The 16th International Conference on Telecommunications – ConTEL 2021

PhD Forum – Book of Abstracts

Editors:
Maja Matijašević
Irena Oršolić

University of Zagreb
Faculty of Electrical Engineering and Computing

Zagreb, Croatia
June 30 – July 2, 2021

Published by:

University of Zagreb
Faculty of Electrical Engineering and Computing
Unska 3, Zagreb, Croatia, HR-10000

Editors:

Maja Matijašević, University of Zagreb, Faculty of Electrical Engineering and Computing, Zagreb, Croatia
Irena Oršolić, University of Zagreb, Faculty of Electrical Engineering and Computing, Zagreb, Croatia

The papers in this proceedings comprise the book of abstracts for the PhD Forum held in the scope of the 16th International Conference on Telecommunications – ConTEL 2021. The papers are published as presented and without modifications. Responsibility for the contents of the papers published in this proceedings rests upon the authors and not upon the University of Zagreb, Faculty of Electrical Engineering and Computing.

ISBN: 978-953-184-275-4

Steering Committee

Maja Matijašević
University of Zagreb, Faculty of Electrical Engineering and Computing, Zagreb, Croatia
Dinko Begušić
University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia
Tihana Galinac-Grbac
Juraj Dobrila University of Pula, Pula, Croatia
Darko Huljenić
Ericsson Nikola Tesla, Zagreb, Croatia
Drago Žagar
Josip Juraj Strossmayer University of Osijek, Faculty of Electrical Engineering, Computer Science and Information Technology, Osijek, Croatia

Program & Organizing Committee

Irena Oršolić
University of Zagreb, Faculty of Electrical Engineering and Computing, Zagreb, Croatia
Andrej Grgurić
Ericsson Nikola Tesla, Zagreb, Croatia
Višnja Križanović
Josip Juraj Strossmayer University of Osijek, Faculty of Electrical Engineering, Computer Science and Information Technology, Osijek, Croatia
Goran Mauša
University of Rijeka, Faculty of Engineering, Rijeka, Croatia
Maja Škiljo
University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia
Reinhard Teschl
Graz University of Technology, Graz, Austria

List of Reviewers

Begušić, Dinko
Bonefačić, Davor
Galinac Grbac, Tihana
Grgurić, Andrej
Huljenić, Darko
Kainrath, Klaus
Leitgeb, Erich
Mauša, Goran
Oršolić, Irena
Skočir, Pavle
Speckbacher, Lucas
Škiljo, Maja
Teschl, Reinhard
Tržec, Krunoslav
Žagar, Drago

Foreword

The PhD Forum, hosted by the 16th International Conference on Telecommunications, ConTEL 2021, in Zagreb, Croatia, took place with in-person attendance at the ConTEL 2021 conference venue and online participation via zoom audio and video and conferencing platform. As a novel adjustment to such a "hybrid" format, the posters were displayed both in the physical space and in the virtual world using SpatialChat, a group video chat virtual meeting platform.

The format of the event was as follows. To be included in the ConTEL 2021 PhD Forum programme, doctoral students were invited to submit a two-page extended abstract for review. The submissions were reviewed by the PhD Forum Program & Organizing Committee members and the members of the ConTEL Technical Program Committee, based on relevance to the conference, innovativeness, and quality of (written) presentation. A total of 11 submissions were accepted, presented "live" in the PhD Forum session at the conference, and finally included in this booklet.

The authors of accepted extended abstracts each prepared a poster for the – physical and virtual – poster display. Depending on the ability of each participant to travel, two presentation options were possible: 1) face-to-face at the conference venue, or, 2) online via zoom.

At the PhD Forum session, which was live-streamed via zoom, the session chair Irena Oršolić welcomed the authors and session participants, and briefly introduced the program of the Forum and the voting procedure for selecting the best PhD Forum contribution (poster and presentation). Each student was then given a strictly-timed 2-minute time slot for an introductory "pitch talk" about his or her poster. After the pitch talks, the students and the audience moved to the physical poster display area, while simultaneously joining into the virtual poster room via SpatialChat to be "together" with the online-only participants, to discuss posters.

The winner of the best poster competition was determined by the members of the audience in a secret ballot vote, which was facilitated by another online platform (StrawPoll). The winner was Sara Vlahović, a doctoral student at the University of Zagreb.

I would like to thank the General Chairs of the ConTEL 2021 conference, Wilfried Gappmair and Mario Kušek, as well as the Program Chairs Franz Teschl and Marin Vuković, and all the members of the Steering and the Program & Organizing Committees, for their great support and help. I would also like to extend a well-earned congratulations to Irena Oršolić, the Program & Organizing Committee chair, on a job well done.

Maja Matijašević, University of Zagreb

Steering Committee Chair

TABLE OF CONTENTS

Performance Estimation of Encrypted Video Streaming in Light of End-User Playback-Related Interactions Based on Machine Learning

Ivan Bartolec, Lea Skorin-Kapov
University of Zagreb, Faculty of Electrical Engineering and Computing
Department of Telecommunications
Zagreb, Croatia
Email: {ivan.bartolec, lea.skorin-kapov}@fer.hr

***Abstract*—From a network provider's perspective, with the deployment of traffic encryption, new transport protocols, new compression methods and codecs, and the move to the HTTP Adaptive Streaming (HAS) paradigm, Quality of Experience (QoE) monitoring for HAS video services has become challenging. The task becomes even more challenging with end-users commonly invoking some form of playback-related interactions. This paper presents an overview of our research related to estimating end-user QoE-related Key Performance Indicators (KPIs) in-light of user-initiated playback interactions by exploiting Machine Learning (ML) techniques. The main goal is to define a methodology for training and testing of ML models for HAS video KPI estimation. The methodology is based on research regarding user interactions when using video streaming services, and includes automated data collection, processing, training, testing and analysis of derived models.**

***Index Terms*—Quality of Experience, Encrypted Video, Machine Learning, User Behavior, User Interactions**

I. Introduction

The percentage of individuals using the Internet over mobile (cellular) devices, who primarily run mobile applications on smartphones, has seen a significant global upward trend over the past decade [1]. Driven by applications such as video-on-demand services, and live video streaming services, video traffic accounts for nearly three-quarters of mobile data traffic, with further growth expected due to increases in delivery of higher video resolutions (e.g., UHD, 4K), and new immersive services (e.g., 360 video streaming, networked VR/AR, cloud gaming, IoT). Based on the user's actual perception of network performance and service quality, Quality of Experience (QoE) aware management should be deployed, aimed at detecting and mitigating QoE degradations [2].

Due to user privacy protection, major Over-the-Top (OTT) video streaming providers (e.g., YouTube, Netflix, Twitch) employ network traffic encryption, thus resulting in network providers being faced with the challenge of estimating end user QoE, and monitoring video Key Performance Indicators (KPIs) such as resolution, video bitrate, or stalling. Furthermore, considering realistic application usage scenarios, end user behavior adds to the challenge, with users commonly invoking some form of interaction impacting the video playback (e.g., seeking, pausing, skipping to another video), thus further having an impact on traffic characteristics and, consequently, on utilized QoE and KPI estimation models [3] [4].

II. In-Network Quality of Experience Monitoring

Considering the challenge of monitoring and estimating QoE, with no in-packet available information about content and streamed quality levels, network providers are forced to rely only on data that is available to them. Solutions for QoE monitoring rely on QoE models, specifying a mapping of monitored parameters to QoE. Such a model is reported in ITU-T Recommendation P.1203, the first standardized QoE model for audiovisual HTTP-based adaptive video streaming services delivered over reliable transport protocols [5]. Recent studies have investigated the potential of exploiting ML techniques for correlating network layer data of encrypted YouTube traffic with application layer KPIs (e.g., initial delay duration, stalling, video quality level) [6]. Several approaches were tested, differing in client software used for collecting ground truth data, underlying transport protocols, prediction type (e.g., near real-time prediction, or per-video session prediction), and ML frameworks. However, most studies tend to idealize end user behavior, collecting data without any kind of user playback interactions. As a consequence, it is questionable to what extent the proposed models are applicable in real-world network scenarios.

III. Playback-Related User Interactions

Monitoring and understanding the impact of user behavior is essential for designing video delivery systems and utilizing efficient QoE-driven monitoring and management. To create a realistic synthetic dataset that contains relevant playback-related user-interactions, we need to propose a model of user interactions, and common user behavior patterns. To achieve this, we implemented an Android service which served as an event logger of user interactions (e.g., pausing, seeking, replaying, entering or exiting fullscreen, etc.) in a YouTube Android application. During the interaction-monitoring campaign in May and June of 2021, events from 816 video sessions were collected, resulting in a total number of 4524 events. In

16th International Conference on Telecommunications - ConTEL 2021, PhD Forum
ISBN: 978-953-184-275-4, June 30 - July 2, 2021, Zagreb, Croatia

summary, approximately 87% of video sessions were abruptly terminated by the user. Figure 1 depicts most performed types of user interactions and their overall amount from all of the video sessions combined.

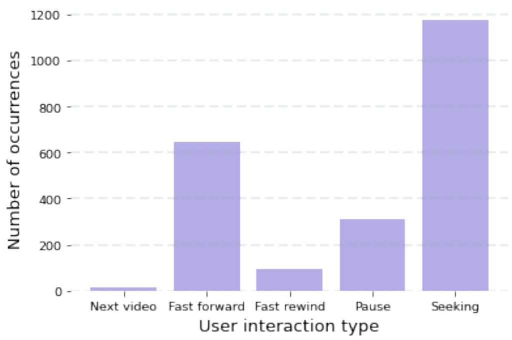


Fig. 1. Most commonly performed user interactions during the interaction-monitoring campaign.

While certain user interactions may be driven by viewer's lack of interest in the content being viewed, a change in service behavior may influence a user to interact with the video player. Complementary to the interaction-monitoring campaign, users were asked to fill a questionnaire containing questions regarding different video viewing scenarios. In one such scenario, users were asked how they would react if video degradations (e.g., stalling) occured during a video stream they were viewing. Results indicate how more than 95% of viewers would perform some kind of playback interaction (Figure 2).

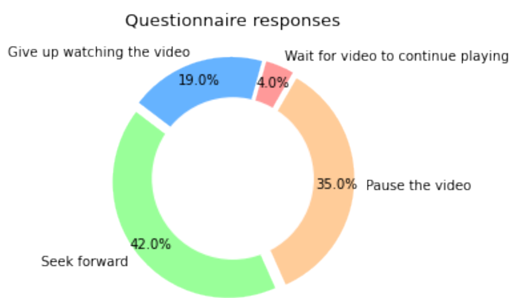


Fig. 2. Questionnaire responses regarding the viewer's behavior during video degradations (based on 26 responses)

IV. User Interactions in the Quality Estimation Process

Each interaction affects the video delivery behavior in a different way, thus consequently impacting traffic characteristics. Given the wide range of different potential interactions, multiple interaction occurrences, various combinations of interactions, and different time points of executions (including parallel interaction executions) spanning across a video session, an infinite space of interaction execution possibilities exists, all of which influence the traffic characteristics differently.

Results from initial studies regarding the impact of user interactions on ML classification accuracy (depicted in Figure 3) motivate the need to systematically include data corresponding to various interaction scenarios when training QoE-related KPI classification models [3] [4].

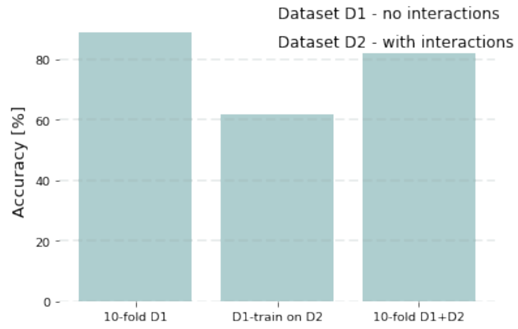


Fig. 3. Accuracy of Random Forest models for classifying average video bitrate in 3 classes (adapted from [3]).

V. Approaches for Model Training.

Various QoE-related KPI estimation approaches may be utilized, differing in prediction type, ML task, datasets on which models were trained (e.g., with all interactions, with certain interactions, without interactions), or in the number of models used to obtain desired output. In both our previous study [4] and in ongoing work, we are investigating the performance of ML-based KPI classification models for mobile YouTube videos trained on data with and without various combinations of user interactions. Models are trained and validated with the aim being to identify which types of interactions need to be included when training KPI estimation models. An open research question is the extent to which model performance could be improved with additional data provided, either from the OTT service provider or from the different layers.

Acknowledgment

This work has been supported in part by the Croatian Science Foundation under the project IP-2019-04-9793 (Q-MERSIVE).

References

[1] Cisco Annual Internet Report (2018-2023), March 2020, Accessed: 2020-09-07

[2] Baraković, et al., "Survey and Challenges of QoE Management Issues in Wireless Networks." Journal of Computer Networks and Communications 2013 (2013).

[3] Bartolec, et al., "In-network YouTube Performance Estimation in Light of End User Playback-related Interactions." 2019 Eleventh International Conference on Quality of Multimedia Experience (QoMEX). IEEE, 2019.

[4] Bartolec, et al., "Inclusion of End User Playback-Related Interactions in YouTube Video Data Collection and ML-Based Performance Model Training." 2020 Twelfth International Conference on Quality of Multimedia Experience (QoMEX). IEEE, 2020.

[5] ITU-T. Recommendation 1203.3 - "Parametric bitstream-based quality assessment of progressive download and adaptive audiovisual streaming services over reliable transport-Quality integration module,". Tech. rep. International Telecommunication Union (2017).

[6] Orsolic, et al., "Youtube QoE Estimation Based on the Analysis of Encrypted Network Traffic Using Machine Learning." In 2016 IEEE Globecom Workshops (GC Wkshps), pp. 1-6. IEEE, 2016.

Personal thermal comfort modelling with implementation of smart technologies

Ana Čulić
LTEF- Laboratory for Thermodynamic and Energy Efficiency
Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split
21000 Split, Croatia
aculic00@fesb.hr

Sandro Nižetić
LTEF- Laboratory for Thermodynamic and Energy Efficiency
Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split
21000 Split, Croatia
snizetic@fesb.hr

Petar Šolić
Department for Information and Communication Systems
Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split
21000 Split, Croatia
psolic@fesb.hr

***Abstract*— Thermal comfort (TC) is an important issue in buildings, since it has impact on the occupant's health, ability to work or function effectively, satisfaction with the environment etc. Development of the smart technologies in the building sector brings new opportunities for the energy management approach. User-centric technological solutions are being applied in various segments of the building performance. Within heating and cooling systems, new trends are directed towards development of the personal thermal comfort models. Developed models are trying to provide individualized environmental conditions for the occupants in the buildings, putting user's internal parameters i.e. physiology and preferences as the crucial information for system design. This work provides major findings related to the current state-of-the-art in personal thermal comfort detection as well as description of the methodology of the field investigation of personal thermal comfort in office building with wearable sensors. Collected information could be useful for modelling the personal thermal comfort as important basis for smart regulation of the building energy systems.**

Keywords — thermal comfort, energy efficiency in buildings, personalized comfort models, smart buildings

I. Introduction and Related Work

The building sector has been recognized as crucial to accomplish sustainable developments goals [1][2]. There is a great perspective to achieve energy savings by improving the efficiency of the heating, ventilation and air conditioning (HVAC) system in the buildings. In the modern building solutions, smart technologies are becoming increasingly important. Also, the role of the users is recognized as an important factor for the building performance efficiency [3]. In accordance with the new building paradigm, human needs are placed as the central point for energy optimization and user actions are integrated in building management processes [4]. In the HVAC system domain, the human dimension is included through the thermal comfort component which can be reflected through the occupant's health, productivity, satisfaction with the environmental conditions etc. Thermal comfort is defined as "the condition of mind that expresses satisfaction with the thermal environment" and is currently regulated through ASHRAE 55 and ISO 7730 standards based on the Predicted Mean Vote (PMV) model [5][6]. It takes into account four environmental variables (air temperature, air velocity, relative humidity and mean radiant temperature) and two human-related (clothing insulation - CLO and metabolic rate - MET) variables. However, above-mentioned standardized approach is found to be too general and has been questioned lately. Researchers have pointed out that it might be insufficient, as it doesn't take into account individual differences of the occupants, i.e. the diversity in their metabolic rate, clothing level, expectations, gender, physiology etc. [7][8]. This can lead to disproportion between the calculated and real energy consumption in the buildings which leads to irrational energy use (overcooling / overheating) [9]. Personalized, user-centric thermal-comfort models are recognized as promising solutions to the above-mentioned drawbacks, aiming to optimize both the energy consumption and user comfort. Personal comfort models are considered as data-driven, and are dedicated to collecting the individual real-time information from the user and the surroundings (i.e. air temperature) via sensors. This approach provides a huge amount of information used as input to the developing models. Therefore, the overall accuracy of the model is directly conditioned by the appropriate selection of the influential parameters [10]. To develop accurate thermal comfort models, human perspective should be better investigated. Human segment encompasses monitoring physiological signals (herat rate, body temperature) and user's subjective evaluation of the environmental conditions. Some studies have tried to develop personalized thermal comfort conditions in the buildings by adjusting thermal conditions in small building areas or installing devices for heating or cooling to target specific parts of the human body [11]. Another approach, data-driven is based on the collecting relevant thermal comfort parameters with sensing devices and development of methods for managing the indoor conditions based on the collected information in order to achieve thermal comfort of the users. The selection of the parameters for data driven thermal comfort modelling relies mostly on the physical and personal variables defined in the PMV model [5], but in the literature, some additional parameters were found to be related with the thermal comfort of the individual, i.e. skin temperature [12] and heart rate (HR) of the occupants [13]. Data-driven approach for personal thermal comfort was motivation for the thermal comfort investigation in the office building, and is described further in the paper. Related work includes various experiments with sensing technologies. Wearable devices were used for physiological data acquisition from the users i.e. Apple watch series 4 [14], Microsoft Band 2 [15] and Empatica E4 wristband [16] for heart rate and skin temperature data and activity-based sensor Move 3 in [17] for measuring metabolic rate. In [18] authors applied different approach using Kinect camera and in [19] video camera was used for user's metabolic rate and CLO values detection. [20] tried to detect the occupant's skin temperature with a thermal camera. The main objective of the experiment within presented phD work is to investigate the correlation between the human physiological parameters and the environmental conditions in offices with the subjective evaluation from the users.

