SoniControl 2.0

Endbericht | Call 13 | Projekt ID 3480

Inhalt

1 Introduction

This is the final project report of the netidee project SoniControl 2.0. The goal of the project SoniControl (http://sonicontrol.fhstp.ac.at) is the development of a first ultrasonic firewall to protect users against ultrasonic tracking by companies like Silverpush. We have published the app developed in a first netidee project (project no. 1701) beginning of 2018 on Google PlayStore in a German and English version. Since then it was downloaded more than 40.000 times and the project was reported in more than 70 national and international press articles on platforms like heise.de and theregister.co.uk.

Since then we continuously got requests from users for new functionality. Most important features needed to make the firewall applicable to a broader target group were (i) more diagnostic features (visualizing and sonifying detections for a more tangible user experience), (ii) providing metadata about the detections (e.g. the type of detected message), (iii) sharing detections with other users, and (iv) extending the firewall to iOS. The goal of the project "SoniControl 2.0" was to realize large parts of this functionality. This report summarizes the all developments performed in the follow-up project SoniControl 2.0.

2 Project Description

Beschreibung der Projektziele / Zielgruppe und inhaltlicher Überblick über das Projektergebnis (max. 5 Seiten)

2.1 Project goals

The major goal of SoniControl 2.0 was to increase the utility of the app for the users, to increase its visibility in the community and to strengthen the sustainability of SoniControl. Overall the project SoniControl 2.0 has led to a complete rework of the first version of the app. Particular goals of the project were:

- The integration of a **signal recognizer** that can detect the type of signal (i.e. its protocol). Thereby, we aimed at providing more information to the users and to enable them to selectively block (or allow) communication at the level of individual protocols.
- The extension of SoniControl with techniques for the **visualization** of acoustic messages and for **sonification** (i.e. for making inaudible ultrasound hearable). Thereby, we aimed at making ultrasound more tangible to the users.
- Enabling users to upload their detections to a **sharing host**, i.e. time, location and message type as well as their preferred decision (to either block or allow the communication). Sharing detections helps to distribute knowledge about ultrasonic signal sources and their distribution and contributes to an increased transparency with respect to this novel technology.

- Integrating all of the above functionality in a new consolidated version of SoniControl, i.e. **SoniControl 2.0**.
- Analyzing the feasibility of the implementation of SoniControl on the iOS platform (**feasibility study**). SoniControl requires numerous rather low-level functionality and extended (non-standard) privileges with respect to audio recording. These requirements potentially impede the implementation of SoniControl on the iOS platform
- Continuously updating the **project website** and the **project wiki**.

2.2 Target groups

Overall the project SoniControl 2.0 is targeted towards people who care about privacy: end users of mobile devices, companies willing to protect their business against attacks via covert channels, and companies from the security domain who want to extend their firewalls/virus scanners with our technology. Specific target groups include:

- *Android users caring about privacy*: Since our app is available in English and German, international users can also be addressed worldwide.
- *Companies who want to protect their business against attacks via covert channels*: Companies are often subject to industrial espionage. Thus, all IT systems of a company and the employees' computers/phones must be secured. Ultrasound-based attacks were recently shown to be quite effective to exfiltrate protected information. No enterprise solution exists so far for protection against these attacks.
- *Companies developing security applications like firewalls and virus scanners*: Companies developing security applications for end users and other companies currently do not monitor and protect the ultrasound band. An integration of our technology could fill this gap and enrich their products with protection against ultrasound-based attacks.
- *Open Source Community*: The security / privacy aware open source community could benefit from SoniControl 2.0 by integrating it into other open source solutions (e.g. open source firewalls and browsers) to protect against unwanted ultrasonic communication. SoniControl in turn could benefit from voluntary developers that add new features to the firewall.

2.3 Project results

"Data over audio" is an emerging technology, which is used already by companies like Lisnr and Google. It bears, however, numerous security and privacy concerns. Sound and especially the inaudible frequencies (ultrasound) can be used as a side channel to track internet users and their behavior across different devices without their knowledge. SoniControl aims at the privacy protection of end users and represents a first means to effectively prevent ultrasonic tracking.

Ultrasonic tracking uses the microphones and loudspeakers of our smartphones. SoniControl can detect ultrasonic signals and enables to efficiently block them. In the project SoniControl 2.0, we have added novel functions for sharing detections with other users for improved

security and advanced diagnostic features (message visualization, sonification & recognition) to give users more intuitive and understandable feedback.

Novel features and performed activities in the project include:

- An algorithm that recognizes the type of message and the protocol behind.
- Novel visualization and sonification features to make the detected signals visible and hearable. This is essential to build trust in the firewall i.e. to show what was actually detected.
- An option to share detections via a server for detailed diagnostics and to support other users.
- A feasibility study that evaluates ways to port SoniControl to iOS
- Comprehensive bug fixing and improved stability
- Comprehensive update of user and developer documentation
- A new consolidated app version that includes all developed functionality, i.e. SoniControl 2.0.

