# cosy:sonics - A Mobile App to Explore Technology Reflection Among Students

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*Abstract*—This paper describes the design, implementation and evaluation of the mobile application *cosy:sonics* to explore technology reflection. To this end, three different approaches have been combined: (1) a cryptocurrency parody called *EatCoin* aiming at a direct experience of the useless resource consumption caused by Bitcoin's Proof-of-Work concept, (2) an ultrasonic communication channel circumventing the protection barriers normally provided by a smartphone's flight mode, and (3) a Turing test variant demonstrating the current state of AI-based music composition. The resulting prototype has been tested during a live demo in a scenario triggering intuitive user interest in using the app and has additionally been reviewed by a group of experts from different domains. While it turns out that the application successfully prompted discussion and reflection among the participants, also some weaknesses could be identified during the trials that are considered in future work.

## I. INTRODUCTION

While the so-called "Digital Revolution" is rapidly progressing, critical reflection of the related upcoming technologies is becoming more and more important. Consider, for instance, the Cambridge Analytica scandal which has led to personal data of millions of Facebook users being harvested to analyse political views and use this intelligence for political elections and votes [1]. Contrary to all expectations, people nevertheless still "appear to relate well to Facebook both as a technology (in terms of functionality, reliability, and helpfulness beliefs) and as a 'person' (in terms of competence, integrity, and benevolence beliefs)"[2], despite of the fact that experts recommend to simply delete all social media accounts right away [3].

To explore ways for further triggering technology reflection, we focus on two principles: Firstly, we believe that, for the purpose of such discussions, potential dangers and consequences, which are inherent to future technology, need to be made as tangible as possible and strictly driven by direct user experience. Secondly, we believe that emphasis needs to be made to trained experts, i.e. mainly computer scientists themselves, as those are the people which eventually are in a position to change technology in a way that is more compatible with a human-centric perspective on the world of tomorrow.

Thus, we study the phenomenon of critical technology awareness among students using a mobile app that combines three recent technologies in a carefully crafted joint way. We address the application level, the content level and the level of underlying communication technology at the same time:

First of all, our app named *cosy:sonics* closely resembles a cryptocurrency like Bitcoin, and targets especially its Proof-of-Work concept. However, instead of consuming enormous amounts of electrical energy for basically no purpose like Bitcoin does [4], our app consumes time, more specifically, the precious time of people attending a social get together event. To do so, we have implemented a puzzle which forces users to compare different pieces of classical music and decide whether each of these pieces has been created by a human composer or by an AI-based algorithm. Finally, we use the concept of ultrasonic communication, which is some sort of near field communication, that uses inaudible sound to transfer data. In contrast to Bitcoin, we anticipate that many people have not heard about this technology and are not aware of the privacy issues they are confronted with when using smartphones, for instance [5]. We chose the concept of Bitcoin mining and ultrasound communication deliberately to explore two different examples and different views on a critical reflection of technology.

To stimulate an intuitive incentive for using the app, we have chosen a get together event as basic scenario where participants are required to solve the mentioned AI puzzles to get some food. While in the original scenario, using the app and successfully solving the puzzle has been a requirement to attend the event at all, in our trial successful users have been awarded a so-called *EatCoin*, i.e. some piece of chocolate. The target group to study critical technology awareness are mainly computer science students. We expect them to have an above-average interest and knowledge concerning new technologies. Furthermore, we consider them the future experts within the domain. The study itself was embedded at a faculty event where students could participate voluntarily by using an app. Additionally, the app prototype was presented and discussed in a focus group with experts from the Austrian Federal Ministry for Transport, Technology and Innovation, considered as the actual experts who advise the government and work for political decision makers in relation to new technologies.

The remainder of this paper is structured as follows: After summarising the State of the Art in Section II, we describe our design and development methodology in Section III. Section IV presents the final prototype, while Section V is devoted to the user trials. We discuss results in Section VI, and finally Section VII provides our conclusions and possibe further work.