II. Methodology and Conceptual Approach

Ccommercially available low-cost smart wearable devices „E66 Smart Bracelet Body Temperature and Heart Rate Monitoring Sports Pedometer Smart Watch" (E66) were selected as the measuring devices for the physiological inputs in the experiment. The research was conducted by placing two E66 bracelets to monitor the heart rate and skin temperature of users during day in the office. Simultaneously ambient sensors (Decentlab DL-IAM) were installed for air temperature, relative air humidity and carbon dioxide (CO_2) detection. The conditions in the observed room were adjusted to examine specific temperature change scenarios (heating and cooling). Users were also asked to give a thermal sensation vote through a questionnaire about their subjective evaluation of thermal conditions in the office every hour, or more often if they experience a significant change in the thermal conditions in the room. The thermal sensation vote is based on the ASHRAE 7-point scale (from -3 (cold) to +3 (hot) where zero represents neutral thermal sensation). Overall inputs included personal parameters of the users (heart rate, skin temperature, subjective evaluation, individual differences between subjects i.e. age, sex, BMI, clothing level) and environmental parameters (air temperature, relative humidity, CO_2). Collected information could be useful for modelling the personal thermal comfort as important basis for smart regulation of the building energy systems. The scheme of the proposed system is presented in the Figure 1.

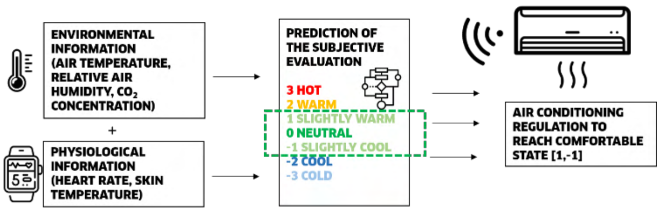


Fig. 1. Air conditioning regulation system based on the thermal comfort prediction of the user

Future Research Work

For the future work, applicability of machine learning algorithms for personal thermal comfort modelling should be conducted on the collected data from the experiment to predict user comfort with the physiological and environmental data as inputs. Finally, based on the prediction of the presonal user's comfort, an algorithm for regulation of the split heat pump air conditioning system is planned to be developed. It could then be investigated if such approach has a perspective for application in smart buildings through intelligent management of heating and cooling systems and the energy efficiency of the proposed systems will be evaluated.

Acknowledgment

This work was supported by the Croatian Science Foundation under the project "Internet of Things: Research and Applications", UIP-2017-05-4206

References

[1] Web source iea.org/topics/buildings, Last accessed June 18, (2021).

[2] Web source: unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement, Last accessed June 18, (2021)

[3] Yan Zhang, Xuemei Bai, Franklin P. Mills, John C.V. Pezzey, Rethinking the role of occupant behavior in building energy performance: A review, Energy and Buildings, Volume 172, 2018, Pages 279-294, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2018.05.017

[4] Mateus Vinícius Bavaresco, Simona D'Oca, Enedir Ghisi, Roberto Lamberts, Technological innovations to assess and include the human dimension in the building-performance loop: A review, Energy and Buildings, Volume 202, 2019, 109365, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2019.109365

[5] International Standard Organization, ISO 7730, Ergonomics of the thermal Environment - Analytical Determination and Interpretation of ThermalComfort Using Calculation of the PMV and PPD Indices and Local ThermalComfort Criteria, 2005.

[6] ANSI/ASHRAE Standard 55 - Thermal Environmental Conditions for Human Occupancy, American Society of Heating, 2013.

[7] Thomas Parkinson & Richard de Dear (2014): Thermal pleasure in built environments: physiology of alliesthesia, Building Research & Information, DOI: 10.1080/09613218.2015.989662

[8] Mishra, Asit & Loomans, M.G.L.C. & Hensen, Jan. (2016). Thermal comfort of heterogeneous and dynamic indoor conditions — An overview. Building and Environment. 109. 10.1016/j.buildenv.2016.09.016

[9] Zhang, Sheng & Yong, Cheng & Oladokun, Majeed & Wu, Yuxin & Lin, Zhang. (2019). Improving Predicted Mean Vote with Inversely Determined Metabolic Rate. Sustainable Cities and Society. 101870. 10.1016/j.scs.2019.101870.

[10] Jung, Wooyoung & Jazizadeh, Farrokh & Diller, Thomas. (2019). Heat Flux Sensing for Machine-Learning-Based Personal Thermal Comfort Modeling. Sensors. 19. 10.3390/s19173691

[11] Rawal R., Schweiker M., Kazanci O.B., Vardhan V., Jin Q., Duanmu L., Personal comfort systems: A review on comfort, energy, and economics, Energy and Buildings, Volume 214, 2020, 109858, ISSN 0378-7788,

[12] Liu, Shichao & Das, Hari Prasanna & Jin, Ming & Spanos, Costas. (2019). Personal thermal comfort models with wearable sensors. Building and Environment. 162. 106281. 10.1016/j.buildenv.2019.106281.

[13] Deng, Zhipeng & Chen, Qingyan. (2020). Development and validation of a smart HVAC control sys-tem for multi-occupant offices by using occupants' physiological signals from wristband. En-ergy and Buildings. 214. 109872. 10.1016/j.enbuild.2020.109872

[14] Fang, Yuan & Lim, Yuto & Ooi, Sian & Zhou, Chenmian & Tan, Yasuo. (2020). Study of Human Thermal Comfort for Cyber–Physical Human Centric System in Smart Homes. Sensors. 20. 372. 10.3390/s20020372.

[15] Alsaleem F, Tesfay MK, Rafaie M, Sinkar K, Besarla D and Arunasalam P (2020) An IoT Framework for Modeling and Controlling Thermal Comfort in Buildings. Front. Built Environ. 6:87. doi: 10.3389/fbuil.2020.00087

[16] Lee Jeehee & Ham Youngjib (2020): Physiological sensing-driven personal thermal comfort model-ling in consideration of human activity variations, Building Research & Information, DOI: 10.1080/09613218.2020.1840328

[17] Nižetić, S., Pivac, N., Zanki, V., Papadopoulos, A.M., Application of smart wearable sensors in office buildings for modelling of occupants' metabolic responses (2020) Energy and Buildings, 226, art. no.

[18] Na H., Choi J., Kim H., Kim T., Development of a human metabolic rate prediction model based on the use of Kinect-camera generated visual data-driven approaches, Building and Environment, Volume 160, 2019, 106216, ISSN 0360-1323

[19] Zang, Miao & Xing, Zhiqiang & Tan, Yingqi. (2019). IoT-based personal thermal comfort control for livable environment. International Journal of Distributed Sensor Networks. 15. 155014771986550. 10.1177/1550147719865506.

[20] Cosma, Andrei-Claudiu & Simha, Rahul. (2018). Thermal comfort modeling in transient conditions using real-time local body temperature extraction with a thermographic camera. Building and Environment. 143. 10.1016/j.buildenv.2018.06.05

Sensing the Environment Changes from Signal Strength Data: Machine Learning Approach

Lea Dujić Rodić and Petar Šolić
Department of Electronics and Computing
University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture
Rudjera Boskovica 32, 21000 Split, Croatia
{dujic;psolic}@fesb.hr

***Abstract*—The IoT vision of ubiquitous and pervasive computing gives rise to future Smart Environments comprising physical and digital world. Rapid population growth has resulted in the increased agricultural production demands where efficient water management is crucial, where as modern urban areas today are faced with vast increase of vehicles and inadequate parking systems. Existing solutions are based on data received from the power hungry/expensive sensors that are transmitting the sensed data over the wireless channel. Over time, the systems become difficult to maintain, especially in remote areas due to the battery replacement issues with large number of devices. Smart irrigation ecosystem and Smart Parking management combined with Machine Learning can provide solutions that successfully solve the soil humidity and free parking sensing task in order to ensure optimal water usage as well as reducing the fuel consumption. This work explores a concept of a novel, low-power, LoRa-based, cost-effective beacon-based mechanism, which achieves humidity and parking sensing with high accuracy using Machine Learning techniques simply by measuring signal strength from the given beacon device.**

***Index Terms*—IoT, Soil humidity, RSSI, LoRa, Machine Learning, Parking Occupancy**

I. Introduction

The constantly evolving and ubiquitous domain of smart connected things known as the Internet of Things (IoT) has found its applications in various areas from healthcare, agriculture, automotive systems, to smart cities [1]. The world population is estimated to rise up to 9.7 billion by 2050 and there will be great demand for food. In agriculture, efficient water usage and irrigation methods are essential for increase of productivity and economic benefit, since it is estimated that 40% of water used for agriculture is lost in developing countries [2]. Yet another effect of the recent rapid population growth is the increase of vehicles in urban city areas. Existing parking systems are inadequate or unable to handle parking loads, since it is estimated that drivers spend around 7.8 minutes in finding free parking lots [3]. One of the major issue that arise from this is the increase of fuel consumption and air pollution. In order to address the above mentioned problems, a novel approach must provide a cost and energy effective device that has unique advantage over the existing solutions.

II. The research topic presentation

In this research, LoRaWAN radio technology was employed, which allowed battery-enabled sensor devices to communicate low throughput data over long distances. Namely, I2C soil-moisture sensor device buried 14 cm below ground was used for soil humidity and temperature monitoring and two indoor LoRaWAN gateways for data collection. For the purpose of collecting parking occupancy detection, five Libelium Smart Parking sensor devices were placed at the faculty parking lot and three LoRaWAN gateways (two indoor and one outdoor). Installed gateways employ TTN technology that allows collection of data from gateways and their storage into a designated InfluxDB database as shown in Fig. 1. The collected data comprised information about parking lot occupancy status, Soil humidity, Received Signal Strength Indicator (RSSI) in dBm, Signal to Noise Ratio (SNR) for every gateway, gateway ID, Sensor ID, as well as the timestamp of the moment at which the data was received by TTN gateway.

Extensive Data analyses revealed that changes of RSSI and SNR highly correlate with the change of Soil humidity and parking occupancy (Fig. 2 and Fig. 4).

For estimation of Soil humidity from RSSI and SNR values, a Long-Short Term Memory (LSTM) neural network model obtained a MSE and MAE errors of 0.00018 and 0.01043, respectively (Fig. 3.), out-preforming other tested algorithms, with hyper-parameters given in Table I. For parking occupancy classification, a Neural Networks (NN) model, (presented in Fig. 5) reached 96% and 95% Accuracy on validation and test set respectfully, and 98% AUC on both validation and test set. As can be seen in Fig. 6), NN model is able to distinguishing occupied and free parking space exceptionally well.

Therefore, a cost-effective solution would employ Machine Learning techniques for detecting changes in the environment solely by measuring signal strength, namely a simple beacon device that will not require any sensor readings.

References

[1] L. Dujić Rodić, T. Perković, T. Županović, and P. Šolić, “Sensing occupancy through software: Smart parking proof of concept,” *Electronics*, vol. 9, no. 12, 2020.

[2] A. N. Harun, M. R. M. Kassim, I. Mat, and S. S. Ramli, “Precision irrigation using wireless sensor network,” in *2015 International Conference on Smart Sensors and Application (ICSSA)*, 2015, pp. 71–75.

[3] T. Perković, P. Šolić, H. Zargariasl, D. Čoko, and J. J. Rodrigues, “Smart parking sensors: State of the art and performance evaluation,” *Journal of Cleaner Production*, p. 121181, 2020.

This work was supported by the Croatian Science Foundation under the project “Internet of Things: Research and Applications”, UIP-2017-05-4206.

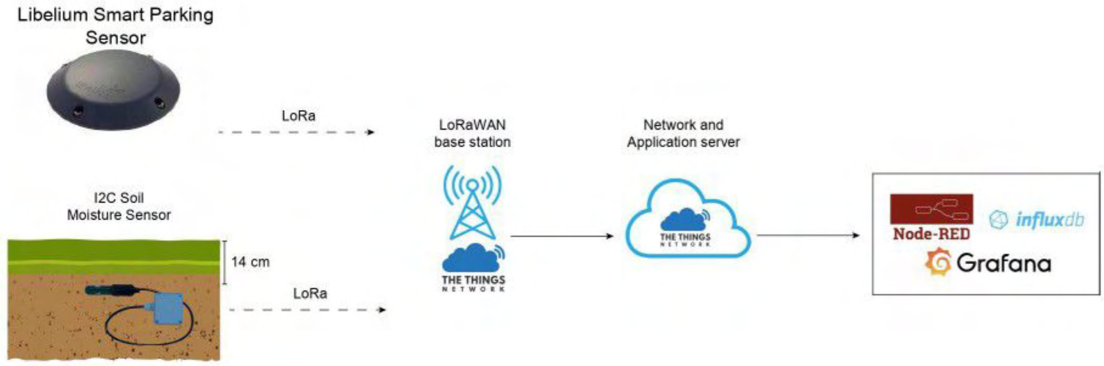


Figure 1: Network architecture of LoRaWAN-based soil moisture and Libelium Smart Parking sensors system.

Table I: LSTM model hyper-parameters

Hyper-parameter	Values
number of neurons	32
Learning rate	0.001
Number of epochs	100
Optimizer	RMSprop

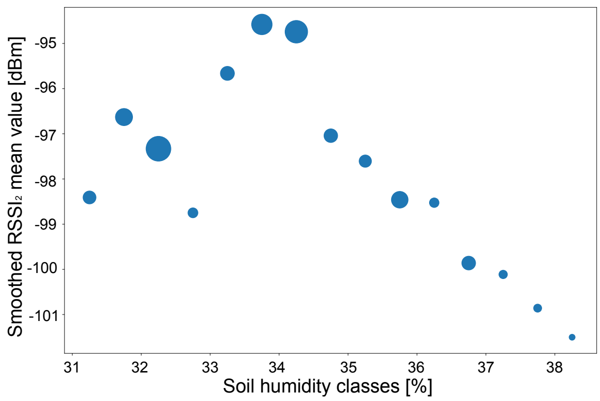


Figure 2: Smoothed $RSSI_2$ values correlated with specific Soil humidity classes. The circle size represents the relative portion of RSSI data within the humidity class.