Beyond the planned goals of the project, we achieved the following additional goals:

- A component to download and integrate firewall rules from other users to the own phone to leverage detections made already by other users.
- A complete refit of the user interface of the application for improved usability. Integration of better user guidance through info buttons and the integration of additional supporting information to the users.
- An integrated map visualization in the SoniControl 2.0 app that shows previous detections and geo-located firewall rules
- The release of the SoniControl 2.0 app on Google Play Store

For more details on the performed work and the achieved results, see the work package descriptions in the following section.

3 State of the Work Packages

3.1 Work Package 1 – *Project Management & Dissemination*

Brief description of the main activities

- Financial planning (controlling sheet)
- Finalizing contract, signing, sending to netidee
- Update project website, create monthly blogs on netidee website
- Request first funding rate

- Organizing regular meetings
- Controlling project hours
- Dissemination of the project
- Writing intermediate report
- Writing end report

Insights into the procedure

The project has progressed as planned. Due to a higher workload during the first months of the project due to projects running in parallel at our institute, fewer resources were consumed by the project as planned. For this reason, we requested a cost-neutral extension of the project by three months, until end of March 2020, which was confirmed by netidee. This enabled us to extend the development and testing time of the app and to more sustainably improve the quality, robustness and usability of the app. Overall all deliverables could be achieved in time.

Brief description of the results achieved

- Contract signed
- Project plan and list of project results finished and approved
- First funding rate requested
- Intermediate report finalized, sent and confirmed
- Second funding rate requested
- Project dissemination at several events (see Section 5 for details)
- Final funding rate requested
- End report finalized and sent

Special successes/ problems

The project progress was highly satisfactory. All planned features could be implemented, tested, and integrated into the SoniControl 2.0 app.

Were there major deviations from the plan? Why?

The project duration was extended by three months in a cost-neutral way, see above (insights into the procedure)

3.2 Work Package 2 – *Advanced Diagnostics*

Brief description of the main activities

In WP 2 there were three major modules which have been implemented:

- the message recognition module

- the visualization module
- the sonification module

Message recognition module:

The recognition module builds upon the existing detection module of SoniControl and enables to determine the actual type or protocol of an ultrasound message. For a detected signal it can, for example determine if the signal is a Silverpush signal (which is most suspicious for ultrasonic tracking) or a Google Nearby signal (which may be used, e.g. for pairing the user's phone with Google Chromecast and thus shall pass the firewall). The recognizer thereby provides important meta-information about what type of communication is currently going on and enables the user to better assess the type of threat she may be exposed to. It further enables to filter messages by type and protocol automatically, which leads to a higher user convenience.

To realize this module, we have implemented a frequency-based algorithm that recognizes the type of ultrasonic message and the protocol behind. By knowing which frequencies are used by a certain protocol, a detector can be built by analyzing the sound spectrogram in the Fourier frequency space. For each protocol to which we have access, we have determined the frequencies manually in advance. The recognition algorithm then matches the spectral signature of the message with our protocol definitions and reports the type of message found. If an unknown message is detected (i.e. a message that does not match any definition), the algorithm returns that an unknown message type was detected.

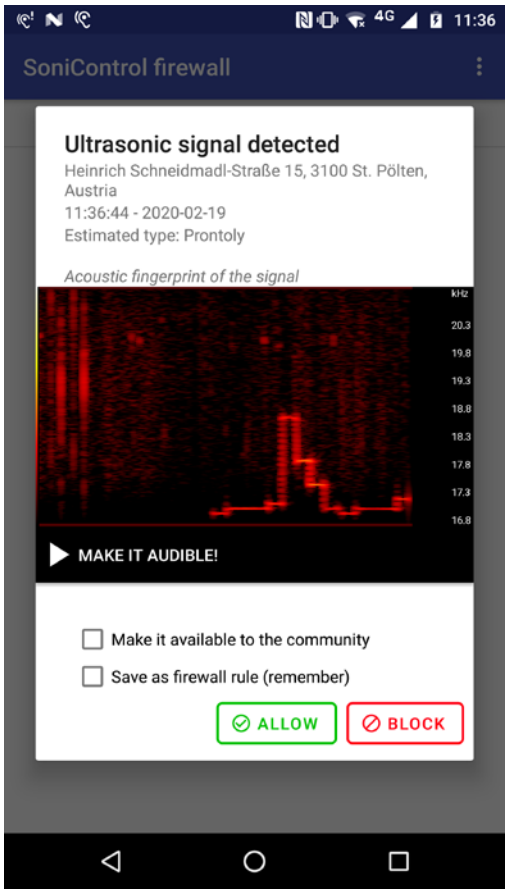
Visualization and sonification modules:

In the first version of SoniControl, detections were reported to the user without additional information about the actual message. To improve user experience, we have developed a visualization and sonification module to make the detected messages visible and hearable. The visualization module computes a short-time Fourier transform (STFT) to generate a spectrogram. The spectrogram is then normalized, mapped to an image and shown to the user directly in the alert dialog of the firewall. The spectrogram reveals the temporal and spectral properties of the message and helps to identify whether a real message was detected or (less likely) some unusual noise in the ultrasonic band. It does not reveal the actual content of the message, which would raise privacy concerns.