## II. STATE OF THE ART

Our work encompasses issues from various different fields. We start to examine studies in the field of technology awareness and critical reflection. Then we review related work in the area of ultrasonic communication and Bitcoin. Both fields have potential issues that concern the awareness and critical reflection of these technologies.

### A. Technology Awareness and Critical Reflection

Reflection is a process of learning, that ideally leads to a deeper understanding of an issue and more complex knowledge about it. Kori et al. [6] argue that technology can be used to enhance the effectiveness of reflection processes while Slovak et al. [7] underline the importance of design for the process of reflection.

Lin et al. [8] identified four characteristics of design features in technology that can help supporting student reflection: (1) *process displays* which explicitly show and explain issues and procedures to learners. (2) *process prompts* which prompt students to develop, explain and evaluate their own solutions. This could be achieved by posing the right questions and leading the learners towards answers. (3) *process models* which provide support to the learner in establishing own knowledge by providing model processes of how an expert would approach solving a similar problem. (4) *forum for reflective social discourse* which incentivises reflection as a social activity among students. The main goal is to trigger meaningful discussions that lead to new insights among the participants.

How people can be mislead or how long they are not aware of a certain dangerous technology, has been demonstrated with the Cambridge Analytica scandal [1]. During Facebook's early days of growth and gaining popularity in 2008, most people trusted the platform blindly [9]. Ten years later, in 2018, the Cambridge Analytica scandal initiated an exodus of users deleting their Facebook accounts but the majority of the users still remain on the platform [10].

### B. Ultrasonic Communication

An example of a powerful new technology many people have not even heard about, is ultrasonic communication. Deshotels [11] analysed the general suitability of inaudible sound as communication channel to transmit data. Humans with ideal hearing can hear frequencies approximately ranging from 20 Hz to 20 kHz. The range reduces noticeably with the age of the person. Smartphones can produce and detect a significant amount of (for humans) inaudible sounds that can potentially be used for the transmission of information. However, a precise range of by smartphones detectable sounds cannot be determined due to the lack of standards among manufacturers [12].

Due to the unorthodox nature of transmitting data acoustically, safety precautions implemented in most operating systems do not target inauble communication. Deshotels [11] experimented in his study with methods to bypass security mechanisms on an Android smartphone. In his scenario he wanted to send sensitive data from a software-protected phone to a receiver. He secured the phone with standard Android measures and various versions of third-party software. However, he found out that most tools do not prevent sensitive data being exfiltrated acoustically, i.e. via inaudible sound, because access to the phone's speaker is usually not considered dangerous or privacy sensitive. There is no way to regulate permissions on which applications are allowed or prohibited of using the phone's speakers.

In a study published in 2017, the authors revealed that a small number of retail stores in two European cities already use ultrasonic beacons, as they call it, for location tracking [13]. Mavroudis et al. [14] studied the privacy and security of such ultrasound ecosystems. They critique the lack of security and privacy measures in mobile operating systems which allow severe "proximity marketing and advanced cross-device tracking techniques" mostly unknown and not recognisable by users.

Among the early approaches to counter these privacy and security issues with inaudible sound communication are Zeppelzauer et al. [5]. They implemented and presented, *SoniControl*, the first ultrasonic firewall app to detect different kinds of ultrasonic signals in real-time.

Two interactive music performances, *Sense of Space* [15] and *Poème Numérique* [16], use ultrasound communication to realise audience participation with smartphones. Both studies, however, focus on audience participation itself, the audience's experience and technological issues with ultrasound. They do not study or discuss privacy and security issues. *Poème Numérique* uses an open source app developed by Bartmann [17]. His work and the app itself provide detailed information and insight which is publicly available on how inaudible communication technology is realised.

Apart from security and privacy issues, it is not entirely clear how inaudible sound affects the human body. However, it is reported that, especially the lower spectrum of high frequency sound (that can, at least partially, be heard by humans) causes symptoms like annoyance, headache, tinnitus, fatigue and nausea. Moreover, ultrasonic signals with high sound pressure may cause hearing damage [18]. These adverse effects were observed only when people were exposed to high frequency noise at the workplace continuously, over a longer period of time. Exposing subjects to low pressure sound only for a short period of time should therefore be harmless.