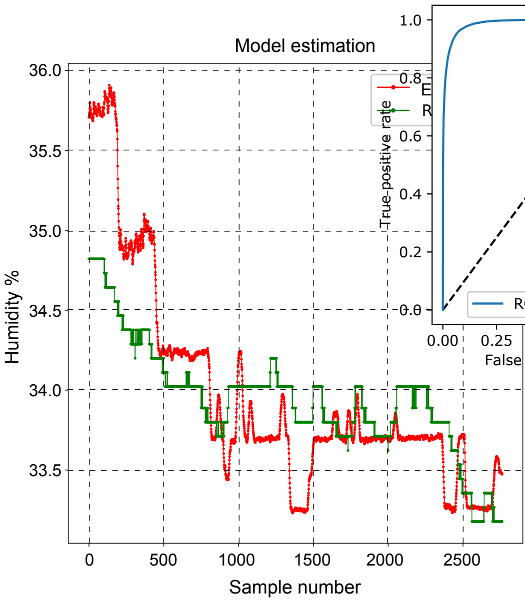


Figure 3: Estimation of soil humidity with the LSTM model compared to expected values of soil humidity.

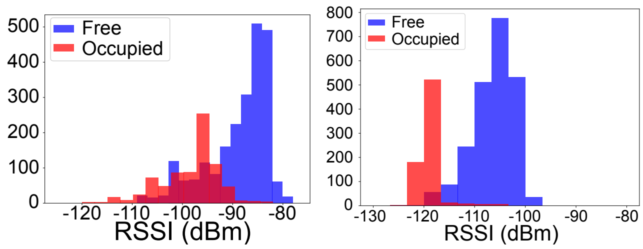


Figure 4: Histograms of RSSI values for Smart Parking Sensor 2 for free and occupied parking status from (left) Gateway 1 and (right) Gateway 3

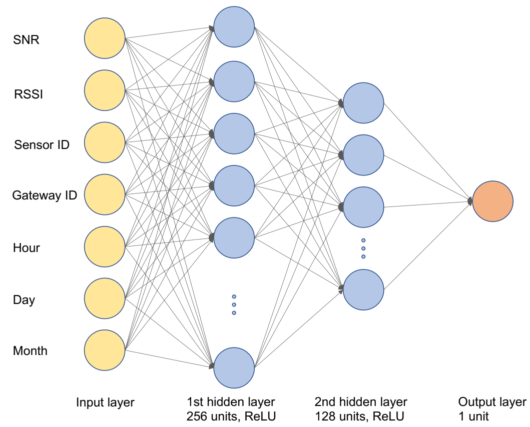


Figure 5: Architecture of Neural Network model for parking space occupancy classification

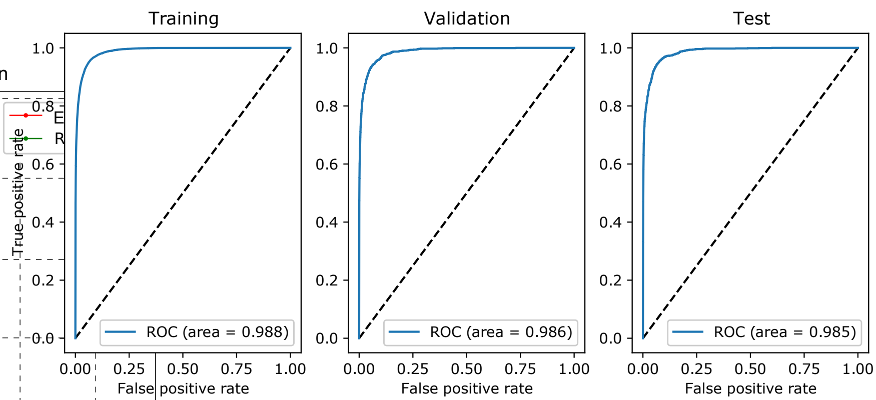


Figure 6: ROC curves for Adam optimizer with the learning rate of 0.001 and 100 epochs.

ConTEL 2021, PhD Forum, ISBN: 978-953-184-275-4

Microwave Frontends for Dependable Wireless Communication and Localization Systems

Gerzon Gomez-Bravo, Reinhard Teschl, Wolfgang Bösch
Institute of Microwave and Photonic Engineering
Graz University of Technology
Graz, Austria
ggomezbravo@tugraz.at,reinhard.teschl@tugraz.at,wbosch@tugraz.at

***Abstract*—Adaptable antenna systems and microwave frontends are key elements of modern wireless localization and communication systems as they affect the overall performance and reliability. Two of the factors that can be exploited are the Polarization Diversity and scaling towards the mmWave frequency. In our approach, we study the advantages and disadvantages of each technique, therefore hardware implementations are proposed to demonstrate their impact in real world scenarios. To evaluate the performance, a two-step plan is in place, starting with the design, simulation and optimization of a Cavity Backed Archimedean Spiral Antenna (ASA) and subsequently moving to the mmWave frequency range to implement Reconfigurable Reflectarrays.**

***Index Terms*—dependability, reconfigurable antennas, circular polarization, localization**

I. Introduction

In recent years, the Internet of Things (IoT) has become one of the most prominent technological trends. A growing portion of IoT devices has been designed for consumer use, with applications varying from home automation to connected healthcare. As IoT deeper integrates into our everyday life, it has become imperative to design more dependable systems, since IoT failures may have disastrous consequences. This issue is the focus of the LEAD Project Dependable IoT that was launched by TU Graz and in which the present work is conducted. The emphasis of this PhD-thesis lies in the design of tunable microwave frontends for applications in communication and localization systems.

Advances in millimeter-wave radio technology have raised increasing attention due to their potential advantages in the implementation of highly accurate positioning systems. Compared with existing wireless technologies, mmWave radios adopt higher carrier frequencies thus offering broader bandwidths, narrower beams, and strong detection ability. These properties make mmWave systems an ideal candidate to implement location-aware adaptive systems [1]. The main objective in this project is to identify efficient frontend architectures with enhanced beamforming capability to optimize the system performance and resource allocation in realistic environments, hence improving system-wide scalability and positioning performance. Building upon the latter, the development of low-profile, power-efficient, and scalable frontends is targeted,

II. Proposed Solutions

To address the challenges imposed by wireless communication and localization systems two possible improvement areas for tunable microwave frontends, both in terms of reliability and accuracy were identified.

A. *Polarization diversity*

One of the most well known techniques used for improving the reliability of a message signal in a wireless system is the diversity scheme. The diversity scheme uses two or more communication channels with different characteristics, to reduce the effect of fading and co-channel interference [2]. This concept relies on the fact that different channels can experience different levels of fading and interference, thus, multiple versions of the same signal are transmitted. Depending on the electromagnetic characteristic of the signals that are being exploited, it is possible to find systems based on time, frequency or space diversity. Nevertheless, there is another not thoroughly exploited characteristic of an electromagnetic signal that can be use in diversity techniques, the polarization of propagating waves [3].

In radar systems, it has been shown that Circularly Polarized Waves (CPWs) can reduce the amplitude fade and improve the anti-multipath fading capability without the need of using additional elements like equalizers [4]. Additionally, when a CPW is transmitted, the polarization is reversed on specular reflection: a right-hand incident wave yields a left-handed reflected wave and vice versa. Thus, under Line-of-Sight (LOS) conditions, the receiving antenna will not be responsive to the odd-bounce reflected waves hence avoiding depolarization. On the other hand, unlike Linearly Polarized (LP) antennas, Circularly Polarized (CP) antennas are ideal to address the challenges associated with mobility on both mobile and fixed devices due to their superior propagation characteristics in adverse weather conditions and non-LOS applications [5].

B. *Scaling towards the mmWave frequency band*

The development of bandwidth intensive applications shows no signs of slowing down in the future. Recent work on mmWave wireless systems showed the potential advantages for highly accurate positioning due to the use of highly directional antennas, which yield superior angular measurements and allow to better resolve multi-path components [6].

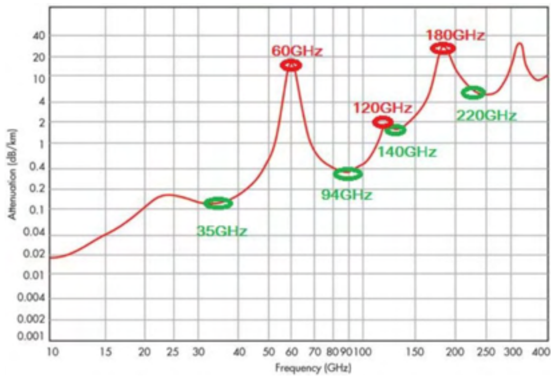


Fig. 1. Atmospheric and molecular absortion at mmWave frequencies [7]

The high-frequency bands in the spectrum above 24 GHz are targeted as having the potential to support large bandwidths and high data rates, ideal for increasing the capacity of wireless networks. Owe to the short wavelengths, mmWave devices can pack more antenna elements in the same physical dimensions in comparison with RF frequencies, obtaining narrower beams [7]. Nevertheless, mmWave systems suffer from some drawbacks too, mainly due to the high attenuation levels caused by atmospheric gases (Fig. 1). It can be observed that in some frequency ranges such as 35, 94, 140, and 220 GHz, mmWave propagation experience relative small levels of attenuation (local minima).

We hypothesize that the shift towards the mmWave frequency range with a location-aware approach, can improve the scalability and dependability of localization systems while reducing their complexity.

III. Hardware implementation

To showcase an implementation on how these concepts can impact the accuracy and the reliability of localization systems, the design of two types of antennas is envisaged. During the first phase of the LEAD Project Dependable IoT, an indoor localization system based on a switchable antenna system was developed, thus, to evaluate the impact of using the polarization diversity technique, the antennas used in said system will be replaced by equivalent CP antennas. Thus, the design goals were defined as: Half Power Beamwidth (HPBW=90 °) to achieve a 360 ° coverage with 4 antennas,axial ratio lower than 3 [dB] in the frequency range of operation, to guarantee the radiation of CP waves. Finally, all the parameters of the CP antenna should be stable in the 3-7 GHz frequency range.

One of the antennas that fits the design requirements is the ASA. This type of antenna is frequency independent, presenting small variations in the different parameters. On the other hand, ASAs present higher gain levels and HPBW compared to other CP antennas. The designed antenna integrates a cavity to reduce the back and side lobe magnitudes. An antenna with this characteristics has been designed and simulated, currently it is in the fabrication process.

On the other side, to address the scalability in frequency and take full advantage of it, one of the most promising options is the concept of the reflectarray antenna. This type is known to have high gain, high directivity and low profile [9]. Reflectarrays are a promising platform to implement reconfigurable antennas with beam scanning capabilities. Recent work has shown that adaptable beam switching can be used to avoid lateral interference to minimize collisions between network nodes, thus reducing network traffic and maximizing scalability [10].

IV. Summary and Outlook

The development of antennas that can improve the reliability and accuracy of localization and communication systems is aimed. Based on this idea, two areas of opportunity have been defined, the application of Polarization Diversity and the scalability in frequency to the mmWave frequency range. To prove these techniques, the design of two types of antennas is under development. At first, a Cavity Backed ASA should be the tool to prove the concept of applying the Polarization Diversity Technique, by substituting LP antennas in an already implemented localization system.The future work will consist of the development of a reflectarray antenna to address the challenge of scalability in frequency, once the impact of using CP antennas is validated, a prototype combining both techniques will be considered for development.

V. Acknowledgment

This work was supported by the TU Graz LEAD project “Dependable Internet of Things in Adverse Environments”.

References

[1] J. Arnold, L. Simic, and P.Meahoenen, ”Experimental Feasibility Study of Motion Sensor-Aided mm-Wave Beam Tracking”, Proceedings of the 1st International ACM Workshop on Millimeter-Wave Networks and Sensing Systems (mmNets), pp. 5–10, 2017.
[2] Kajiwara, A., Effects of Polarization, ”Antenna Directivity, and Room Size on Delay Spread in LOS Indoor Radio Channel”, IEEE Transactions on Vehicular Technology, vol.46, pp. 169–175, 1997.
[3] Kajiwara, A., “Line-of-Sight Indoor Radio Communication Using Circular Polarized Waves”, IEEE Transactions on Vehicular Technology, vol.44, pp.487—493,1995
[4] R. Efurd, M. Cohen, and E. Sjoberg, “Advanced intrapulse polarization agile radar nears deployment,” MSN , pp. 67-76, Feb. 1984.
[5] V. Rafii, J. Nourinia, C. Ghobadi, J. Pourahmadazar, and B. S. Virdee, “Broadband circularly polarized slot antenna array using sequentially rotated technique for C-band applications,” IEEE Antennas Wireless Propag. Lett., vol. 12, pp. 128–131, 2013.
[6] Z. Abu-Shaban, X. Zhou, T. Abhayapala, G. Seco-Granados, and H.Wymeersch, ”Error Bounds for Uplink and Downlink 3D Localization in 5G Millimeter Wave Systems,” IEEE Transactions on Wireless Communications,vol. 17, pp.4939–4954, 2018.
[7] Wang, X., Kong, L., Kong, F., Qiu, F., Xia, M., Arnon, S., Chen, G., ”Millimeter wave communication: A comprehensive survey,” IEEE Communications Surveys and Tutorials, vol.20, pp.1616–1653, 2018.
[8] Großwindhager, B., Rath, M., Kulmer, J., Bakr, M. S., Boano, C. A., Witrisal, K., Römer, K, ”SALMA: UWB-based single-anchor localization system using multipath assistanc”,SenSys 2018 - Proceedings of the 16th Conference on Embedded Networked Sensor Systems, pp. 132–144, 2018.
[9] Hum, S. V., Perruisseau-Carrier, J., ”Reconfigurable reflectarrays and array lenses for dynamic antenna beam control: A review”, IEEE Transactions on Antennas and Propagation, vol. 62, pp. 183–198, 2015
[10] D. Steinmetzer, A. Loch, A. Garcia-Garcia, J. Widmer, and M. Hollick, ”Mitigating lateral interference: Adaptive beam switching for robust millimeter-wave networks,”,Proceedings of the 1st International ACM Workshop on Millimeter-Wave Networks and Sensing Systems, 2017.

Efficient procedures in assessment of incident power density on non-planar tissue models under electromagnetic exposure in mmWave spectrum

Ante Lojić Kapetanović*, Dragan Poljak†
Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture
University of Split, Split, Croatia
*alojic00@fesb.hr, †dpoljak@fesb.hr

***Abstract*—Given that the 5^{th} generation mobile communication technology (5G) is currently being actively deployed worldwide, international guidelines and standards for human exposure to radiated electromagnetic fields have been revised. Entering the mmWave frequency range, incident (or epithelial) power density is adopted as the new dosimetric reference level. However, most of the researchers still use classical and outdated techniques that rely heavily on finite difference schemes which introduce rough approximations of human tissue geometry, and thus lose the mathematical rigor of the formulation and do not acquire physical interpretability of the final result. This paper aims to present threefold progress to current efforts in assessment of incident power density: (i) use of non-planar, multi-layer models of human tissue; (ii) application of realistic exposure scenarios; (iii) faster and more accurate computation supported by modern data-driven techniques.**

***Index Terms*—computational dosimetry, incident power density, 5G communication technology**

I. Introduction

Due to the increase in the number of smart personal mobile devices and the consequent need for greater network capacity and reliability, the 5^{th} generation mobile communication technology (5G) utilizes mmWave frequency spectrum. As biological effects of radiation in ultra and super high frequency bands of radio spectrum, 3 GHz to 30 GHz and 30 GHz to 300 GHz, respectively, have been scarcely investigated, the international guidelines [1] for human protection from electromagnetic fields have been revised, focusing on frequencies above the transition frequency of 6 GHz. For such high frequencies, the effect of radiation is substantial on the surface and negligible elsewhere throughout the tissue. Therefore, novel dosimetric reference level for human exposure has been determined as the incident power density (IPD). IPD is a free space approximation of the absorbed power density averaged over an irradiated area of tissue, A, of either 1 cm^2 or 4 cm^2, corresponding to the area of the exposed surface of 1 g or 10 g cube of tissue, respectively [2]. It is defined as the surface integral of the real part of the magnitude of the Poynting vector, $\vec{S}$, as follows:

$$S_{ab} = \frac{1}{2A} \iint_A \Re[\vec{S}] d\vec{s} \tag{1}$$

where $\vec{S} = \vec{E} \times \vec{H}^*$ and yields a direction of the electromagnetic wave propagation.