The sonification module allows the user to playback the message in the hearable range. This module provides acoustic feedback to the user about a detection and makes it more tangible for the user that something has happened which could not be perceived in a natural way. To make the detections hearable, we perform a pitch-shifting on the detected message (only on the part above 17kHz). Pitch shifting reduces the pitch frequencies of the message and brings them into the hearable range without distorting the temporal dimension (i.e. the duration of the message stays the same). The result is a hearable message that the user can playback on demand.

We expect that the visualizer and sonifier component will significantly contribute to raising awareness to ultrasonic tracking by providing more tangible feedback to the users. Numerous users already requested this feature. Thus, it was given highest priority in the project.

A screenshot showing the final “detection dialog” with the spectral visualization and the sonification option (“make it audible!”) is shown below. The dialog also shows the detected signal type (“estimated type: …”).



Insights into the procedure

Initial tests have shown that visualization and sonification significantly improve the touch and feel of the app. The feedback is now much more tangible and false detections can easily be identified (i.e. when there is no structure in the spectrogram the likelihood of a false detection is high).

Brief description of the results achieved

All three modules (the message recognizer, the sonifier and the visualization module) were finished and extensively tested (partly in WP 5).

Special successes/ problems

The employed pitch-shifting algorithm from the “superpowered” library (https://superpowered.com/) supports only a pitch-shifting of up to one octave. This has

shown to be sufficient to make the sounds well hearable. The quality of the visualization depends on the signal to noise ratio (SNR) and varies between different smartphone models. A proper contrast normalization was thus necessary to improve the visual appearance of the spectrogram.

Were there major deviations from the plan? Why?

There were no deviations

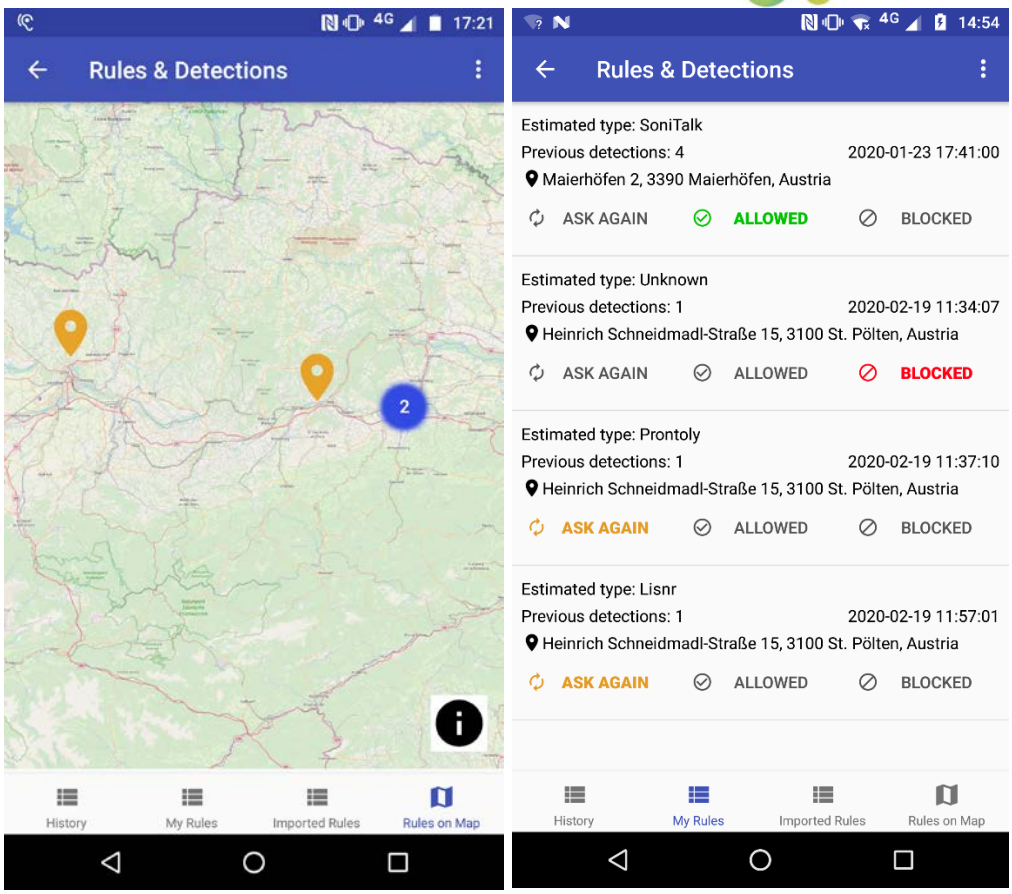
3.3 Work Package 3 – *Sharing Functionality*