### C. Cryptocurrencies

In contrast to ultrasonic communication, cryptocurrencies are publicly well-known. Their gaining popularity, and in particular those of Bitcoin, and their developments according to market prices initiated a broad media coverage recently.

Our focus is not Bitcoin or any other cryptocurrency itself, but the fact, that Bitcoin mining causes an increasing energy consumption. The energy needed worldwide for the underlying Proof-of-Work concept is nearly as high as the power needed of the country of Denmark [19]. This seems to be problematic in two ways. First, the Bitcoin mining

process, which uses blockchain technology to solve complex mathematic equations, is more or less useless for anything else than the Proof-of-Work awarded with Bitcoins [20]. Second comes the problem with the increasing energy consumption which is aggravated by the fact that primarily carbon is used to power Bitcoin mining. This is a contradiction to the global commitment to mitigate greenhouse gas emissions [21].

### III. DESIGN ASPECTS AND DEVELOPMENT

We used the open source app *Poème Numérique* as basis for our prototype app [17]. As the original app realised an avant-garde music performance with audience participation [16], we only use the basic app structure and the implementation of the ultrasonic communication technology, but completely re-designed the interaction design and the user interface for our study purposes. Contentwise we adapted the audience participation concept as well, but not for a music performance and with a complete different content.

The focus of our prototype was to develop an aesthetically pleasing user interface that is intuitively to use and provides enough information to explain the underlying ultrasonic communication technology. However, at the same time we try to keep it as simple and plain as possible to avoid any unnecessary content.

#### A. User Interface Design

For the design of the prototype, we followed the fundamental design principles of Norman [22]. In the following, we describe how our app design incorporates these guidelines. In general, every view of the interface has very limited options for the user to interact. That way, it is unlikely for the user to get confused. This approach complies with the design principle of constraints.

Due to the unorthodox ultrasound communication technology, we implemented an introduction. These introductory pages appears when the user starts the application. The top screenshots in Figure 1 show two views of this introduction. These pages, designed as a carousel, give a brief overview of the ultrasound communication technology. For usability reasons, we added appropriate signifiers as dots beneath the tab indicating the active page.

To ensure discoverabilty, all possible functionalities must be visible to the user and the current status of the application apparent. All points of interactions were realised with native Android controls (i.e. buttons) to quickly access them. Furthermore, the status of the application is indicated by a monkey icon prominently placed in the center of the main screen as illustrated in the two bottom screenshots in Figure 1. This monkey icon shows to the user clearly if the app is listening for ultrasound triggers and is ready to execute actions or not.

It is important, that the user has constant knowledge about the state of the application. Aside of that, the underlying ultrasonic communication technology should be transparent. Thus, the app provides clear feedback and shows a conclusive message whenever it detects an ultrasound trigger (see Figure 1, bottom right). This helps shaping a conceptual model of
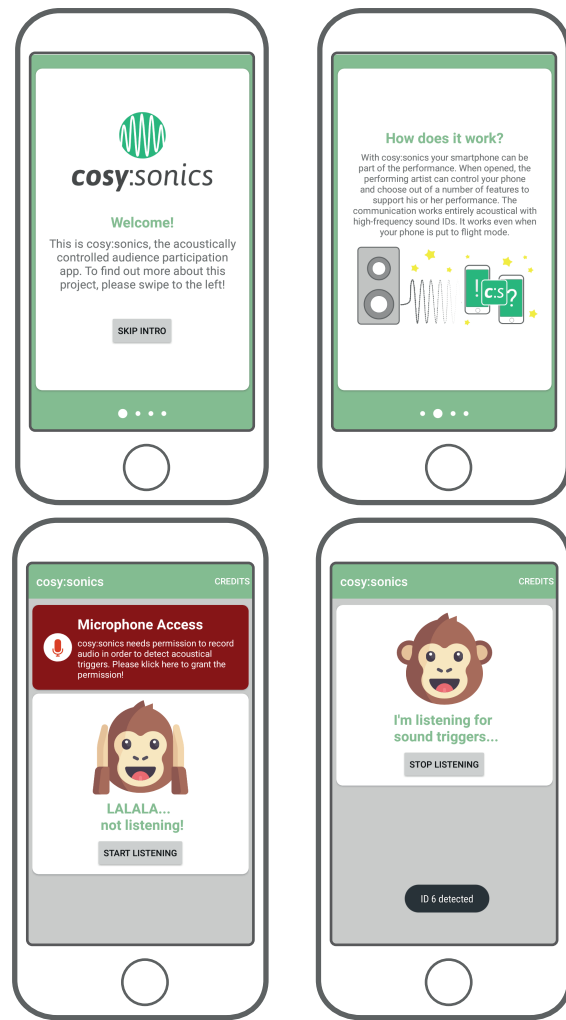