More than ever, simulations of human exposure have to be executed with high numerical accuracy, and within more realistic exposure scenarios. This paper summarizes current efforts on potential improvements in relation to the overall computational dosimetry research for human exposure to radio-frequency electromagnetic waves conducted so far [3], focusing on near-field conditions.

II. Improvements in the assessment of the IPD

A. Realistic sources of radiated electromagnetic fields

Human exposure simulations are conducted by placing a center-fed half-wave dipole as a realistic source of radiated electromagnetic fields in the immediate vicinity of the model of human head. Current distribution along the dipole is governed by the Pocklington integro-differential equation, and the solution is carried out by means of Galerkin-Bubnov scheme of the indirect boundary element method. It is then straightforward to obtain electric and magnetic field equations from the boundary element formalism itself [4].

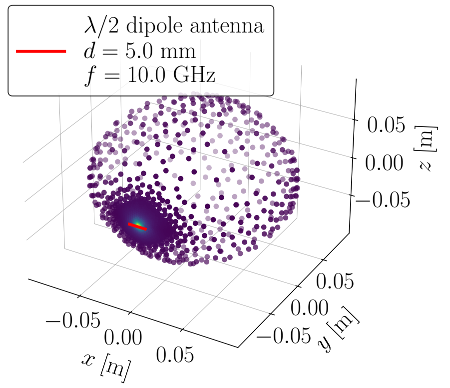
B. Application of automatic differentiation

Automatic differentiation (AD) is a set of techniques in which a numeric computer program can be differentiated algorithmically to machine precision without producing round-off and truncation errors [5]. AD is ubiquitous in many computational sciences, notably machine learning, but still underutilized in the area of computational dosimetry and computational electromagnetism in general. Thanks to the renaissance in the development of AD-powered libraries, authors in [6] showcase seamless implementation of AD in the assessment of the IPD with some illustrative examples. AD has been proven superior over numerical differentiation by means of the computation speed and accuracy.

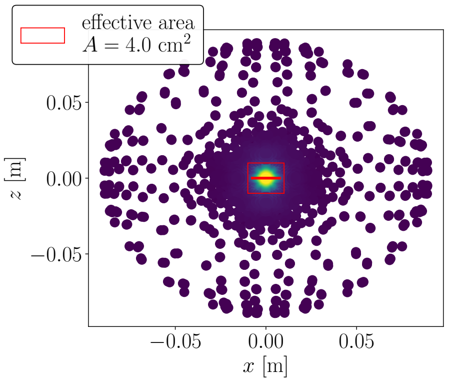
C. Realistic human models

Non-planar geometries, either spherical as in figs. 1a and 1b or realistic as in figs. 2a and 2b, require the use of a surface integration of vector field in order to obtain the solution of eq. (1). For spherical models, one can perform a Gaussian quadrature tailored to a specific geometry by converting the Cartesian representation of point cloud to spherical coordinates, demonstrated in fig. 1c. For realistic models, analytical

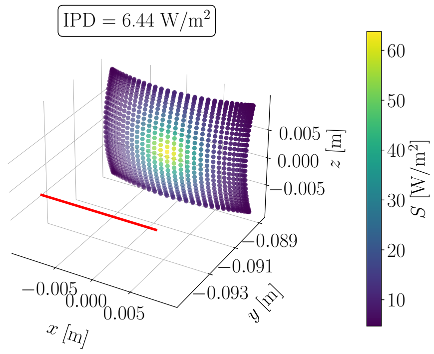
16th International Conference on Telecommunications - ConTEL 2021, PhD Forum
ISBN: 978-953-184-275-4, June 30 - July 2, 2021, Zagreb, Croatia



(a) 3-D point cloud defines the surface of the spherical model of human head.

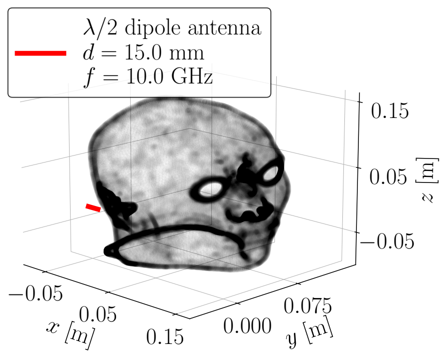


(b) 2-D point cloud in xz plane.

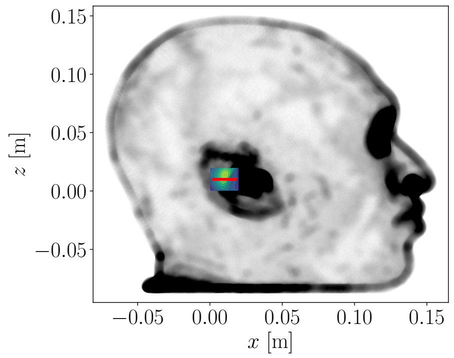


(c) Effective irradiated area of the surface, w.r.t. which the IPD is computed by using the Gaussian quadrature adapted to handle surface integrals.

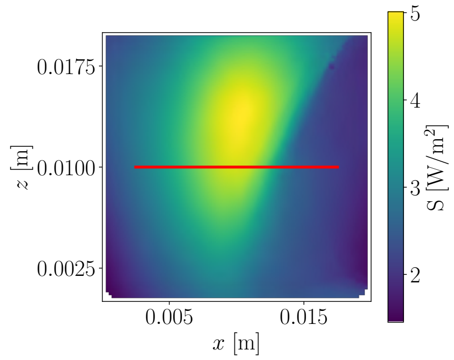
Fig. 1: Power density distribution over a 3-D spherical, homogeneous model of human head, which diametrically extends to 18 cm. Half-wave dipole, set to operating frequency of 10 GHz, is located at a distance of 5 mm from the averaging area.



(a) Geometry of the common exposure scenario while using a personal mobile device.



(b) 2-D view from the perspective of a personal mobile device.



(c) Effective irradiated area of the surface, w.r.t. which the IPD needs to be computed.

Fig. 2: Power density distribution over a 3-D realistic model of human head. Averaging area, A, equals to 4 cm^2, distance between the half-wave dipole and the averaging area, d, is 15 mm, and operating frequency of the dipole, f, is set to 10 GHz.

definition of the integral variable vector, $d\vec{s}$, is unfeasible. The parametrization of such averaging surfaces will have to be performed via physics-informed neural networks [7], where the y axis could be expressed as the functional of x and z axes, fig. 2c. This extends into future research work.

III. Concluding Remarks

This paper provides a concise overview of the research conducted to improve the computation speed and numerical accuracy of simulations of human exposure to radiated electromagnetic fields through the incident power density. Future work will deal with the numerical evaluation of the incident power density on extremely irregular surfaces, e.g., exposed regions of human head, where common quadrature techniques cannot be applied effectively.

References

[1] International Commission on Non-Ionizing Radiation Protection (ICNIRP), "Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz)," *Health Physics*, vol. 118, pp. 483–524, 2020.

[2] Y. Hashimoto, A. Hirata, R. Morimoto, S. Aonuma, I. Laakso, K. Jokela, and K. Foster, "On the averaging area for incident power density for human exposure limits at frequencies over 6 GHz," *Physics in Medicine and Biology*, vol. 62, no. 8, pp. 3124–3138, 2017.

[3] A. Hirata, S. Kodera, J. Gomez-Tames, and I. Laakso, "Human exposure to radiofrequency energy above 6 GHz: review of computational dosimetry studies," *Physics in Medicine & Biology*, vol. 66, no. 8, 2021.

[4] D. Poljak, *Advanced Modeling in Computational Electromagnetic Compatibility*. Wiley, 08 2006.

[5] A. G. Baydin, B. A. Pearlmutter, A. A. Radul, and J. M. Siskind, "Automatic differentiation in machine learning: a survey," *Journal of Machine Learning Research*, vol. 18, no. 153, pp. 1–43, 2018.

[6] A. L. Kapetanovic and D. Poljak, "Application of automatic differentiation in electromagnetic dosimetry – assessment of the absorbed power density in the mmWave frequency spectrum," *In review for 2021 6th International Conference on Smart and Sustainable Technologies (SpliTech)*, pp. 1–6, 2021.

[7] M. Raissi, P. Perdikaris, and G. Karniadakis, "Physics-informed neural networks: A deep learning framework for solving forward and inverse problems involving nonlinear partial differential equations," *Journal of Computational Physics*, vol. 378, pp. 686–707, 2019.

ConTEL 2021, PhD Forum, ISBN: 978-953-184-275-4

LPWAN for use in agriculture

Ana Pejković
J. J. Strossmayer University of Osijek
Faculty of Electrical Engineering, Computer Science and Information Technology, Osijek, Croatia
ana.pejkovic@ferit.hr

Josip Spišić
J. J. Strossmayer University of Osijek
Faculty of Electrical Engineering, Computer Science and Information Technology, Osijek, Croatia
josip.spisic@ferit.hr

Matko Zrnić
J. J. Strossmayer University of Osijek
Faculty of Electrical Engineering, Computer Science and Information Technology, Osijek, Croatia
matko.zrnic@ferit.hr

Abstract— ***Devices used for IoT in agriculture have specific requirements needed to function in remote areas. The devices will have their power source, so the network must be energy efficient, electricity consumption must be minimal. Long-range communication and low energy consumption are crucial for function, and LPWAN technologies are designed for that purpose. Leading technologies are analyzed individually, then compared considering agricultural applications. In this paper, we present our future work, IoT solutions in agriculture using LoRa technology.***

Keywords—LPWAN (Low Power Wide Area Network), LoRa, Sigfox, NB-IoT

I. Introduction

Given current smart systems for data collection and processing in agriculture, conventional wireless technology has a short range of high-energy systems for monitoring environmental parameters. LPWAN (Low Power Wide Area Network) is a name for high-range, low-power technologies. The specifics of LPWAN technologies are low energy consumption and long-range, from 10 to 40 km in open areas, while in urban areas, the range is from 1 to 5 km. For use in agriculture, long-range and low power is required. LPWAN is the only group of wireless technologies that can offer long-range and low power. In addition, a great advantage is the cost of use. These characteristics make LPWAN technologies the most practical for IoT in agriculture. There are many LPWAN technologies, and new ones are constantly emerging and existing ones are being improved, but currently, LoRa, Sigfox, and NB-IoT are leaders in the field. To allow communication to all users, the duty cycle is limited to 1%, so that each device can send data only 1% of the time. Exceptions are technologies like NB-IoT that use a licensed spectrum. LPWAN technologies have features suitable for wireless sensor networks that do not require frequent communication and data transmission over long distances and with high transmission speeds [1].

II. LPWAN technologies

A. LoRa

LoRa is a physical layer developed by Semtech Corporation. The second part is LoRaWAN, which are open specifications developed by the LoRa Alliance, determined by the Medium Access Control (MAC) and LoRa network layer. LoRa uses CSS (Chirp Spread Spectrum) modulation that enables two-way long-range communication with low power consumption. The data transfer rate and communication range can be adjusted by the Spreading Factor (SF). A higher expansion factor allows for a more extended range and reduces the data transfer rate with a higher risk of data loss as data transmission time increases. The CR rate factor (Code Rate), which can be 4/5, 4/6, 4/7, or 4/8, also affects the range and speed of data transfer by adjusting. The bandwidth is set to 125 kHz, 250 kHz, or 500 kHz.

Depending on the expansion factor, bandwidth, transmission power, encoding factor, and midrange, the speed is 0.3 to 50 kbit / s, while the maximum size of the message to be sent is 243 bits [2]. It is possible to use three modes of communication, where class A consumes the least energy and class C the most. Power consumption will depend on the time the device spends in a particular state and class. The device can send data, receiving data, and "sleep" mode where the device saves energy. The device enters sleep mode each time it finishes sending or receiving data to achieve maximum power efficiency. When receiving data, the device switches from standby to active mode, which significantly increases power consumption. The highest power consumption is when sending data, and this depends on how much power is used during transmission, where more power consumes more energy. Periods are spent in certain states depending on the class used for work. Class A operates so that the device is in sleep mode when there is no data exchange. Class B indicates the device's activity, and thus higher energy consumption, while class C work in such a way that the device is constantly working and listening to incoming messages while not sending data. So, although the device itself is designed for minimum power consumption, power consumption depends on the mode of operation. Using Class A with several daily data transfers means that the device will spend most of its time in sleep mode, thus achieving energy efficiency, with a standard battery having a lifespan of more than ten years [3].

B. Sigfox

Sigfox is the name for a company founded in France in 2009 and wireless LPWAN technology. It enables communication over long distances with low power consumption and low data transfer speed. It does not use licensed channels; it uses an ISM band ranging from 862 MHz to 928 MHz. In addition, it uses a 192 kHz UNB (Ultra Narrow Band) band. The modulation technique it uses is Binary Phase Shift Keying (BPSK), so end devices use a bandwidth of 100 Hz per message with a transmission speed of up to 600 bit / s depending on where the device is located. The very narrow bandwidth allows low noise levels, low power consumption, and high receiver sensitivity. The package to be sent contains 12 primary data so that the maximum quantity can be sent at one time. It is possible to transmit only 36 seconds and six messages within an hour, making 140 messages per day while only four messages per day can be received, which means that it can not receive a confirmation for each message sent. Globally, Sigfox is divided into seven geographical zones according to radio configuration. Operating rules are defined for each zone like operating frequency, power of transmitting, spectrum access, etc. Because of differences in rules, laws, and obstacles, Sigfox provides LQI (Link Quality Indicator), which points to the quality of connectivity. LQI is based on the sensitivity of receiver RSSI (Received Signal Strenght Indicator), many receiver nodes, and RC zones. For better QoS (Quality of Service), Sigfox uses the Cooperative Reception method. With these methods, the end device is not connected to just one gateway, but any gateway near the device can receive a message from the end device. To enable better QoS because multiple receivers can receive the same message, which is redundant, it is more likely to receive a message if one receiver is not the direct message [4].

C. NB-IoT

NB-IoT (Narrowband Internet of Things) belongs to the licensed cellular technology of low-power Wide- Area Network, LPWAN based on LTE (Long-Term Evolution). Bandwidth NB-IoT can coexist in the Global System for Mobile Communications (GSM). NB-IoT technology is made from pre-existing LTE functionality. It has many similar features to mobile networks, but belongs to LPWAN technologies because it consumes less energy than existing LTE technologies, has a more extensive range, and a large capacity of the device, which can be more than 52000 per channel. It can function in three different ways: Standalone operation; In-band operation, and Guard band operation. It can use one 200 kHz GSM channel in standalone mode, while bandwidth uses one or more Physical Resource Blocks (LB) from LTE, which is 180 kHz. To avoid interference, the NB-IoT must not send data in time and frequency as well as LTE. When in In-band operation mode, the NB-IoT is located along with the LTE band. In this way, the maximum transmission power is used, and interference is present only on one side located next to the LTE band [5].

III. COMPARISON AND APPLICATION

Differences between LoRa, Sigfox, and NB-IoT are not significant considering their general specifications like range, power consumption, latency, and bandwidth. Detailed specifications are shown in Table 1. NB-IoT developed from cellular technologies has advantages of already developed infrastructure. It can be easily deployed and used in locations within the range of cellular towers. The negative side of NB-IoT is use in highly remote and isolated areas where cellular towers are not in range. Sigfox uses an unlicenced ISM band just like LoRa and similarly to NB-IoT, it has its infrastructure. The advantage of Sigfox is longer range than LoRa or NB-IoT. Another significant aspect of Sigfox is the limited data packets that can be sent.With limited data packets, not only is the amount of data that can be sent limited but it also limits encryption data. A low-power and long-range system based on LoRa technology will be presented and applied in our future works. A temperature sensor and a soil moisture sensor will be used to collect information of moisture and temperature parameters. If there is a need for monitoring of other parameters, sensors will be added to detect carbon dioxide concentration, light intensity sensor etc. LoRa is a wide range wireless communication technology that allows energy savings, transparent transmission, and monitoring. The transferred data will be stored, processed, and displayed using the application. The system consists of an application layer, a network layer, and various sensors. Two types of sensors are used: a soil moisture sensor and a temperature sensor. The communication module used in the network layer is based on the LoRa protocol. The system will be set up and applied to the cornfield. The collected data will help the field manager more easily monitor environmental conditions in real-time and timely response to various climatic disasters.