Brief description of the main activities

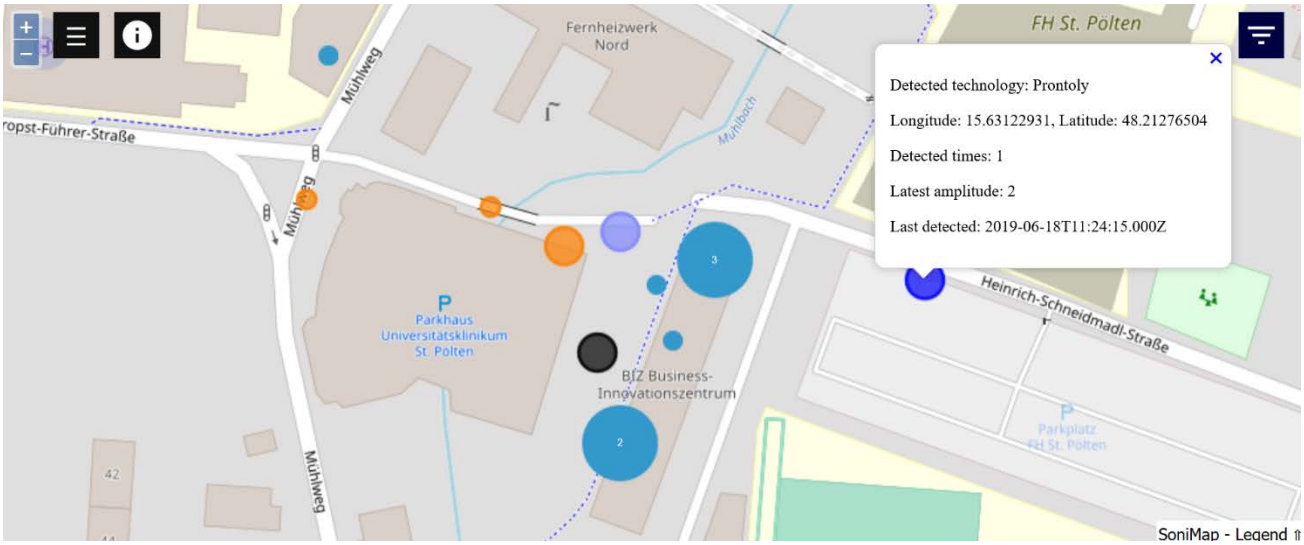
To leverage the power of the user community, users should have the opportunity to share their detections with other users. For this purpose, we have implemented a web-service to which detections can be uploaded. The server hosts the collection of anonymously uploaded detections and shows their location on a map. In this way, the users can inform themselves about potential ultrasonic tracking in places they, e.g., plan to go to or where they frequently stay. Users can also share false alarms on the server to enable us to further improve the detector.

The sharing functionality consists of two modules: the sharing *server* and the sharing *client*. The sharing server is a web-service with a MongoDB database as storage backend where the data is stored in the form of JSON objects. The sharing client is a software service integrated into SoniControl that enables the user to upload a detection to the server together with metadata such as location, time and the type of message.

The figures below show the map visualization of detections as well as the view showing the firewall rules configured (and potentially shared) by the user.



The map visualization is also available via the web-backend. A view as provided in the browser is shown below. Close-by detections are clustered (blue circles with numbers) to improve readability. Individual detections are colored by detected type. By clicking on a detection, additional information is displayed such as address, message type, data of last detection and the overall number of times the signal was detected.



Insights into the procedure

The sharing functionality could be implemented as planned. A non-relational database (MongoDB) turned out to be a good solution to storing anonymously shared detections on the server. A REST interface was implemented for uploading the data.

Brief description of the results achieved

- SoniControl Web-backend, accessible via: http://sonicontrol-server.herokuapp.com/
- SoniControl Client module that enables sharing of detections

Special successes/ problems

A major challenge that we had to solve was the pre-processing of the captured audio before sending it to the webserver. This was mainly because the Android platform uses pulse code modulation (PCM) as audio format, which is difficult to handle. To solve this issue we implemented a file exporter that converts the PCM format into a standard WAV format.

Were there major deviations from the plan? Why?

There were no deviations.

3.4 Work Package 4 – *iOS Conceptualization*

Brief description of the main activities

For the planned implementation of SoniControl on the iOS platform (the implementation is beyond this project), different implementation-specific aspects need to be investigated in detail to assess the feasibility of an implementation of the SoniControl features on iOS. The reason to perform this feasibility study is that the iOS platform is stricter in some regards than the Android platform, e.g. when it comes to continuous background operation, continuous recording, and the availability of required signal processing algorithms. For this purpose, we have performed a literature research and analyzed for each component of the SoniControl app possible ways to implement them on the iOS platform.