Fig. 1. App screenshots of the first two introduction views (top) and two screenshots of the ultrasound receiver views (bottom).

how a user thinks the application works which is critical to initiate technology reflection.

The *EatCoin* mining views have more content and therefore a higher density of objects. Figure 4 (bottom) shows the views of the *EatCoin* mining module. The controls in these views are grouped in blocks to resemble their affiliation and relationships (see Figure 2). The first view is the introduction to this module where the user can start the mining process (see Figure 4, bottom left). The upper half of the second screen enables interaction with the media player (see Figure 4, bottom center). The user may start, pause or rewind the track as necessary. The bottom set of controls provides options to answer the puzzle. Upon finishing the puzzle, a voucher of the mined *EatCoin* with a hash- and QR-code of the user's performance will appear (see Figure 4, bottom right). The user may save or dismiss this voucher. Saved *EatCoins* will be visible on the main screen and can be fetched at any time.
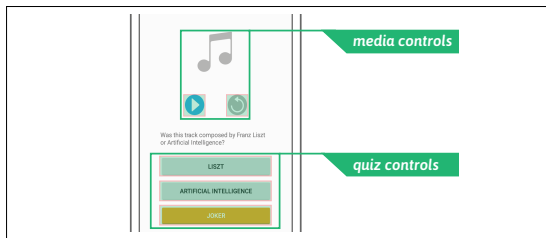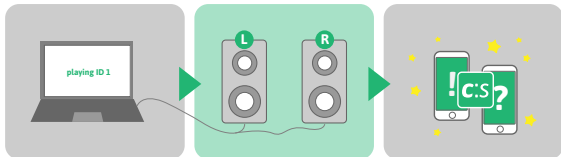
Fig. 2. Controls are grouped in blocks.



Fig. 3. A schematic overview of the communication setup.

### B. Implementation

The major part we re-used from the open source app *Poème Numérique* [17] concerns the development platform itself and the ultrasound communication technology. As development platform we also used Xamarin Forms [23] which provides a framework to develop cross-platform applications for the major mobile operating systems.

Concering the ultrasound technology we adapted, the available implementation offers 17 distinguishable sound IDs to trigger certain events on nearby smartphones. One ID consists of two simultaneously played high frequency sounds in the range between 18 kHz and 20.7 kHz. Thus, a separate computer with a stereo sound system is required to transmit ultrasound triggers targeting nearby smartphones. If a mono system with one speaker is used, the two high frequency sine waves can interfere on a single speaker membrane resulting in different, not detectable sound IDs.

Figure 3 illustrates a schematic overview of the communication. Furthermore, the original implementation uses a synchronization ID to reduce false positives. A detailed documentation of this ultrasound technology is available in the work of Bartmann [17].

### IV. THE FINAL PROTOTYPE

The final app is a fully functional prototype to be used in a demo show case in various ways. The main objective is to highlight the rather unorthodox technology of communicating via high frequency sound and the vast amount of energy consumption used for Bitcoin mining. We distributed the *cosy:sonics*[1] prototype in the Google Play Store [24] to ensure that participants at the test events are able to quickly download and easily install the application. We did not publish an iOS

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[1]Note that the name of the application is a fusion between *COSY* indicating the responsible research group "Cooperative Systems" at the University of Vienna, and *sonics* to highlight the ultrasonic communication approach.

