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PhD Forum - Book of Abstracts

The 14th International Conference on Telecommunications – ConTEL 2017

PhD Forum – Book of Abstracts

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Matija Džanko

University of Zagreb
Faculty of Electrical Engineering and Computing

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Foreword

The PhD Forum, hosted by the 14th International Conference on Telecommunications – ConTEL 2017, in Zagreb, Croatia, is an event dedicated to PhD students. On behalf of the steering committee, it is my pleasure and honor to write this foreword to the PhD Forum's Book of Abstracts.

Following the positive experience of the first PhD Forum at SoftCOM 2016 in Split, Croatia, the steering committee decided to co-locate the PhD Forum with ConTEL 2017, as another well-established, IEEE technically co-sponsored conference. This arrangement gave the PhD students the opportunity to present their doctoral research work-in-progress to a diverse and international community of top-researchers, as well as to interact and network with their peers. This year's PhD Forum was also the first with international students' participation, including doctoral students from four Croatian universities (the University of Zagreb, the University of Split, the Josip Juraj Strossmayer University of Osijek, and the University of Rijeka) and the University of Würzburg in Germany.

To be included in the ConTEL 2017 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 external reviewers, based on relevance to the conference, innovativeness, and quality of (written) presentation. A total of 17 submissions were finally accepted, and they are included in this book.

The PhD Forum programme was organized as a poster session, preceded by a set of fast-paced introductory "pitch talks", offering a preview of the posters. The purpose of a pitch talk was to provide a brief outline of one's doctoral research work, with the goal to "set the stage" for further discussion over the upcoming poster session. Each student was given a strictly-timed 2-minutes' slot to present – a difficult task that many of them handled amazingly well. The session chairs, Ognjen Dobrijević and Višnja Križanović, also deserve special mention for expertly moderating the session. Photographs at the end of this book capture some notable moments from the pitch talk session, as well as the discussions regarding the posters. The winner of the best presentation award was determined by the members of the audience in a secret ballot vote. The winner was Tomislav Štefanec, a part-time doctoral student at the University of Zagreb and an employee at the Ericsson Nikola Tesla company in Zagreb, Croatia.

Finally, I would like to thank all the members of the Steering Committee, as well as the Program & Organizing Committee, for great support and the job well done.

Maja Matijašević, University of Zagreb

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On location privacy vulnerabilities in WiFi networks

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***Abstract*—Location privacy concerns have been further increased by today's omnipresence of WiFi technology. One such interesting source of private location data is the users Prefered Network List (PNL), as the device stores the list of previously used hotspots. Collecting such data is done by monitoring WiFi traffic, however nowadays more and more devices no longer transmit their PNL in clear, thus not allowing for an easy setup for the attacker. In this work, we will discuss the implications of revealing ones PNL obtained by passive attacks, as well as an active attack we have devised, thus circumventing the protection implemented by user equipment manufacturers.**

I. Introduction

One of the most challenging problems in todays IoT and mobile era is location privacy. Different mobile devices, such as smartphones, tablets, wearable gadgets and more, constantly collect different informations from its surrounding areas. Those informations can be then used to develop different technologies such as WiFi based positioning systems [1]. Other examples are radio signals emmited by devices connected to different mobile carrier networks where you determine ones location using cell tower trilateration. Data collected this way has a lot of usages on the market, not only beeing a huge threat to the actual security of the user beeing followed, but also as a big data research tool, indoor tracking, localization or as a marketing tool delivering targeted services based on location or other profiled data for a particular user.

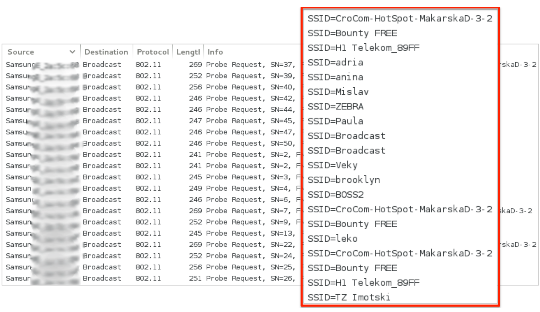

Fig. 1. SSIDs contained in user's PNL

The IEEE 802.11 communication standard for WiFi has also introduced a mayor data leak which an adversary can use to damage user's location privacy. Using a protocol called Active Service Discovery, user's WiFi card, in order to decrease