Insights into the procedure

The main insights from the performed research is (i) that most of the components can be implemented in a straight-forward manner on the iOS platform and (ii) that the background audio recording represents the main obstacle in the implementation. It cannot be guaranteed if the app would pass the review from the Apple Store and unfortunately, this question cannot be answered in advance. Especially the permission to resume audio capturing while the app is in the background seems to be difficult to obtain from the reviewers but necessary for the proper operation of the firewall. This functionality is, however, crucial for the implementation of a firewall that operates continuously in the background. Since it is not possible to get a permission from Apple in advance, the actual feasibility of realizing SoniControl as an iOS app remains questionable.

After performing the feasibility study, we consider the extension of SoniControl to other platforms than Apple, such as Windows 10 (e.g. to protect surface devices) a more promising approach (especially with regard to future applications in the business sector).

Brief description of the results achieved

The result of the WP is a report that describes a first concept for porting SoniControl to the iOS platform together with possible limitations and solution strategies.

Special successes/ problems

See “Insights into the procedure” above.

Were there major deviations from the plan? Why?

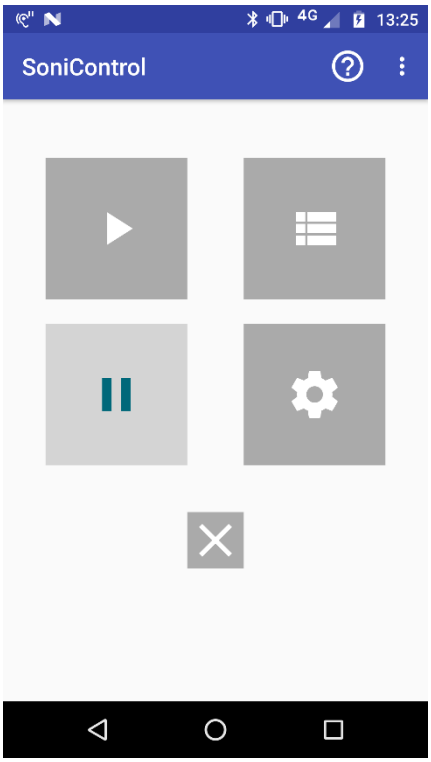
There were no deviations to the project plan.

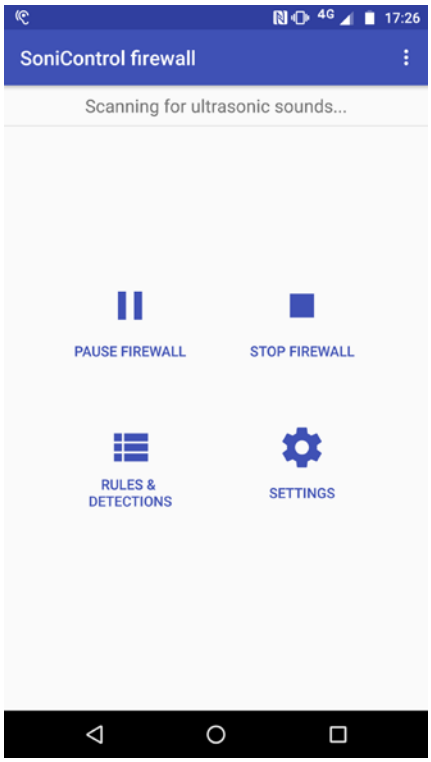
3.5 Work Package 5 – *Integration and Release*

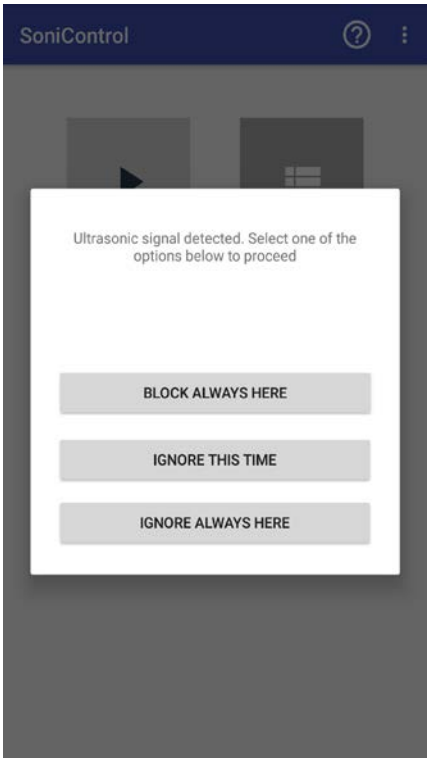
Brief description of the main activities