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app for the evaluation within this study. It would habe been possible due to the cross-platform development of Xamarin, but we could not test the iOS version thouroughly for these public trials.

### A. Startup Screens

At startup, the *cosy:sonics* app provides a short overview of how the app works, information about the event it is used in, and a recommendation to switch the smartphone to flight mode for the best experience (see Figure 4, upper section 'startup and introduction'). The latter hint with the flight mode intends to make users aware of the fact that their phones are disconnected from all networks but still 'reachable' through ultrasound.

### B. The Main Screen and Triggerable Events

The centerpiece of the main screen is the monkey icon that indicates the current status of the app (see Figure 4, middle section 'main screen and triggerable events'). If the monkey covers his ears, *cosy:sonics* is not listening for sound triggers. However, if the app is actively recording and listening for sound triggers, the monkey smiles with his ears uncovered. A text label underneath the monkey provides additional information about the status. The user can control the status of the app by pressing the Start/Stop Listening button. On startup, this button is highlighted in orange to not overlook it.

The app incorporates nine events to be triggered by receiving the respective ultrasonic frequencies. Figure 4 illustrates these nine triggerable events in the middle section on the right. In particular, these are four different screens with combinations of blinking in different colors and vibrating: (1) plain blinking, (2) blinking in the colors of the rainbow, (3) plain vibrating or (4) vibrating in the rhythm of a heartbeat. Additionally, the app provides two information slides to be triggered and shown on the users smartphone. These slides aim to raise awareness for the substantial energy consumption of Bitcoin mining. Figure 4 shows such an information slide at the bottom on the left. Finally, the *EatCoin* module opens as described next, when the respective sound ID is received.

### C. The EatCoin Module

In the process of Bitcoin mining, miners have to show a Proof-of-Work by using computational power to solve specific tasks that can only be solved in a brute-force manner. This process uses substantial amounts of energy and its reasonableness is controversial. As an analogy to that, we introduce *EatCoin* mining, that consumes various amounts of the user's time instead of computational power. Three ultrasound IDs can trigger this module to start a different puzzle. Any puzzle includes a different amount of questions and therefore take varying amounts of time to solve.