TABLE 1. LPWAN COMPARISON

Technology	**LoRa**	**Sigfox**	**NB-IoT**
Range (km)	<20	<50	<10
Bandwidth	150/250/500 kHz	100 Hz	180 kHz
Frequency (MHz)	868	868	800/900/1800
Data rate	50 kbps	100 bps	200 kbps
Latency	10 ms	30 ms	10 s
Battery life (years)	>10	<10	>10

IV. CONCLUSION

LPWAN technologies fulfill all the requirements for IoT in agriculture unless there is a need for large data transfer or low latency. Data collected from sensors in the field can be transferred over a large distance in relatively real-time with low power consumption and low expenses. Low power consumption is practical considering that devices used for IoT in agriculture need to have their power supply. Long-range is required considering that devices for agriculture are located in remote and vast areas. LPWAN, LoRa, Sigfox, and NB-IoT provide all the necessary specifications for practical and efficient IoT in agriculture. Further research will be dedicated to testing and comparing these communication technologies and selecting the most suitable IoT in agriculture.

ACKNOWLEDGMENT

This work is supported by the project "IoT-field: An Ecosystem of Networked Devices and Services for IoT Solutions Applied in Agriculture," co-financed by the European Union from the European Regional Development Fund within the Operational program Competitiveness and Cohesion 2014-2020 of the Republic of Croatia.

REFERENCES

[1] K. Mekki, E. Bajic, F. Chapel, and F. Meyer, "A comparative study of LPWAN technologies for large-scale IoT deployment," ICT Express, vol. 5, no. 1, pp. 1–7, Mar. 2019, DOI: 10.1016/j.icte.2017.12.005.

[2] H. C. Lee and K. H. Ke, "Monitoring of Large-Area IoT Sensors Using a LoRa Wireless Mesh Network System: Design and Evaluation," IEEE Trans. Instrum. Meas., vol. 67, no. 9, pp. 2177–2187, 2018, DOI: 10.1109/TIM.2018.2814082.

[3] O. Khutsoane, B. Isong, and A. M. Abu-Mahfouz, "IoT devices and applications based on LoRa/LoRaWAN," in IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society, Beijing, Oct. 2017, pp. 6107–6112, DOI: 10.1109/IECON.2017.8217061.

[4] M. I. Nashiruddin and A. Yusri, "SigFox Network Planning for Smart Metering Based on Internet of Things for Dense Urban Scenario," 2020 8th Int. Conf. Inf. Commun. Technol. ICoICT 2020, 2020, DOI: 10.1109/ICoICT49345.2020.9166398.

[5] R. Nicole A. Adhikary, X. Lin, and Y.-P. E. Wang, "Performance Evaluation of NB-IoT Coverage," in 2016 IEEE 84th Vehicular Technology Conference (VTC-Fall), Montreal, QC, Canada, Sep. 2016, pp. 1–5, DOI: 10.1109/VTCFall.2016.7881160.

Human Exposure to Electromagnetic Radiation of HF Wireless Power Transmitter: Analytical and Numerical Results

[1]Petra Rašić, [2]Zoran Blažević
University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture
Split, Croatia
[1]prasic@fesb.hr, [2]zblaz@fesb.hr

***Abstract* — In this paper, human body exposure to high frequency (HF) electromagnetic field is analyzed. Antennas and wireless power transfer (WPT) systems are analytically and numerically modelled in free space. The analysis is carried out for simplified cylinder model of human body exposed to HF radiation in terms of induced electrical field and current density at frequency of 13.56 MHz. The results obtained analytically are validated by numerical simulations in commercial software FEKO, based on Method of Moments (MoM). It is shown that there is no significant difference in current density and induced electrical field while using different approaches (analytical and numerical) which is excellent for theoretical calculations limited on simplified models so both approaches can be used for human body exposure estimation in defined scenarios.**

Keywords—human exposure; analytical approach; current density; specific absorption rate

I. INTRODUCTION

As wireless power transfer (WPT) includes a radio frequency (RF) transmitter that sometimes can be settled near a living being, this paper investigates a possibility to derive some simple closed-form analytical formula for human model exposure estimation and analysis. For that purpose, as a first step, a simplified approximation of a human body by an equivalent cylinder is applied. Many dosimetry studies have been performed to evaluate the exposure levels with respect to the basic restrictions [1-6]. The purpose of this paper is to address the analytical modelling approach for evaluation of antenna influence on wire structure representation human body model and show how it can be used in defined scenarios. The frequency domain formulation is based on the integro differential equation of the Pocklington type. This paper presents an electromagnetic wireless power transmitter environment consisting of the human, modelled as cylinder, and antenna transmitting on the frequency of f = 13.56 MHz. The results were compared with international protection standards.

The paper is organized as follows: Section 2 provides analytical description of WPT system; numerical modelling is given in Section 3; results are given Section 4; the conclusion is given in Section 5.

II. ANALYTICAL FORMULATION

The geometry of interest is related to human body model represented as thin wire structure at defined frequency. It is assumed that human is barefoot placed in free space with arms are in close contact with the human body. Equivalent model assumption means that the height L and width a of the model equals to the height and width of the average human.

A. ELECTRIC FIELD

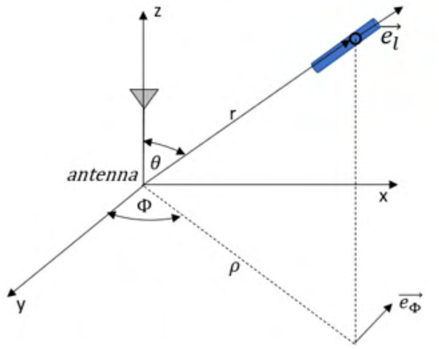


Fig. 1. Near field modeling with TE10 mode.

Electric field TE10 mode (shown in Fig. 1) can be formulated as [7]:

$$\vec{\boldsymbol{E}} = -j\beta\sqrt{\frac{3PZ_0}{4\pi}}\left[\frac{1}{j\beta r}+\frac{1}{(j\beta r)^2}\right] sin\theta e^{-j\beta r}\overrightarrow{e_\phi} \quad (1)$$

where Z_0 is impedance of free space, θ is polar wave angle, $\beta = 2\pi/\lambda$ is phase constant and P is radiated power:

$$P = \eta_{rad} P_G \quad (2)$$

η_{rad} is antenna efficiency and P_G is the power supplied to the transmitter antenna by the matched generator at its input.

B. CURRENT DENSITY

Pocklington equation in differential form is given by:

$$\frac{d^2I(z)}{dz^2} + k^2 I(z) = f(z) \quad (3)$$

where:

$$k = \sqrt{\frac{\mu\varepsilon}{2\pi}} \quad (4)$$

and:

$$f(z) = -j\omega\frac{2\pi\varepsilon}{\ln\frac{2h}{a}} E_Z(z,a) \quad (5)$$

where $h = L/2$. Differential equation of second order can be solved using method of variation constants with using the boundary condition on end of wire $I(h) = I(-h) = 0$. Using Eqs. 3-5 and after performing some mathematical manipulations solution of Pocklington equation is given as:

$$I(z) = 4\pi\frac{E_z}{j\omega\mu\ln\frac{2h}{a}}\left[1-\frac{coskz}{coskL}\right] \quad (6)$$

III. NUMERICAL FORMULATION

Electromagnetic modelling of WPT system is carried out using commercial software FEKO (Method of Moments-MoM for wire antenna) whereas surface equivalent principle (SEP) is applied for homogeneous dielectric bodies of simplified shape. The WPT system uses perfectly electrically conducting (PEC) small loop antenna with radius of 2.5 cm at f = 13.56 MHz shown in Fig. 2a. Free space characteristics of antenna are shown in Table I. Transmitter input power is set on 5 W (where no mismatch at the input is assumed). The human is modelled as cylinder in vertical position with length L = 1.8 m and radius a = 0.2 m with corresponding electrical characteristics of the tissue [8]. Transmitter antenna is set in front of human model at height of 1.2 m, as shown in Fig.2b, which is the worst-case scenario assumption similar to [9]. The values of d_{p1} and d_{p2} equal to the gap between the cylinder and the loop antenna.

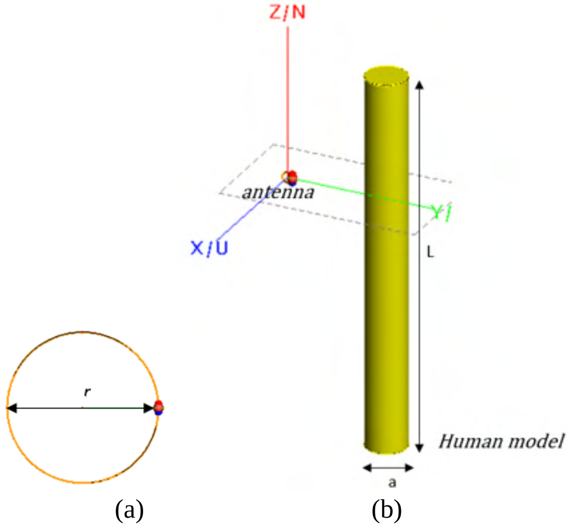


Fig.2. (a) Geometry of antenna,
(b) simplified cylinder human body model standing in free space and transmitter antenna.

TABLE I. Free space characteristics of the simulated antenna

Frequency f (Hz)	R_{in} (Ω)	η_{rad} (%)
13.56M	1.1146E-04	0.5311

IV. DISCUSSION OF RESULTS

The total electric field E and current density J are analyzed analytically (using Eqs. 1-2 and Eqs. 3-6, respectively) and numerically (in FEKO). The values of electric field E are taken are taken in 181 points along the human body model. The results for total electric field E are given at Fig. 3 and for current density J in Table II for gaps d_{p1} = 40 cm and d_{p2} = 20 cm. Observing the obtained results for total electric field distribution, it is evident that all curves have the same behavior. Also, analytical results are slightly lower in amplitude because of limitations of analytical models. The maximum electric field E and current density values J are obtained at 1.2 m model height because the position of transmitter antenna and voltage source. Peak value of the current density obtained by simulations and calculations are below the prescribed recommendations for general (P) and professional population (W), as shown in Table II.

TABLE II. Comparison of the current density J top value with basic INCIRP and Croatian recommendations

Current density (J) calculated top value [A/m²]					**Basic INCIRP recommendations J [A/m²]**	
***f* (Hz)**	**FEKO**		**ANALYTIC**		**P**	**W**
	d_{p1}	d_{p2}	d_{p1}	d_{p2}		
13.56 M	4.55	9.43	3.93	8.35	**10**	**50**

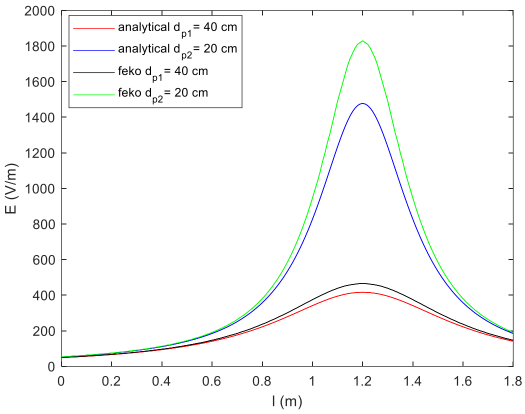


Fig.3: Total electric field E distribution along the cylinder human body model (in FEKO simulated at defined distance without human body model).

V. CONCLUSION

A simplified model for the assessment of human exposure to HF electromagnetic field, based on the human equivalent antenna representation of the body is presented in this work, numerically (by FEKO) and analytically (using Pocklington integro differential equation with excitation function in the form of the incident field). The current density and electric field are calculated analytically and numerically. The method presented in this work can provide rapid estimation of the phenomena and the obtained results can be of practical use in an engineering sense. Therefore, the main feature of the method presented so far is related to the simplicity and efficiency.

REFERENCES

[1] Ilkka Laakso; Takuya Shimamoto; Akimasa Hirata; Mauro Feliziani, "Applicability of quasistatic approximation for exposure assessment of wireless power transfer", 2014 International Symposium on Electromagnetic Compatibility, Tokio
[2] Akimasa Hirata; Shogo Tsuchida; Ilkka Laakso, „Variability of SAR in different human models due to wireless power transfer with magnetic resonance",2013 International Symposium on Electromagnetic Compatibility.
[3] Akimasa Hirata; Tetsu Sunohara; Ilkka Laakso; Teruo Onishi, „SAR in a simplified human model due to wireless power transfer with induction coupling", 2013 7th European Conference on Ant. and Prop. (EuCAP).
[4] A. Christ, M. Douglas, J. Nadakuduti, N. Kuster, "Assessing Human Exposure to Electromagnetic Fields From Wireless Power Transmission Systems", Proc. of the IEEE, vol. 101, no. 6, pp. 1482-1493, 2013.
[5] M. Koohestani; M. Ettorre; M. Zhadobov, „Wireless power transfer: Are children more exposed than adults?", 2017 11th European Conference on Antennas and Propagation (EUCAP).
[6] Tetsu Ilkka Laakso; Akimasa Hirata; Teruo Onishi: „Induced field and SAR in human body model due to wireless powertransfer system with induction coupling", 2014 International Symposium on Electromagnetic Compatibility, Tokyo.
[7] Lee J. and S. Nam, "Fundamental aspects of near-field coupling small antennas for wireless power transfer", IEEE Trans. Antennas Propag., Vol. 58, No. 12, 3442-3449, 2010.
[8] IT'IS Database, from Internet: http://www.itis.ethz.ch/virtual-population/tissue-properties/database/dielectric-properties.
[9] ICNIRP, "Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz)," Health Phys., Vol. 74, 494–522, 1998.

Hybrid hardware/software datapath for near real-time reconfigurable high-speed packet filtering

Denis Salopek, Miljenko Mikuc
University of Zagreb, Faculty of Electrical Engineering and Computing
Zagreb, Croatia
denis.salopek@fer.hr, miljenko.mikuc@fer.hr

***Abstract*—With the growth of the Internet and the rapid increase in network speeds, the need for high-performance, high-throughput network devices is simultaneously increasing. In order to provide the required services and function properly, these devices must process network traffic at high speeds, reaching tens or even hundreds of millions of packets per second. The lack of flexible and accessible high-throughput network devices that can handle these requirements becomes a problem, especially for packet filtering. The goal of this research is to combine both hardware and software technologies and use the best of them in a hardware/software hybrid to develop a network datapath for high-throughput packet filtering.**

***Index Terms*—high-speed networking, hardware/software hybrid, packet classification, packet filtering**

I. Introduction

Many devices used in the Internet need to keep up with the increasing throughput speeds and traffic volume, for example: routers, firewalls, load-balancers, and other function-specific appliances that find their use in various high-traffic environments (e.g., data centers, ISPs, etc.). In order to perform any type of traffic processing, it is necessary to inspect each packet individually. This can make the task difficult or even impossible if a device is deployed in an environment for which it was not created.

The inability to process large amounts of traffic can lead to undesirable consequences: packet loss or even complete failure of the device, depriving users of the services offered. This can happen for two main reasons: an immense number of regular users have tried to access the server but the server has not been able to withstand it, or some bad actors have tried to send a very large amount of traffic to the server to deny service to regular users. The latter is called Denial of Service (DoS). When there are multiple bad actors, it is defined as a Distributed DoS (DDoS) attack.

According to Cisco [1], the number of DDoS attacks is increasing and will reach about 15 million per year in 2023. There are different types of DDoS attacks as noted in this taxonomy [2], and one of the most difficult to handle are volume-based attacks. It is impossible to combat the sheer volume of traffic without distinguishing the "bad" packets from the "good" ones and filtering them out before they reach the service. This is especially problematic when dealing with very high traffic speeds (10 Gbps and above).