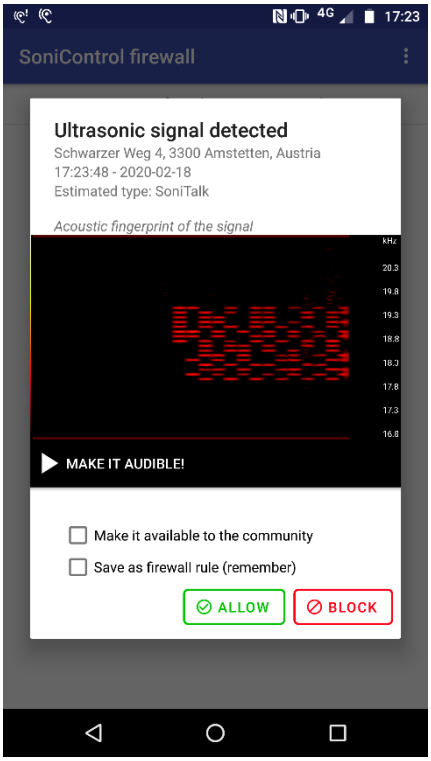
In this WP, we have integrated the individual modules (visualization, sonification, sharing and recognition of the message type) into the SoniControl 2.0 application. Beyond this, we have implemented additional functionality, namely an **import function** that enables to download previously shared detections from other users to the own phone. Additionally to location and type of signal, the decision of the uploading user can be retrieved (and changed later). The figure below shows the import functionality.

Additionally, we have reworked and face-lifted the entire user interface of SoniControl. The figures below show the layout of SoniControl 1.0 (left) vs. SoniControl 2.0 (right) for the main menu and the detection dialog.









Insights into the procedure

User tests have shown that the face-lifting has considerably improved the usability of the app and has made it easier to understand what the different buttons and functionalities are dedicated for.

Due to the additional complexity of the resulting application, which resulted from the integration of numerous additional features, the efforts for adequate testing of the individual components and their mutual interactions have also been higher. The last three months of the project have focused intensively on the testing, bug fixing and consolidation of the individual functionalities as well as the entire app.

Brief description of the results achieved

All developed functionality has been integrated successfully into the new app. The user interface has been reworked considerably and all new functionality has been tested intensively. Due to the good progress made in the project, we have already released the final SoniControl 2.0 app on Google Play store after a longer beta test phase. The icon of the app is shown below.

Special successes/ problems

There were no larger unexpected complications in the implementation. All components could be integrated smoothly which was, partly due to the clean and well-organized software architecture that we have established in the previous project.

Were there major deviations from the plan? Why?

The extended project runtime gave us sufficient time for intensive testing of the app.

3.6 Work Package 6 – *Documentation*

Brief description of the main activities

The main task of WP6 was extending and updating the user and developer documentation. Both tasks could be achieved successfully in time.

Brief description of the results achieved

Both developer and user documentation have been updated and made available via the project website as well as via the netidee website.

Special successes/ problems

None.

Were there major deviations from the plan? Why?

No deviations to the plan so far.

3.7 Work Package 7 – *External Communication & Dissemination*

Brief description of the main activities

The goal of the WP was the dissemination of the project on different channels, i.e. to the scientific community and to the public, in the form of interviews in radio / TV and in magazines as well as the presentation of news items on the project website and the netidee website. The dissemination strategy in particular focused on presenting the project at several events (see below).

Insights into the procedure

The effects of dissemination have strongly exceeded our expectations. The topic of ultrasonic tracking catches the attention and interest of many people and we regularly got requests from the media and from companies on the topic. The SoniControl app has so far been downloaded more than 40.000 times.

Brief description of the results achieved

Dissemination activities included so far (sorted chronologically, containing only the dissemination starting with January 2018, i.e. the end of the previous project):

- Presentation of SoniControl at the 22th **Netzpolitischer Abend** in the Meta Lab in Vienna (January 29, 2018)
- Exhibition of SoniControl at the **Lange Nacht der Forschung** (April 13, 2018) in St. Pölten
- Presentation of SoniControl in a **Keynote** held by Matthias Zeppelzauer at the "**Digital Livestyle Preview**" event in Munich (June 28, 2018) for a selected group of international journalists from different IT-related media and magazines.
- Exhibition of SoniControl at the **ARS Electronica Festival** (September 6-10, 2018) in Linz where around 300 visitors could try out ultrasonic communication and see how this technology works.
- Award of the **Austrian Open Source Award** for the research project SoniControl in the category Systems and Security, 2018.
- Presentation of SoniControl together with SoniTalk at the **ACM Multimedia Conference** in Seoul, South Korea, 22 - 26 October 2018 (http://www.acmmm.org/2018/), which is the premier conference for multimedia experts and practitioners across academia and industry.

