modulation method but experienced more computational time due to the FFT calculation of the signal for each bit of the data. This means that the time for decoding the signal increases along with the text message size. Using this modulation technique, the default parameters were set to 18 kHz for coding the ‘0’, a bit duration of 40 milliseconds and an FSK shift of 1 kHz, meaning the coding for the ‘1’ was at 19 kHz. With this configuration, we were able to achieve almost no error data transmission between the two Android smartphones.

V. Conclusion

In this paper, we presented the feasibility of the typical Android smartphone as a near-ultrasonic communicator. With the tested Android smartphones, the available frequencies in the near-ultrasonic range as a communication system was around 18 kHz to 20 kHz with some variation existing among different devices. Our best achieved bitrate with our implementation was 33 bits per second but further work could increase this value. The maximum distance at which we were able to decode messages between devices was up to 10 meters with each device aligned and facing each other. In this paper, we attempted to overcome the attenuation issues and implemented error correcting schemes to produce correct data decoding. Our approach, focused on trying different modulation techniques, could be the key to a stable near-ultrasonic communication system. Improving the robustness of the communication protocol can be further explored in this study such as adding a checksum at the end of the binary. This implementation could be used for more robust and controlled communication mechanisms such as TCP/IP protocols, where the messages are re-sent if they are not received correctly.

REFERENCES

[1] IARC, "IARC classifies radiofrequency electromagnetic fields as possibly carcinogenic to humans," 31 May 2011. [Online]. Available: http://www.iarc.fr/en/media-centre/pr/2011/pdfs/pr208_E.pdf. [Accessed 5 10 2018].

[2] B. Wang and J. Saniie, "Software defined ultrasonic system for communication through solid structures," in *IEEE International Conference on Electro Information Technology (EIT)*, 2018.

[3] X. Huang, J. Saniie, S. Bakhtiari and A. Heifetz, "Applying EMAT for ultrasonic communication through steel plates and pipes," in *IEEE International Conference on Electro/Information Technology*, 2018.

[4] W. Jiang and W. M. D. Wright, "An indoor airborne ultrasonic wireless communication network," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control,* vol. 65, pp. 1452-1459, 2018.

[5] J. Saniie, B. Wang and X. Huang, "Information Transmission Through Solids Using Ultrasound," in *IEEE International Ultrasonics Symposium*, 2018.

[6] P. Getreuer, C. Gnegy, R. F. Lyon and R. A. Saurous, "Ultrasonic communication using consumer hardware," *IEEE Transactions on Multimedia,* vol. 20, pp. 1277-1290, 2018.

[7] B. Wang, J. Saniie, S. Bakhtiari and A. Heifetz, "Architecture of an ultrasonic experimental platform for information transmission through solids," in *2017 IEEE International Ultrasonics Symposium (IUS)*, 2017.

[8] S. Indriyanto and I. Y. M. Edward, "Ultrasonic Underwater Acoustic Modem Using Frequency Shift Keying (FSK) Modulation," in *2018 4th International Conference on Wireless and Telematics (ICWT)*, Nusa Dua, 2018.