Currently, the most common methods to protect the service from such large-scale DDoS attacks are to either delegate the traffic to third-party providers that scrub and return traffic using a technique called "scrubbing", or use hardware-based filters in special appliances at the edge of their network. There are certain industries (e.g., in financial sector) that must adhere to rules and regulations related to privacy and data confidentiality, so any option that requires traffic to be sent to a third party introduces potential misuse of confidential information and therefore security and privacy risks. The only way to avoid this is to use on-premise appliances.

II. Methodology

There is an abundance of existing hardware and software solutions that promise both high throughput and high performance, but at the cost of drawbacks on both fronts. Hardware solutions can be expensive, difficult to upgrade and modify, and suffer from limited space and high power consumption due to Ternary Content-Addressable Memory (TCAM) — a technology often used in these kinds of solutions.

Software solutions could until recently withstand large traffic and even the strongest attacks only with firewalls in general-purpose operating systems [3]. With the 100 Gbps network cards becoming a commodity, this is no longer the case, as these firewalls cannot keep up with today's packet processing speed requirements. Even with the recent development of high-performance and flexible packet processing software frameworks, it still does not provide sufficient speed for more complex packet processing, such as one based on longest prefix matching (LPM).

An alternative to both hardware and software solutions is something that takes the best of both worlds and combines it as a hardware/software hybrid. This combination can provide a cheap, flexible solution that is easy to update and maintain, but still fast enough to handle a large number of packets passing through it, using the speed of hardware devices and the flexibility of software solutions. There are three common ways to combine hardware and software: by using FPGA technology [4] [5], graphic processing units (GPU) [6], or by using smart network interface controllers (smart NIC) [7].

III. Implementation

This research attempts to find the sweet spot for the hybrid filter by analyzing both the software and hardware sides and empirically determining the optimal way to divide the workload between them. The model of this system is shown in Fig. 1.

The main challenge is to maximize the offload to hardware depending on the hardware/software specifications and requirements while minimizing the overhead of communication between these two components. This is achieved by a workload distributor, which should be configured to parse the user-defined ruleset and configurations, and divide the workload for hardware and software. At the same time, it

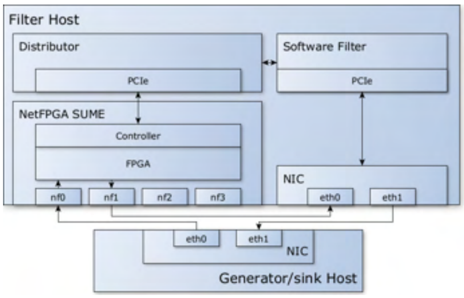


Fig. 1. Hybrid packet classification model and testbed setup: the hardware part (NetFPGA) is acting as a pre-filter for the more complex software filter. The protoype implements the transmission of packets over network interfaces and communication between the two with metadata attached to the packets. The currently used hardware has limited transmission rates, so the alternative configuration (transmitting packets over PCIe) is not suitable. The distributor communicates with the hardware controller via PCIe and with the software filter via CPU and on-board memory.

should communicate with both and modify any required parameters within the systems in near real-time.

The hardware part of the filter is implemented using NetFPGA [8], to simplify software filtering by dynamically offloading certain rules, parts of rules or needed computations, especially those that can benefit from parallelism — one of the advantages of FPGA.

Some classification systems filter packets individually: by matching source/destination IP addresses and ports, and by matching other specific patterns in packets. The research of [7] has shown performance increase of a hybrid system compared with software-only firewall: from 2 Mpps to 35 Mpps for a simulated DDoS attack of 1000 different IPv4 addresses. Even though the increase was due to powerful hardware, this system still depends on TCAM to offload rules to hardware memory, limiting the number of filtered IP addresses to nowhere near the number of large DDoS attacks, while decreasing performance with every added IP address.

However, filtering volumetric DDoS attacks can be done more effectively by whitelisting or blacklisting specific source/destination IPv4 addresses. For appliances on larger networks, maintaining relatively large databases of whitelisted or blacklisted IP addresses/ranges and searching them would yield better results than filtering a specific IP address on a per-rule basis. This type of search would need to use LPM, and part of this research would be exploring how can it be used as the basis for such a hybrid system.

The developed software part of the filter is suitable for LPM classification, which provides fast packet filtering for millions of entries (IP addresses).

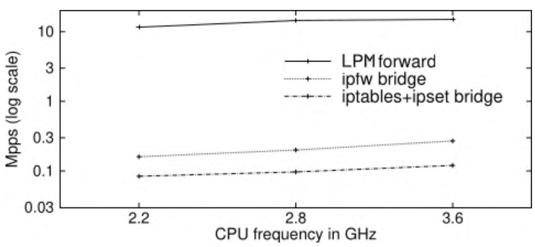


Fig. 2. Software firewalls vs LPM packet processing: a large performance gap between standard firewalls (ipfw and iptables+ipset bridge) and a filter utilizing LPM (LPM forward).

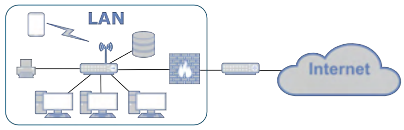


Fig. 3. On-premise DDoS filter on the edge of a LAN: when placed between an insecure network (such as Internet) and LAN, it would protect the LAN by dropping any suspicious packets before reaching their victim.

Since this is a software filter, it disregards some of the drawbacks of hardware filters: most notably, the lack of memory, which allows packet classification for high-throughput networks and defense against even some of the largest DDoS attacks. The initial results of this software filter for 10 Gbps traffic and around 300,000 filtered IPv4 addresses/prefixes can be seen in Fig. 2.

The testbed for this model shown in Fig. 1 uses synthetic traffic generated with another host and the sink to confirm that the correct packets are discarded/forwarded with the filter. Hybrid filter location in the network for a realistic case is shown in Fig. 3.

IV. Conclusion

In this paper, an idea for a hybrid filtering system has been presented that would improve the current state of hardware, software and hybrid packet filtering systems combining software LPM and reconfigurable FPGA filtering.

The goal of this research is to take advantage of both software and hardware filtering methods while minimizing the impact of their disadvantages, as well as improve their performance by including a separate distributor that splits the workload depending on the analysis previously performed.

The research will continue by completing the hardware part of the implementation as well as the distributor.

Acknowledgment

This work has been supported by Croatian Science Foundation under the project IP-2019-04-1986 (IoT4us: Human-centric smart services in interoperable and decentralized IoT environments).

References

[1] https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11–741490.html
[2] Mirkovic, J., Reiher, P., “A taxonomy of ddos attack and ddos defense mechanisms”, ACM SIGCOMM Computer Communication Review, Vol. 34, No. 2, 2004
[3] Šimon, M., Huraj, L., Černansky, M., “Performance evaluations of iptables firewall solutions under ddos attacks”, Journal of Applied Mathematics, Statistics and Informatics, Vol. 11, No. 2, 2015
[4] Li, B., Tan, K., Luo, L., Peng, Y., Luo, R., Xu, N., Xiong, Y., Cheng, P., Chen, E., “Clicknp: Highly flexible and high performance network processing with reconfigurable hardware”, in Proceedings of the 2016 ACM SIGCOMM Conference, 2016
[5] Fiessler, A., Lorenz, C., Hager, S., Scheuermann, B., Moore, A. W., “Hypafilter+: enhanced hybrid packet filtering using hardware assisted classification and header spaceanalysis” IEEE/ACM Transactions on Networking, Vol. 25, No. 6, 2017
[6] Go, Y., Jamshed, M. A., Moon, Y., Hwang, C., Park, K., “Apunet: Revitalizing GPU as packet processing accelerator”, in 14th USENIX Symposium on Networked Systems Design and Implementation (NSDI 17), 2017
[7] Miano, S., Doriguzzi-Corin, R., Risso, F., Siracusa, D., Sommese, R., CREATE-NET, F. B. K., “High-performance server-based ddos mitigation through programmable data planes”, 2019
[8] Zilberman, N., Audzevich, Y., Covington, G. A., Moore, A. W., “Netfpga sume: Toward research commodity 100gb/s”, 2014

Quality of Experience Evaluation of Remote Reality Based Applications: Case of FPV Drone Piloting

Matko Šilić, Mirko Sužnjević, and Lea Skorin-Kapov
University of Zagreb, Faculty of Electrical Engineering and Computing, Zagreb, Croatia
{matko.silic, mirko.suznjevic, lea.skorin-kapov}@fer.hr

***Abstract*—With the development of better network infrastructure and a new generation of wireless networks, the technology of telepresence and remote reality is becoming more prominent. Applications of this kind of technology include remote control of vehicles, remote inspections, telemedicine, assisted/directed/supervised autonomy, etc. In order to provide the highest possible end-user quality of experience for this kind of system, it is necessary to evaluate the quality through subjective studies and build the system according to the results. This research aims to evaluate the quality of experience in the case of an FPV drone piloting system. The QoE evaluation will be used to develop an optimization algorithm that will, using a specific QoE model, dynamically adjust video encoder parameters considering the network state. This paper provides an insight into concepts and technologies in this research, followed by an overview of the results of completed studies and plans for future work.**

***Index Terms*—Quality of Experience, Unmanned Aerial Vehicles, FPV, Cloud Gaming, Video Streaming, Remote Reality**

I. Introduction

Remote Reality (RR) is a form of telepresence technology that, through the appropriate network infrastructure, enables an immersive experience of a remote real environment in real-time with latency low enough to enable an interactive experience in very dynamic scenarios. The specific RR technology we are focusing on in this research is immersive first-person view (FPV) drone piloting. FPV is a method of controlling a radio-controlled (RC) vehicle from the driver's or pilot's viewpoint. As drones equipped with cameras have become increasingly popular among consumers, technologies enabling FPV control have gained broader interest. FPV offers an immersive flight experience by allowing the user to control a drone using a live video feed, whereby the video signal is transmitted from the drone's camera to a head-mounted display (HMD), i.e., FPV goggles.

One of this technology's critical requirements is to enable high-speed video signal transmission from the transmitting side to the receiving side. Video signal latency is very important in all remote-controlled [1], or autonomous vehicles [2] due to the basic functionality and ability of safe control of such systems. Due to these strict latency requirements, FPV technology stagnated, with analog video transmission currently representing the most common implementation. Our research is directed towards developing a system based exclusively on digital technology, i.e., the digital video signal is encoded on the transmitting side in a suitable format for network transmission to the receiving side via IP-based wireless networks. Introducing digital transmission technology and wireless networks (e.g., 4G, 5G) would enable higher quality video and support a much greater range than analog transmission.

Given variable network conditions commonly observed in wireless and mobile networks (e.g., bandwidth availability, delay, packet loss, etc.), there is a need for algorithms that dynamically adjust the video encoder parameters to the network state. Because of the specific characteristics corresponding to real-time remote vehicle control, which differentiate such use cases from a general-purpose remote control, there is a need for the development of specific Quality of Experience (QoE) models [3]. Authors in [4] define the concept of Quality of Experience as: "*the degree of delight or annoyance of a person whose experiencing involves an application, service, or system. It results from the person's evaluation of the fulfillment of his or her expectations and needs with respect to the utility and/or enjoyment in the light of the person's context, personality and current state*."

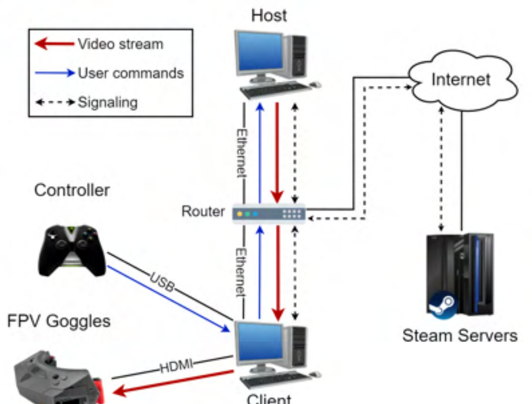


Fig. 1. Laboratory setup

II. Methodology

A. Challenges

In order to develop an optimization algorithm based on a QoE model, there is a need to conduct a series of subjective user studies. Getting meaningful results requires a review of related literature to identify relevant case studies for testing. User studies are planned to be conducted using two laboratory setups: a virtual prototype, i.e., a drone flight simulator, and piloting a real drone in controlled network conditions. The

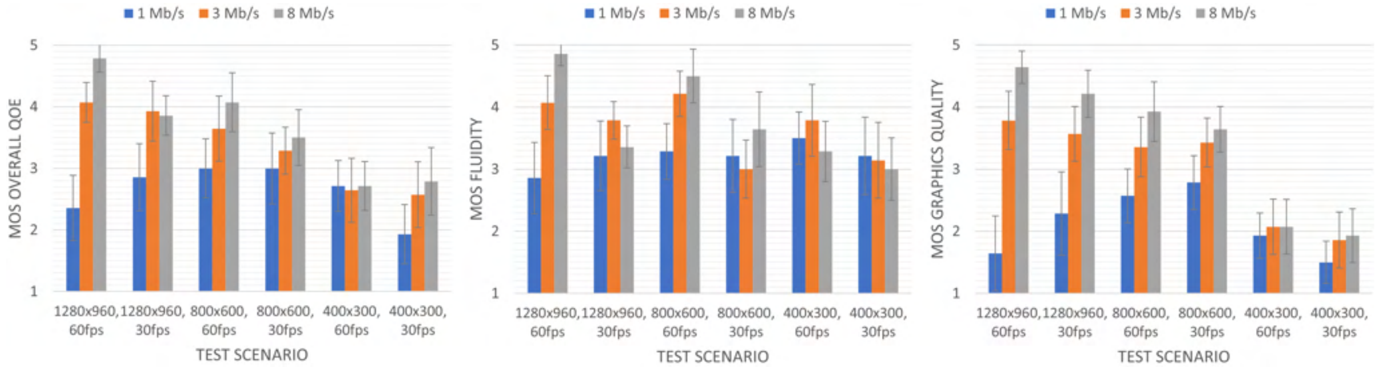


Fig. 2. Subjective ratings of overall QoE, fluidity, and graphics quality, respectively (95% CI shown).

goal of subjective tests is to determine the influence of the video encoding parameters and the network on the objective and subjective characteristics of video transmission. A good definition of the methodology is crucial for prototype design but also for conducting the testing. As video encoders are very complex systems with a large number of parameters, in practice, it is impossible to examine the impact of each parameter through user studies, and it is necessary to dimension the space of influential parameters and measured characteristics qualitatively. In addition, it is necessary to define the levels of experience of the respondents and their possible impact on the results of user studies.

B. Preliminary study

We conducted our first study using a drone flight simulator in a laboratory setup (Fig. 1), which simulated remote drone control utilizing cloud gaming technology with the addition of FPV goggles as an output display. In this study, we focus solely on manipulating the video encoding parameters of the video stream to observe their impact on QoE. Based on related work [5], we manipulate resolution, frame rate, and bitrate.

The study procedure was realized as follows: at the beginning of the test, participants were first familiarized with the procedure, presented with the simulator and the controller, and then given a 10-minute window to familiarize themselves with the flight simulator controls. After that, the participants were asked to put on the FPV goggles and begin with scenario testing. Video encoder parameters were manipulated as follows: resolution between 3 levels (1280x960 px, 800x600 px, and 400x300 px), frame rate (frames per second, fps) between 2 levels (60 and 30 fps), and bitrate between 3 levels (8 Mbps, 3 Mbps, and 1 Mbps). When combined, this resulted in a total of 18 scenarios, each lasting 90 seconds. After finishing each test scenario, the participants were instructed to report *overall QoE*, *perceived fluidity of the virtual world*, and *perceived graphics quality*, on a standard 5 point Absolute Category Rating (ACR) scale [6]. Upon finishing the testing, the participants took off the goggles and were instructed to fill out a Simulator Sickness Questionnaire (SSQ), specified according to Balk et al. [7]. The quality MOS scores are given in Fig. 2.

III. Results and Conclusions

Results indicate a significant impact of video encoding parameters on perceived QoE. Additionally, we collected user reports on their willingness to continue using the drone simulator for each test scenario. Data showed a significant drop-off of willing users in test cases where the MOS for overall QoE was below 3.5. Furthermore, we gathered user reports on simulator sickness symptoms manifested during the use of the FPV drone simulator. Simulator sickness is a key issue in FPV systems, as symptoms may cause degradation in QoE and affect user study outcomes.