- Presentation of SoniControl at the **DeepSec Conference 2018** in Vienna on November 30, 2018 in the course of the *Reversing and Offensive-oriented Trends Symposium* (ROOTS).
- **Honorable Mention** of project SoniControl of the **Lower Austrian Innovation Award**. Presentation of SoniControl at Lower Austrian Innovation Award Event including an interview with Landesrätin Bohuslav: https://www.netidee.at/sonicontrol-20/sonicontrol-noe-innovationspreis
- Selection of SoniControl as a showcase project for the initiative "**Haus der Digitalisierung**": https://www.virtuell-haus.at/digigalerie/details/59402083-a775-49a5-83d6-3f26a6f91734
- A comprehensive article about the technology behind SoniControl and SoniTalk as well as the risks and chances of ultrasonic communication with the title "Data over Sound" in **KES Magazine** on information security by Matthias Zeppelzauer: https://www.kes.info/archiv/heft-archiv/jahrgang-2019/ausgabe-20194/
- Demonstration of SoniControl and SoniTalk at the **Lower Austrian Forschungsfest** in a stage performance in front of an audience of more than one hundred people ("*Wie werden Handys ausspioniert und was kann man dagegen tun?*" http://www.noe.gv.at/noe/Wissenschaft-Forschung/Forschungsfest_Noe.html).
- A **television feature** about ultrasonic communication in the ORF series: "Digital Leben - Vernetzt, verstehen, profitieren", Tuesday September 17, 2019, 7:20pm, ORF Niederösterreich
- Further dissemination activities (e.g. mentions of the project in newspaper articles) can be found on our project website: https://sonicontrol.fhstp.ac.at/#dissemination
- A **radio feature** about ultrasonic communication in the Ö1 series: "matrix", February 8, 2019, 7:05pm with the title "Digitale Tarnung": https://oe1.orf.at/programm/20190208/542809/Digitale-Tarnung
- The project SoniControl has motivated a group of lawyers to analyze **legal aspects of ultrasonic communication and tracking** with respect to the General Data Protection Regulation (GDPR) and the telecommunications act and to publish a comprehensive article about it with the title: "Rechtliche Einordnung von Audio Tracking": https://www.eylaw.at/news/detail/rechtliche-einordnung-von-audio-tracking. Their major conclusion is that explicit consent from the user is a basic requirement for ultrasonic communication.
- Additionally, we have regularly posted blog posts on the netidee website, the project website as well as on the research website of our university: (https://www.fhstp.ac.at/de/@@search?SearchableText=sonicontrol&sort_on=&sort_order=).

Special successes/ problems

none

Were there major deviations from the plan? Why?

There were no deviations from the project plan.

4 Implementation of Funding Requirements

Dieses Kapitel ist nur relevant, wenn in der Fördervereinbarung spezielle Förderauflagen festgelegt wurden. In diesem Fall soll in diesem Kapitel dargestellt werden, wie diese berücksichtigt werden.

There were no specific funding requirements

5 List of Project Results

Kurzbeschreibung der erreichten Projektendergebnisse jeweils mit Open Source Lizenz und Webadresse (netidee Vorgaben beachten!)

1	*Intermediate report*	*CC-BY SA-3.0 AT*	*https://www.netidee.at/sonicontrol-20*
2	*Project end report*	*CC-BY SA-3.0 AT*	*https://www.netidee.at/sonicontrol-20*
3	*Developer documentation*	*CC-BY SA-3.0 AT*	*https://www.netidee.at/sonicontrol-20*
4	*User documentation*	*CC-BY SA-3.0 AT*	*https://www.netidee.at/sonicontrol-20*
5	*Project One Pager*	*CC-BY SA-3.0 AT*	*https://www.netidee.at/sonicontrol-20*
6	*External Communication*	*CC-BY SA-3.0 AT*	*See final project report under: https://www.netidee.at/sonicontrol-20 (this document, Section 8)*
7	*SoniControl 2.0 App*	*GPL*	*https://github.com/fhstp/SoniControl*
8	*Feasibility Concept for iOS implementation*	*CC-BY SA-3.0 AT*	*https://www.netidee.at/sonicontrol-20*

6 Exploitation of Project Results in Practice

Angaben zur Verwertung der Projektergebnisse in der Praxis

Several exploitation directions or strategies for the continuation of the project and the further development of SoniControl are planned. This includes the aim to acquire a third-party-funded research project involving partners from industry where the SoniControl firewall shall be integrated as a security layer for ultrasonic communication solutions for Industry 4.0 and Internet of Things (IoT) applications.

Aside from these efforts to acquire funding for further development, we plan to extend SoniControl and to port it to other platforms. Especially, we aim at porting SoniControl to the Windows platform to enable the easier integration of SoniControl into security software and services.

7 Dissemination / Networking

Beschreibung der im Rahmen Ihres netidee-Projektes bereits erfolgten bzw. noch geplanten Öffentlichkeitsarbeit oder Vernetzung

Please see Section 3.7 for a summary of all dissemination and networking activities.

8 External Communication Documentation

The external communication documentation is a required deliverable for every netidee project. Due to the thematic context, we have decided to include this documentation directly in the final project report.

As requested a separate work package for dissemination and communication with external parties has been established (WP7). The work in this WP helped significantly to communicate the project to a broader public (e.g. presentation at ARS Electronica and Lower Austrian Innovation Price) but also to the relevant scientific community (e.g. presentation at ACM Multimedia and DeepSec conference). See Section 3.7 for a summary of all efforts for dissemination and for raising visibility of the project.