For the puzzle the user listens to a number of samples of classical music pieces and has to decide, whether the piece was composed by a human composer or by artificial intelligence. The music examples are based on *Kulitta*, a framework for automated music composition [25]. At the end of the puzzle, the user receives an *EatCoin* as reward, regardless of the
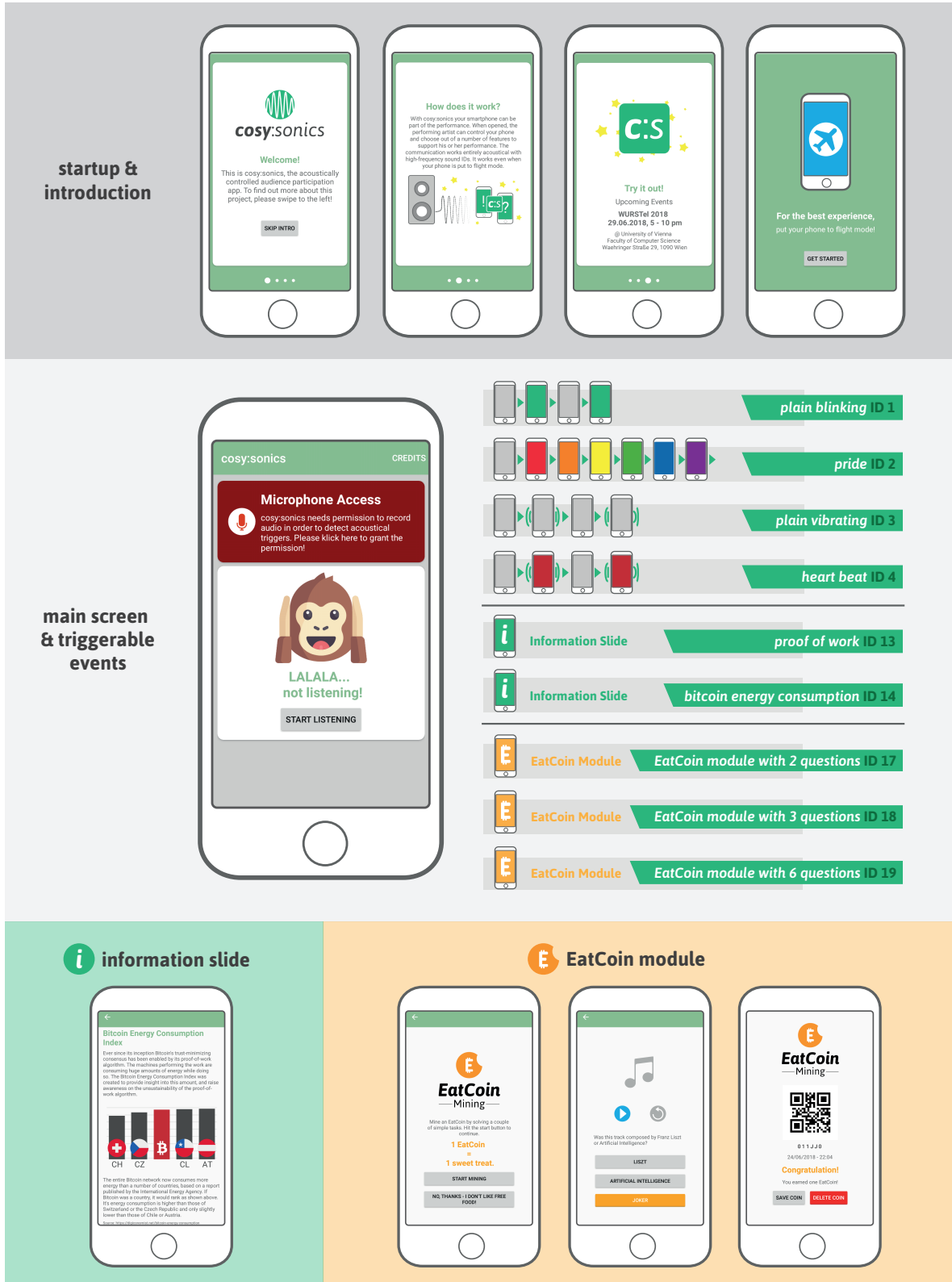
Fig. 4.  cosy:sonics prototype overview

| Modell-No | OS | API level |
|---|---|---|
| Samsung Galaxy S3 (GT-I9300) | Android 6.0.1 | 23 |
| Samsung Galaxy A3 (SM-A310F) | Android 5.1 | 21 |
| Samsung Galaxy S6 | Android 7.0 | 24 |
| OnePlus 6 | Android 8.1 | 27 |

TABLE I
THE FOUR TEST DEVICES.

performance at the puzzle. Crucial to the process of mining *EatCoins* is to consume the users time and not whether answers are correct or incorrect.

After completing the quiz, the user will see a voucher for one *EatCoin* with a summary of his performance and a QR-Code for verification. If the user chooses to save the *EatCoin*, this voucher is saved persistently within the app. Saved *EatCoins* will appear on the main screen. The voucher can be reopend by clicking on the button.

## V. EVALUATION

For evaluation, we conducted functional tests, an in-situ evaluation, and a focus group with experts. Right after the app development, we tested the prototype's functionality on different smartphone devices. For an in-situ evaluation, we demonstrated and used *cosy:sonics* during a get together event for students and faculty members at the University of Vienna. Finally, we discussed the prototype with an expert group of the Austrian Federal Ministry for Transport, Technology and Innovation.