IV. Future Plans

In our ongoing and future work, we plan to study the impact of latency and packet loss before continuing with tests involving the piloting of real drones via wireless networks. Additionally, we intend to upgrade the simulator used for testing by adding better controls and more engaging tasks. We also aim to investigate frame rate levels below 30 fps for optimization, as well as the manipulation of additional video encoding parameters for very low bandwidth levels. Finally, in addition to conducting a more extensive scale user study, we plan to consider human factors and involve highly experienced participants in piloting aerial vehicles.

References

[1] K. Brunnström, E. Dima, T. Qureshi, M. Johanson, M. Andersson, and M. Sjöström, "Latency Impact on Quality of Experience in a Virtual Reality Simulator for Remote Control of Machines," *Signal Processing: Image Communication*, vol. 89, p. 116005, 2020.

[2] H. Ji, S. Park, J. Yeo, Y. Kim, J. Lee, and B. Shim, "Introduction to Ultra Reliable and Low Latency Communications in 5G," *arXiv preprint arXiv:1704.05565*, 2017.

[3] J. Nightingale, P. Salva-Garcia, J. M. A. Calero, and Q. Wang, "5G-QoE: QoE modelling for ultra-HD video streaming in 5G networks," *IEEE Transactions on Broadcasting*, vol. 64, no. 2, pp. 621–634, 2018.

[4] S. Möller and A. Raake, *Quality of experience: advanced concepts, applications and methods*. Springer, 2014.

[5] I. Slivar, L. Skorin-Kapov, and M. Suznjevic, "Cloud gaming qoe models for deriving video encoding adaptation strategies," in *Proceedings of the 7th MMSys'16*, 2016, pp. 1–12.

[6] I.-T. Recom., "P.910: Subjective video quality assessment methods for multimedia applications," *International telecommunication union*, 1999.

[7] S. A. Balk, M. A. Bertola, and V. W. Inman, "Simulator sickness questionnaire: Twenty years later," 2013.

Narration Accessibility Feature - a Screen Reader Simulator for Unity Applications

Iva Topolovac, Matea Žilak, Željka Car
University of Zagreb, Faculty of Electrical Engineering and Computing
10000 Zagreb, Croatia
e-mail: iva.topolovac@fer.hr, matea.zilak@fer.hr, zeljka.car@fer.hr

***Abstract*—Nowadays, visually impaired persons use digital devices thanks to accessibility options such as high contrast and zoom tools, as well as screen readers that should work with every application on every platform. Screen readers allow users to use different applications using the same interactions, making navigation easier even in newly installed applications. However, applications developed using certain development platforms such as Unity are not compatible with screen readers, leaving visually impaired users without their main navigation tool. This was the motivation for developing an innovative accessibility feature, a screen reader simulator, for applications developed in Unity that do not have screen reader support by default. The developed accessibility feature - Narration is compatible with desktop and mobile platforms.**

***Index Terms*—serious games, people with disabilities, social inclusion, screen reader, accessibility, Unity**

I. Introduction

Accessibility is a measure of how well products, services and the environment meet the needs of all users, regardless of age or ability. Accessibility is becoming an increasingly relevant issue that is evident from the various Web accessibility regulations around the world [1]. Although there is a legal requirement for some websites and applications to be accessible for mobile devices, and there are WCAG guidelines [2] that can help designers and developers achieve this, there is still a lot of room for improvement. To achieve full accessibility, compatibility with assistive technologies must be ensured, which is extremely important for some users. For example, a screen reader is an assistive technology whose compatibility with smartphones and computers is essential for visually impaired and blind individuals to perceive digital information. Although screen readers are a technology that has long been integrated into most widely used operating systems (e.g., Android, iOS), their compatibility with game engines such as Unity has not yet been fully achieved. More specifically, an enabled screen reader on a device may cause a game developed in Unity to be non-interactive (e.g., buttons cannot be pressed in the startup scene).

Although Unity does not render user interface elements in a way that works with external screen readers, there is a plugin available at Unity Asset Store entitled UI Accessibility Plugin (UAP), that provides screen reader support for Unity apps [3]. Even though the UAP plugin has been used in [4], there are some drawbacks to using it. First, until recently (April 2021), it was not free. The plugin is rated by only a few users according to which support is either not provided or is extremely delayed. Additionally, the plugin shows issues in compatibility with new iOS versions, it is yet to be tested with newer Android versions. This presents a challenge of interfacing with accessibility APIs at the OS level as OS updates are being released monthly. There is an example of enabling Unity apps to communicate with the native accessibility services in Android and iOS but it is still a work in progress [5]. Finally, for Croatian speaking users there is no localised TTS system and the UAP plugin offers compatibility only with the operating system's screen reader which has no support for Croatian language.

To overcome these challenges, an innovative feature for accessible serious games that simulates a screen reader for applications developed in Unity was implemented. Since there is no free speech synthesizer for Croatian language, custom recordings were implemented in this accessibility feature. This feature was implemented in a serious game for raising awareness about the importance of proper interactions with people with different types of disabilities [6]. This work is part of the PhD research on accessibility and emerging technologies, as well as the R&D project on technology enabled digital inclusion.

II. Narration: a Screen Reader Simulator

The *Narration feature* was implemented in the serious game called The Encounter[1] to enable the visually impaired users to use the application even though it was made with Unity.

A. Implementation process

The implemented narration feature works on desktop (web version) and on Android and iOS devices. Narration is implemented to work with interactions screen reader users are familiar with, a single click/tap for moving to the next UI element (which is also read aloud) and a double click/tap to select the current element. All other interactions with the application are disabled when the narration is turned on. The detection of single and double clicks, as well as handling actions upon UI item selection, is done with a script. The script contains recordings, each of which plays in a cycle (for single clicks/taps) until a selectable UI element - a button - is selected with a double click/tap. Selecting a button with a

[1] http://www.ict-aac.hr/index.php/hr/ict-aac-razvijene-aplikacije/web-aplikacije/ict-aac-susretnica-web

double click/tap while narration is on will result in the same actions as clicking the button while narration is off. The list of recordings is customizable and should be used so that each recording represents a single UI element.

B. Use case: The Encounter application

Implementing narration would solve a few challenges listed in the following text. The main challenge was to allow visually impaired users to turn on the feature when they first launch the application, and to allow other users to continue using the application without having to turn it on. This challenge was solved by having instructions on how to use narration read aloud upon the first launch. Upon the first launch the user can either do a long press to use the application with narration, or a single click/tap to continue without narration. The narration can be turned on or off later in the application's settings as well. Another challenge was to signal the user to initiate the reading cycle i.e., start the first recording with a single click/tap when a new scene is loaded. As the signal, each time a user opens a new scene, the text *new scene* is read aloud. Moreover, some UI elements are selectable, while others are not. This is also important for visually impaired users, which is why the signal *button* was recorded and put at the beginning of all recordings that are mapped to selectable UI elements. A general diagram showing the narration flow is presented in Fig. 1.

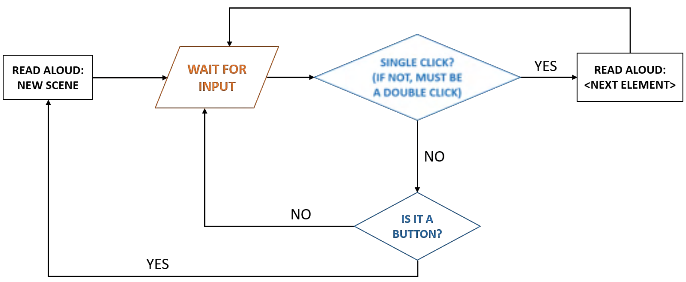
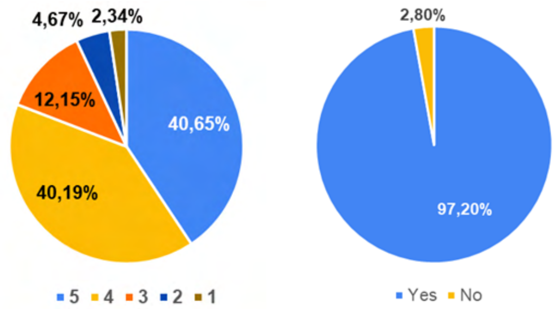


Fig. 1. High level narration flow diagram

III. User evaluation results

The first iteration of the user evaluation included 192 students, while the second iteration included 22 students from the University of Zagreb, Faculty of Electrical Engineering and Computing. In both iterations, students were asked to test the built-in screen reader on their mobile devices (*VoiceOver* or *TalkBack*) to familiarise themselves with the possible interactions when using a screen reader before testing the narration in the Encounter application. Some of the evaluation results from both iterations (214 respondents) are presented next.

Distribution of ratings for questions related to the narration intuitiveness and the reading order is presented in Fig. 2. Most participants (around 81%) rated the narration intuitiveness with 4 or 5 out of 5 rating (a). Next, regarding the reading order of elements in a particular scene, a significant percentage of participants (97.2%) responded that the order was intuitive, indicating that they were able to navigate the application without difficulty and that the narration feature was consistent across different scenes (b).



(a) Ratings distribution for narration intuitiveness

(b) Ratings distribution for element reading order intuitiveness

Fig. 2. Pie charts showing the evaluation results

The application was also tested with an experienced screen reader user who is blind. After testing the application, an evaluation interview was conducted with the blind participant. Here are some of the answers and additional suggestions for improvement: the instructions for using the narration read aloud when the application is first started are brief and clear; there were no problems activating the narration (the interaction for doing so is appropriate); allow movement within the application in the opposite direction; add an exit button to all game scenes.

IV. Conclusion

The solution described in this paper can be implemented in any other application developed with Unity that includes a user interface (even 3D and augmented reality applications). The described flow of the narration, although similar to existing screen readers' flow, is an innovative feature that is unique for Croatia, especially since there are no official free text-to-speech tools for Croatian visually impaired users. As narration was tested with over two hundred students who already had experience with screen readers and who rated it as a very intuitive feature, as well as with a blind screen reader user, further improvements and validation testing with more visually impaired users are planned for the future.

References

[1] W3C WAI, "Web Accessibility Laws & Policies," Jan. 2019. [Online]. Available: https://www.w3.org/WAI/policies/

[2] ——, "Web Content Accessibility Guidelines (WCAG) Overview." [Online]. Available: https://www.w3.org/WAI/standards-guidelines/wcag/

[3] MetalPop Games, "UI Accessibility Plugin (UAP)." [Online]. Available: https://assetstore.unity.com/packages/tools/gui/ui-accessibility-plugin-uap-87935

[4] L. S. Guedes, L. A. Marques, and G. Vitório, "Enhancing Interaction and Accessibility in Museums and Exhibitions with Augmented Reality and Screen Readers," in *Computers Helping People with Special Needs*, 2020, pp. 157–163.

[5] S. Hebditch, "Unity Accessibility Extensions." [Online]. Available: https://unity-accessibility-extensions.readthedocs.io/

[6] I. Topolovac, I. Rasan, Z. Car, and I. Majerski, "Collaborative Framework for Implementation of Accessible Digital Solutions," in *Agents and Multi-Agent Systems: Technologies and Applications 2021*, 2021, pp. 53–63.

QoE Assessment for Virtual Reality Gaming

Sara Vlahović, Lea Skorin-Kapov
University of Zagreb, Faculty of Electrical Engineering and Computing, Zagreb, Croatia
{sara.vlahovic, lea.skorin-kapov}@fer.hr

***Abstract*—Virtual Reality (VR) technology is increasingly utilized for entertainment purposes, such as digital gaming. However, unlike non-immersive platforms, VR comes with a set of additional challenges for developers and consumers alike, as even a short VR gaming session may be able to provoke different types of discomfort, from cybersickness to muscle pain, as well as deteriorate cognitive performance. In our work, we aim to investigate various features of the VR gaming experience, and use data obtained during user studies as input for multidimensional models of VR gaming Quality of Experience (QoE), while collecting valuable insights for VR game development.**

***Index Terms*—Quality of Experience, Immersive Media, Virtual Reality, Gaming**

I. Introduction

More immersive than virtually any other platform, VR technology may pose a welcome disruption to the already incredibly prolific world of game development. However, while the VR gaming industry revenue projections for the upcoming period [1] appear promising, the platform has yet to be fully embraced by game developers, as well as its target consumer base. Therefore, if the goal is to bring this type of service into the mainstream, efforts should be made towards finding new ways of exploring and optimizing the Quality of Experience (QoE) for VR gaming. The full definition of QoE for immersive media — such as VR — is as follows [1]: *"the degree of delight or annoyance of the user of an application or service which involves an immersive media experience. It results from the fulfillment of his or her expectations with respect to the utility and/or enjoyment of the application or service in the light of the user's personality and current state."*

In addition to features that characterize immersive media [1], [2] (i.e., immersivity, interactivity, explorability, believability, and plausibility), relevant dimensions of the VR gaming experience can also be found in the taxonomy presented in [3], which refers to computer gaming QoE. In addition to presence and immersion, this taxonomy observes the interplay between aspects such as appeal, interaction quality, playing quality, tension, and flow. Many user (e.g., experience, motivation, static and dynamic human factors, etc.), context (e.g., physical environment, social context, novelty), and system (e.g., genre, game mechanic, aesthetics and design characteristics, frame rate, network delay, etc.) factors that are likely to influence VR gaming QoE have already been listed in ITU-T Recommendation G.1032: Influence factors on gaming quality of experience [4].

[1]https://bit.ly/3v7EaNr

However, sources stemming from computer gaming research often disregard the aspect of physical discomfort, as it is not a significant issue for the majority of other gaming platforms. It does, however, often appear during VR gameplay. The most commonly mentioned negative effect of VR use comes as a result of a sensory conflict triggered by the visual motion cues used to simulate movement through the virtual world. This uncomfortable state, characterized by disorientation, gastrointestinal and oculomotor symptoms, has been referred to as cybersickness and discussed at length in various works, such as literature reviews by Davis et al. [5] and Chang et al. [6]. Physical discomfort in VR may also originate from device factors (most notably headset design) and physical movement, with mid-air interaction often resulting in arm/shoulder muscle fatigue. This aspect, however, is sometimes leveraged in exergaming solutions, enabled by the six-degrees-of-freedom tracking in commercial VR systems. To prevent excessive discomfort, a design framework for balancing exertion with enjoyment was presented in [7]. In addition to physical discomfort, multiple studies (e.g., [8], [9]) suggest VR exposure may affect participants' cognitive performance, as reaction time tends to increase after VR use. The reason behind this effect is unclear, although it may be attributed to cybersickness [8], visual motor adaptation [9], or a slight delay between the users' movement and the visual feedback [9].

During our research process, our goal is to adopt a holistic approach to evaluating QoE of VR games, building upon existing gaming QoE models by further focusing on VR-specific features. The first step of the research process will be to develop the initial user testing methodology based on a combination of subjective and objective metrics for measuring different aspects of user experience. We aim to adopt an iterative approach, with the results of each experiment further informing the design for studies to come, as we shift our focus between different factors. After completing the experimental phase, collected data will be analyzed using relevant statistical methods, resulting in a proposed multidimensional model of QoE for VR gaming. The results of user studies will also serve as input for the development of guidelines for designing and evaluating QoE-aware interaction methods for VR gaming.