The different dissemination strategies are connected with varying expenses and benefits. A coarse estimation of different efforts is summarized in the following table and shall help other projects to optimize and align their dissemination efforts.

Strategy	Expense	Benefit
TV	Average	High
Radio interviews	Low	Average
Press release	Average	Very high

Publication at conference	High	Average
Presentation at Community event	Average	Average
Exhibitions	High	High
Application for prices/contests	High	High if gained, otherwise little

Table 1: Dissemination strategies, their expense and potential benefit

9 Project Website

Wird zusätzlich zur netidee-Projektwebsite noch eine eigene Website betrieben, so ist hier die Adresse anzugeben.

The project website can be found here: https://sonicontrol.fhstp.ac.at

10 Planned Activities after netidee-Project End

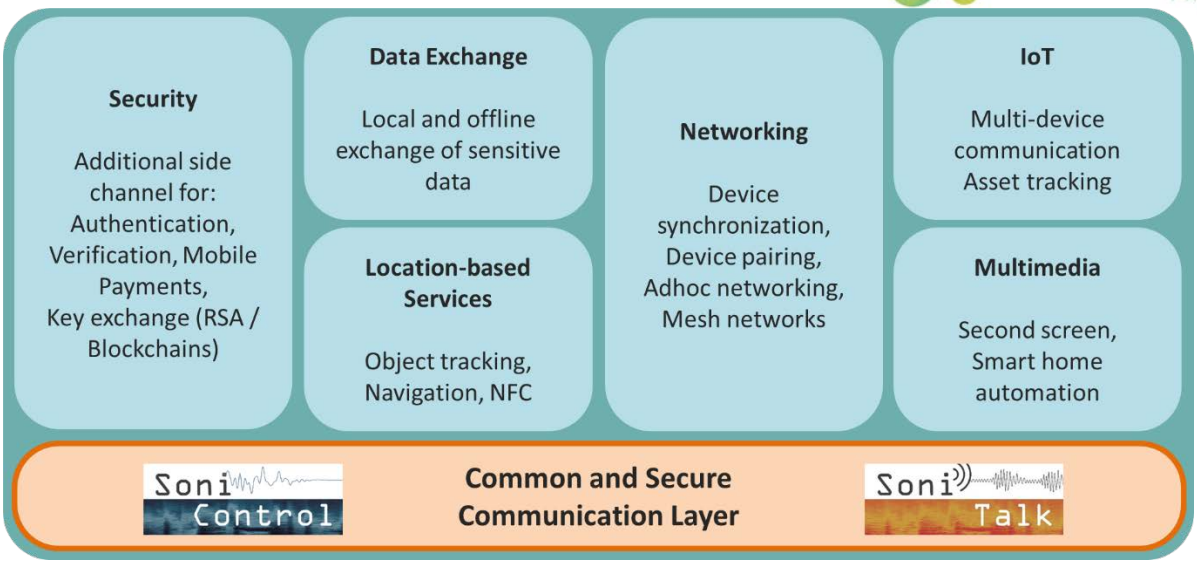
Sind weiterführende Aktivitäten nach dem netidee-Projektende geplant?

In the project SoniControl 2.0, we have established a number of cooperations with companies interested in our technology. We plan to further develop the SoniControl firewall and to integrate it into existing/novel tools and security suites. First, we will approach companies in the IT security domain to establish cooperation and to perform contract research by e.g. integrating our technology into their products, extending functionalities of SoniControl to their needs, and adapting SoniControl to novel use cases. Second, we will approach security-sensitive companies from the IT- and industry sectors to jointly develop solutions for protecting them against acoustic covert channels with our technology. Third, we plan to integrate the SoniControl firewall into the new ultrasonic communication protocol SoniTalk (developed at our institute, http://sonitalk.fhstp.ac.at) to establish a secure and transparent ultrasonic communication channel for future IoT and Industry 4.0 applications. Finally, a long-term goal is to launch a spin-off company from the FHSTP, that commercializes the developed ultrasonic communication technology and the SoniControl firewall.

11 Ideas for Further Developments by Third Parties

Welche Nutzungs- und Weiterentwicklungsmöglichkeiten für Dritte ergeben sich durch Ihr netidee-Projekt bzw. empfehlen Sie?

An important next step for future development is the integration of SoniControl into SoniTalk (a first open protocol for ultrasonic communication developed in a parallel project), to establish a secure and privacy-preserving communication infrastructure on the basis of ultrasound (see figure below).



Aside from this integration, the further development, testing and refinement of the individual firewall features is an important future task. To this end, we plan to integrate the open source community to support us in fixing bugs and further developing the application as well as to keep the app up-to-date with novel hard- and software infrastructure as it becomes available (e.g. novel Android versions).

12 Acknowledgements

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