### A. Functional Tests

The functional tests included installing and testing the prototype on four different smartphones. Acoustic triggering was executed with off-the-shelf speakers (Logitech Z323) in a quiet, 20 square meter sized room. The smartphones were positioned approximately 2 meters away from the speakers. Varying acoustical features of other rooms were not considered in this test. For the actual test, all implemented sound IDs were triggered consecutively. All devices successfully detected the correct ultrasound IDs. We tested *cosy:sonics* on four different Android-based smartphones as listed in Table I. The app worked without any noticeable problems on all test devices.

### B. In-situ Evaluation

We conducted an in-situ evaluation to explore the potential of the *cosy:sonics* app prototype and to collect basic data from useres. The evaluation took place during the annual *Wiener Usability Research Symposium in Telecommunications (WURSTel)* at the computer science faculty of the University of Vienna on 29th June 2018. We did the live demo after the official lectures and presentations in a casual lobby environment. Interested students were invited to join in an adjacent but separate room and were asked to install the prototype. Figure 5 shows the setting and students using the app.

We demonstrated all available functionalities by triggering all nine ultrasonic sound IDs. For each triggered ID, we gave users enough time to understand the content and explore the functionality. By doing so, we wanted to ensure that



Fig. 5. Impressions of the demo and students using the *cosy:sonics* app

all participants had enought time to fully experience the functionalities and understand the content of *cosy:sonics*. The information slide components within the app were used to give information about the Proof-of-Work concept of Bitcoin and the vast energy consumption that comes with it. The *EatCoin* mining module was used as an analogy to that, using time of the user instead of energy for the mining process.

After the live demo, all participants were asked to fill out a short questionnaire. Table II lists the six questions and summarises the results of this survey. Finally, every user could trade the *EatCoin* mined with *cosy:sonics* for a piece of chocolate, i.e. a so-called *Mozarttaler*, a traditional Austrian tourist gift.

### C. Expert Focus Group

In addition to the in-situ evaluation of *cosy:sonics*, we presented and discussed the prototype in an expert focus group consisting of officials from the Austrian Federal Ministry for Transport, Innovation and Technology as well as researchers from the University of Vienna. The presentation started with of a brief theoretical introduction and a short talk about the context and idea behind *cosy:sonics*. The presentation concluded with a live demonstration where the participants could experience the app with their own smartphones.

| Survey | | n = 15 | |
|---|---|---|---|
| No | Question | Yes | No |
| 1. | **I am a computer science student.** | 8 | 7 |
| 2. | **I knew that high-frequency sound can be used as a medium of communication.** | 10 | 5 |
| 3. | **If so, which applications do you know?** | | |
| | *Excerpt of answers:* *advertising, tracking, bats, therapeutical applications, medicinical diagnostics, short range communication* | | |
| 4. | **I was aware of the fact that bitcoin mining consumes a lot of energy.** | 8 | 7 |
| 5. | **cosy:sonics worked without problems on my device.** | 10 | 5 |
| 6. | **If it didnt, please provide a short description of the problem and the device you used.** | | |
| | *Some phones had troubles detecting the sound triggers. Most participants were able to sort the problem out by getting closer to the speakers or position themselves more centrally in the room, respectively.* | | |

TABLE II
QUESTIONS AND SUMMARISED RESULTS OF THE SURVEY.

In the aftermath, we openly and informally discussed the suitability of *cosy:sonics* to be used as social event access control mechanism at a big IT event to be held in Vienna later in 2018. Several members of the group were concerned about the fact that potential users have to download and install the app to participate in the experiment. They were sceptical, if enough visitors of the conference were willing to overcome that barrier. Another point of criticism was the fact that the app combined too many different topics concerning new technologies. The experts were afraid this could lead to confusion for the users and that it would likely be better to focus entirely on one issue.

## VI. DISCUSSION

The subsequent discussion of the findings and how they relate to the literature referenced earlier is structured across the three main points of criticism that evolved.