II. On-going Research

In our most recent work we have defined the initial methodology for investigating various aspects of user experience during VR gaming sessions. While acquiring user ratings for the overall QoE, as well as various aspects of the gaming experience, collected using the Game Experience Questionnaire

TABLE I
DISTINGUISHING CHARACTERISTICS OF CHOSEN GAMES (PRESENTED IN [10])

Game	Genre	Dominant Interaction	Secondary Interactions	Horizontal Play Angle	Visual Description
Beat Saber	Rhythm game	Slice	Dodging incoming walls by squatting and lateral movement	110° (content in front of player)	Sleek, minimalist aesthethic, dark background with neon elements, no high-frequency textures, no characters, cubes and walls slide towards the player
Order Up VR	Cooking simulator	Pick and place	Turning and bending over to reach required objects	360° (full body rotation required)	Bright, colorful low-poly aesthetic, interior setting, no high-frequency textures, no emissive materials, cartoonish characters slide towards the player
Serious Sam VR: The Last Hope	Action/shooter	Shoot	Lifting one or both arms in protection from incoming attacks	180° (content in front and on both sides of player)	Bright semi-realistic exterior setting, dynamic special effects, semi-realistic monster characters with high-frequency textures and more complex geometry move and fly towards the player, who is also targeted by various projectiles

(GEQ) [11], we have placed our focus on the issues of VR-induced discomfort and cognitive aftereffects. In addition to assessing cybersickness symptoms using the Simulator Sickness Questionnaire (SSQ) [12], we have chosen to investigate the intensity of discomfort experienced as a consequence of device features, such as weight, fit, temperature, display quality, and cable, as well as muscle fatigue and pain felt in different upper body regions. Additionally, our methodology includes the use of objective measures for obtaining reaction time results before and after VR exposure, as well as collecting physiological signals (e.g., electrodermal activity, heart rate) during each VR session on the HTC Vive Pro headset.

Based on our proposed methodology, we have conducted a user study on 20 participants (10 females, 10 males) with results recently presented in [10]. Each participant was asked to play three different commercial VR games (Table I, Figure 1) over three different gaming sessions. While this area of research is fairly broad, requiring further investigation, our preliminary results indicate that even VR gaming sessions as short as 20 minutes may provoke arm fatigue and pain in a significant number of participants, especially with slice or shoot as the primary interaction mechanic. We have also found that symptoms that come as a result of physical exertion may be erroneously attributed to cybersickness when using widely-accepted measures such as the SSQ, which could be mitigated by incorporating alternative metrics of discomfort. Furthermore, our results indicate that reaction time generally increases after VR exposure, which is in line with previous work [8], [9], but the effect may significantly differ depending on the genre and primary interaction mechanic of the game, and does not appear to be significantly correlated with cybersickness.

Fig. 1. Snapshots of test material used in the study (presented in [10]): a) Beat Saber, b) Order Up VR, c) Serious Sam VR: The Last Hope

III. FUTURE WORK

In our future work, we plan to provide a more in-depth analysis of the results, especially with regard to human influence factors such as experience, age, or gender. Our goal is to replicate the experiment using different alternative test material, to observe whether conclusions made based on results obtained so far could be generalized based on genre or interaction mechanic. Further focusing on implementation details for each interaction mechanic, we plan to perform additional user studies with the aim of gaining valuable insights that could serve as guidelines for VR game developers. Lastly, our goal is to use collected data as input for the development of multidimensional models for VR gaming QoE.

ACKNOWLEDGMENT

This work has been fully supported by the Croatian Science Foundation under the project Q-MERSIVE, grant numbers IP-2019-04-9793 and DOK-2020-01-3779.

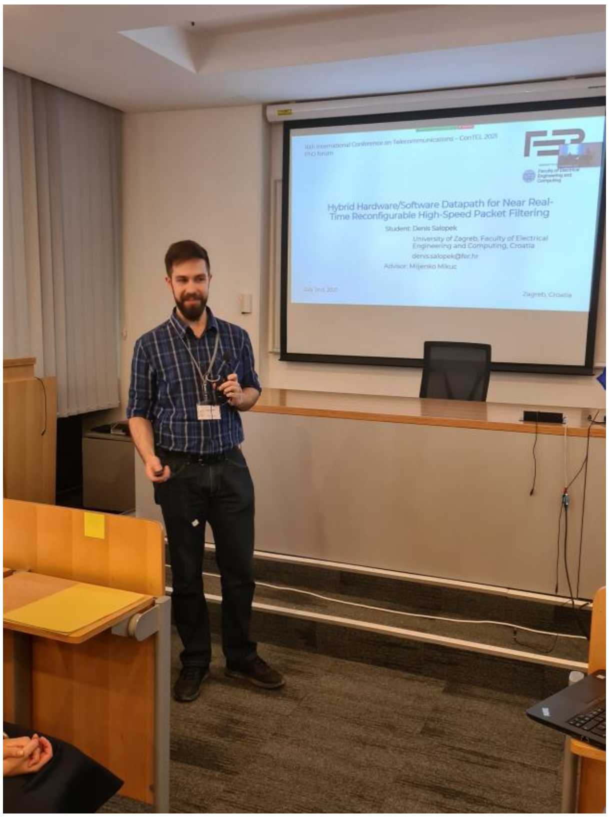
REFERENCES

[1] A. Perkis, C. Timmerer *et al.*, “QUALINET White Paper on Definitions of Immersive Media Experience (IMEx),” *European Network on Quality of Experience in Multimedia Systems and Services, 14th QUALINET meeting (online)*, 2020.
[2] M. J. Schuemie, P. Van Der Straaten, M. Krijn, and C. A. Van Der Mast, “Research on Presence in Virtual Reality: A Survey,” *CyberPsychology & Behavior*, vol. 4, no. 2, pp. 183–201, 2001.
[3] S. Möller, S. Schmidt, and J. Beyer, “Gaming Taxonomy: An Overview of Concepts and Evaluation Methods for Computer Gaming QoE,” in *2013 Fifth International Workshop on Quality of Multimedia Experience (QoMEX)*. IEEE, 2013, pp. 236–241.
[4] ITU-T Recomm. G.1032, “Influence Factors on Gaming Quality of Experience,” *Int. Telecomm. Union-Telecomm. Standard. Sect.*, 2017.
[5] S. Davis, K. Nesbitt, and E. Nalivaiko, “A Systematic Review of Cybersickness,” in *Proceedings of the 2014 Conference on Interactive Entertainment*, 2014, pp. 1–9.
[6] E. Chang, H. T. Kim, and B. Yoo, “Virtual Reality Sickness: A Review of Causes and Measurements,” *Int'l Journal of Human–Computer Interaction*, vol. 36, no. 17, pp. 1658–1682, 2020.
[7] S. Yoo, M. Carter, and J. Kay, “VRmove: Design Framework for Balancing Enjoyment, Movement and Exertion in VR Games,” in *Proc. of the 2018 Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts*, 2018, pp. 295–307.
[8] E. Nalivaiko, S. L. Davis, K. L. Blackmore, A. Vakulin, and K. V. Nesbitt, “Cybersickness Provoked by Head-Mounted Display Affects Cutaneous Vascular Tone, Heart Rate and Reaction Time,” *Physiology & behavior*, vol. 151, pp. 583–590, 2015.
[9] J. M. Mittelstaedt, J. Wacker, and D. Stelling, “VR aftereffect and the relation of cybersickness and cognitive performance,” *Virtual Reality*, vol. 23, no. 2, pp. 143–154, 2019.
[10] S. Vlahović, M. Sužnjević, N. Pavlin-Bernardić, and L. Skorin-Kapov, “The Effect of VR Gaming on Discomfort, Cybersickness, and Reaction Time,” in *2021 Thirteenth International Conference on Quality of Multimedia Experience (QoMEX)*. IEEE, 2021, pp. 1–6.
[11] K. Poels, Y. A. de Kort, and W. A. IJsselsteijn, “D3. 3: The Game Experience Questionnaire: Development of a Self-Report Measure to Assess the Psychological Impact of Digital Games,” 2007.
[12] R. S. Kennedy, N. E. Lane, K. S. Berbaum, and M. G. Lilienthal, “Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness,” *The Int'l Journal of Aviation Psychology*, vol. 3, no. 3, pp. 203–220, 1993.

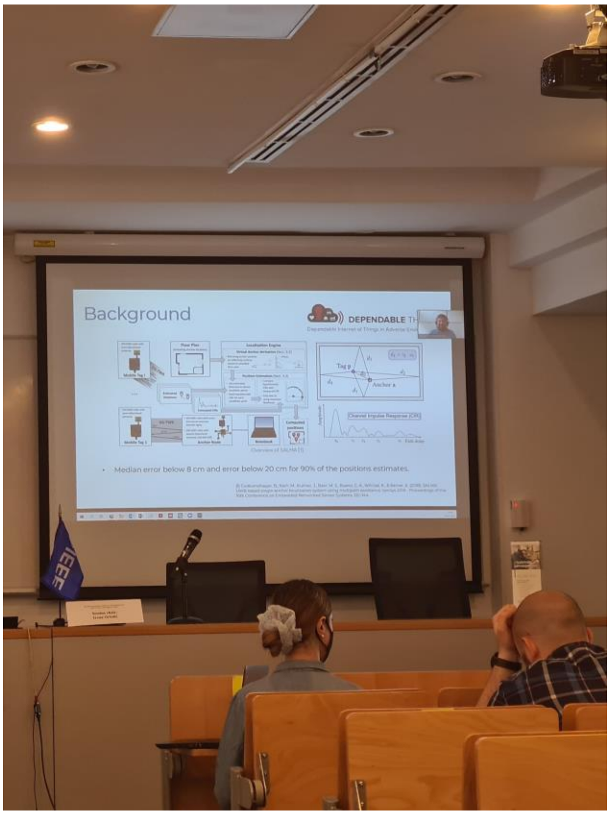
AUTHOR INDEX

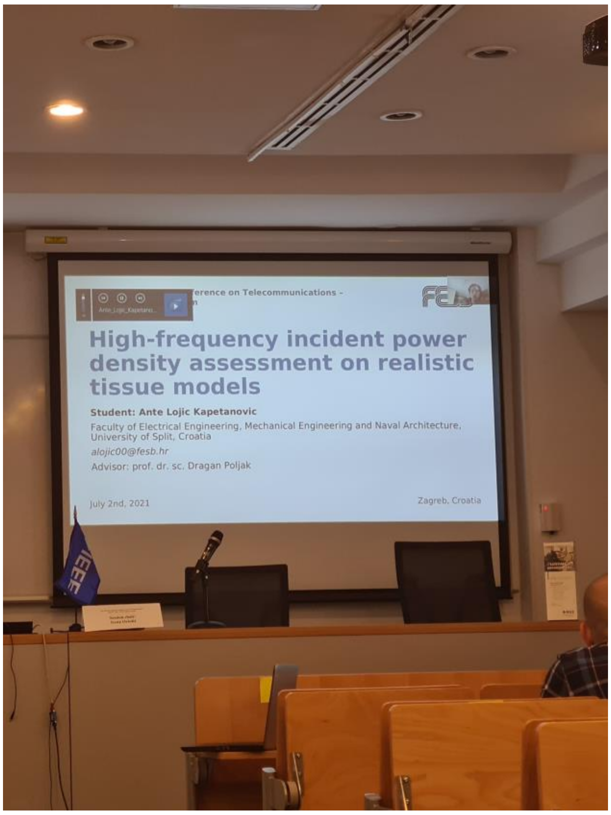
PHOTOS FROM THE PHD FORUM

Welcome and opening address

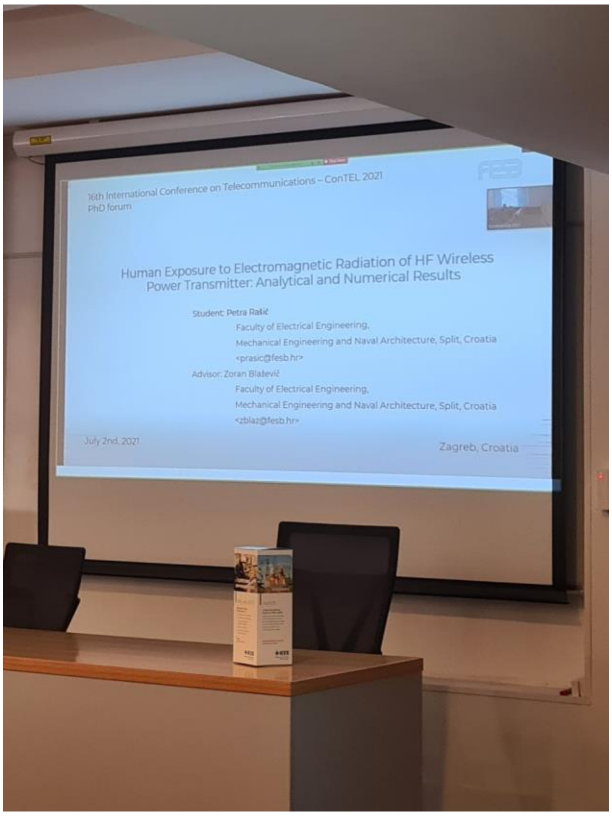


Pitch talk presentations

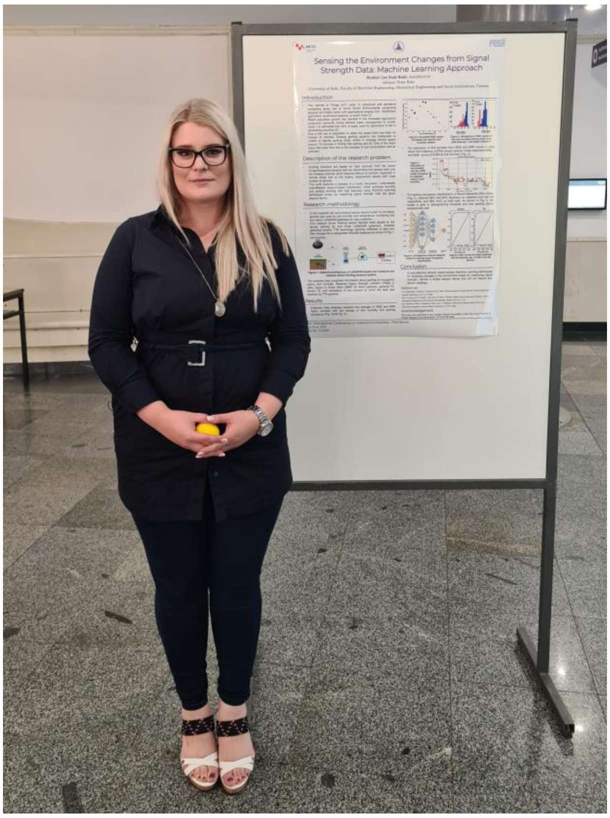




Pitch talk presentations



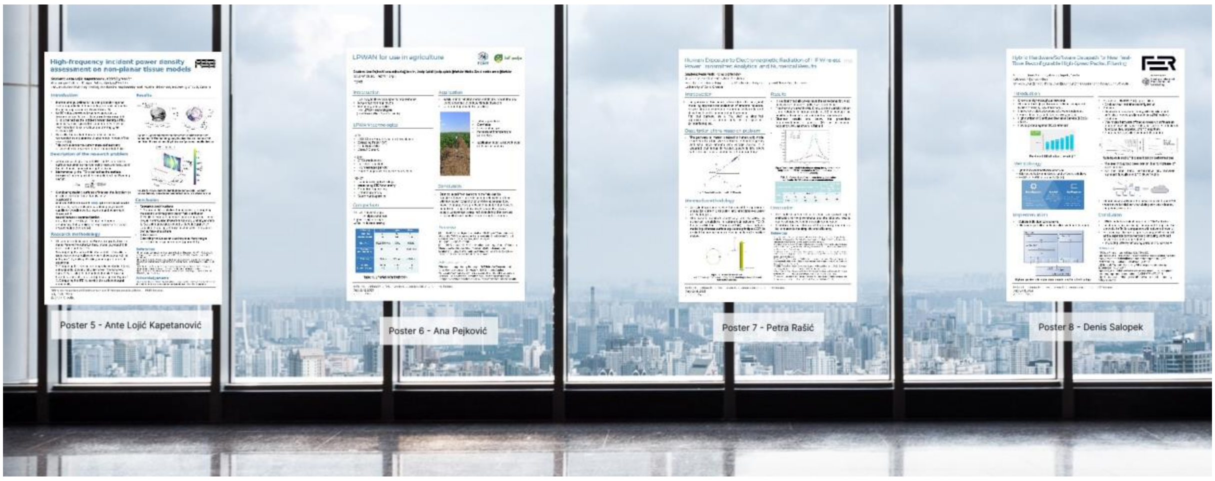
Pitch talk presentations



Poster presentations

Poster presentations

Online poster presentations



Online poster presentations

Online poster presentations

Best PhD Forum contribution award ceremony