### A. Ultrasonic Communication

The communication technology did not work flawlessly for one third of the subject group. While it was not possible to perform a definite analysis of the cause of the problems, it likely has to do with the participants' positioning in the room. To detect an ultrasound trigger, two distinct ultrasounds played by two different speakers must be heard by the smartphone. Being out of the range of one of the speakers could lead to problems. According to our observations and user feedback, it helped them to receive ultrasound triggers when they moved closer to the speakers or positioned themselves more centrally in the room. Aside of that, local conditions may influence room acoustics and lead to further problems rendering the communication technology flaky. The authors

of *Poème Numérique* observed similar problems when using ultrasound communication [16], [17].

Another problem concering the reliability is the lack of general standards for smartphone microphones. Different manufacturers use diverse hardware and software, making results of audio processing vary. Kardous et al. [12] conducted extensive experiments comparing the performance of several sound measurement applications on smartphones and found that results very much depend on the manufacturer of the phone aside of the used software.

Furthermore, it may be possible that smartphone manufacturers will limit the range of frequencies that can be detected by their phone's microphones in future [11] or that users utilise software to prevent undetected communication [5]. This could interfere with ultrasound communication technology in general independent from the use case and even when people are fully aware of the fact that there smartphones are triggered remotely using ultrasound as in our demo scenario.

### B. Native versus Web App

A conceptual point of criticism was that *cosy:sonics* is a native application. Experts from the ministry for transport, technology and innovation feared that download and installation of the app posed too big of an obstacle for many of the visitors of their conference. Indeed, today's users tend to install fewer native apps and spend less time using them than a couple of years ago [26]. We could not ask all participants of our event. But given the fact that we just had 15 participants and there were over hundred at the event overall indicates, that the installation of the app could have been a barrier for many of them.

Another solution would have been using a web app. We could not realise *cosy:sonics* as a web-based application, however, due to the lack of access to native sensor APIs. Aside of that, we wanted to create an application that could be downloaded in advance and that works entirely without the need of internet access, even with the phone put to flight mode. While the possibilities of web-based apps have considerably improved over the last few years, apps that require direct access to certain sensor APIs still have to be implemented natively [27]. Thus, we implemented *cosy:sonics* as native app in the need to access the microphone API to detect ultrasonic sound triggers. With our insights, we contribute to an ongoing discussion within mobile development research to re-think the taxonomy of web, native and hybrid mobile development [28].

### C. Critical Technology Reflection

With *cosy:sonics*, we aimed to study and raise critical technology reflection for two independent topics: (1) the possibilities of inaudible communication through ultrasound and (2) the vast energy consumption of Bitcoin mining. The experts reviewing the application noted, that this could lead to confusing or overwhelming the user. They recommended to define and focus on one key topic. However, the participants of the live demo at the in-situ study did not appear to be

overwhelmed by the mix of two different topics according to the results of the survey.

It is rather striking to see the results of asking our participants about the technology awareness. One third of our study participants did not knew about the possibiliy to use ultrasound as medium for communication. Even more, nearly half of them did not know about the vast energy consumption Bitcoin mining produces. This underlines the importance to foster critical technology reflection and raise awareness for unknown possibilities of new technologies. However, we do not know on the basis of our results whether our immersive technology-centred approach enhances the effectiveness of reflection processes among students [6].

## VII. CONCLUSION

We developed *cosy:sonics*, a mobile app to trigger technology reflection and raise awareness for both, inaudible ultrasound communication and the vast energy consumption of Bitcoin mining. For evaluation, we tested the application in-situ at a live demo with students and discussed it with experts from the domain. The results show, that there are accumulated needs to foster critical reflection among students. A considerable amount of students did not know about the possibilities of ultrasound communication and the sideeffects of cryptocurrency mining. The experts were mainly concerned about overwhelming people when confronting them with more than one challenging topic and the problems with native mobile apps preventing people from using them.

Future work has to be done to improve the ultrasonic communication technology within the app itself. It needs improvement especially regarding its reliability. Aside of that, possibilities to create a web-based application should be analysed. For the technology reflection part, we could further measure if and how the *cosy:sonics* app concept prompts the users to reflect on technology. Finally, a study with a larger audience and a sample aside from students could bring valuable insights.

## ACKNOWLEDGMENT

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