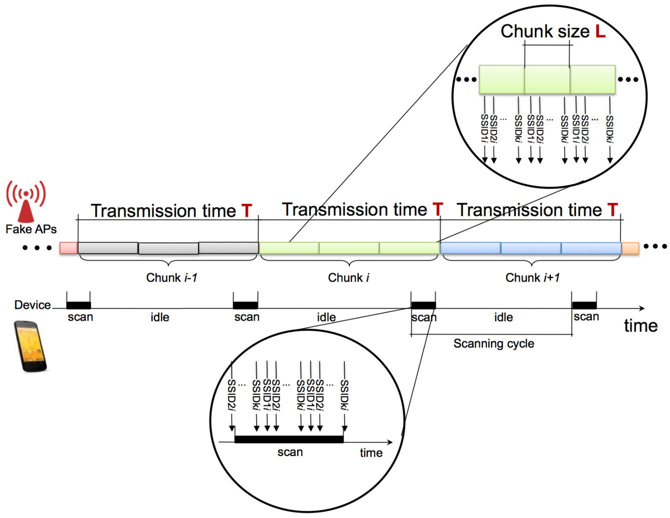

Fig. 2. Base attack setup, attacker uses a fake AP trying to hit the victims WiFi scanning intervals with a correct SSID guess

the required Access Point connection time, sends out Probe Request packets containing the Service Set Identifier (SSID) of various previously used Access Points (AP). Such data can easily be collected by monitoring the WiFi channel using a tool like AirCrack [2]. After collecting the SSID data, as adversary can use a service like Wiggle [3] to geolocate the SSIDs, thus disclosing the user's previous whereabouts. A sample trace can be seen in Figure I.

II. Problem definition

In order to prevent the security vulnerability, user equipment manufacturers have implemented Active Service Discovery with Broadcast, where the Probe request packets contain an empty SSID field, along side with using Passive Service discovery where the device only listens to SSID broadcasts from neighbouring Access Points. Such IEEE 802.11 connection initiation protocols are no longer vulnerable to the mentioned monitoring passive attack since the probe request packets are either not transmitted or contain no relevant data.

III. Research topic and results

Although both Active Service Discovery with Broadcast and Passive Service discovery WiFi operation modes don't

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transmit previously used SSIDs, they will initiate a connection to a known Access Point. Working around this fact, we have modeled and tested an active version of the attack. By mounting an Access point controlled by the adversary using a fake SSID, it is possible to conclude that a particular SSID (from a predefined set) is contained within the user's PNL in case the user's device initiates a connection towards the rogue AP. Modeling and executing such attack is subject to various issues. How often does the victim scan for surrounding APs? For how long? What is the opportunity window for the attack? How good is the channel quality? Which SSIDs should we test? We have tried to answer all of these questions and propose the optimal parameters for such an attack to have maximum success rate at disclosing the victims PNL. Figure 2 depicts the basic attack setup. Within the Active rogue AP attack we have devised a comprehensive mathematical model depicting the attack. Base equation of that model is presented as the advantage that the attacker $\mathcal{A}$ will succesfully execute a location privacy attack against the user's PNL $\mathcal{P}$ (1). We ran real-life tests by executing the attack modifying various model parameters (SSID chunk retrasmission time, chunk size etc.) on various Android and iOS devices (Figure 3), as well as implemented a simulator in matlab.

$$\begin{aligned} Adv_{\mathcal{P}}^{L-priv}(\mathcal{A}) &\triangleq \mathbb{P}[\mathcal{P} \cap \mathcal{D} \neq \emptyset, hit] \\ &= \mathbb{P}[\mathcal{P} \cap \mathcal{D} \neq \emptyset] \cdot \mathbb{P}[hit|\mathcal{P} \cap \mathcal{D} \neq \emptyset] \end{aligned} \tag{1}$$

Other than modeling and testing the performances of the the active attack, we have used a recommender system algorithm [4] to help us generate a dictionary of SSIDs to test. Such a dictionary contains various SSIDs, each assigned a probability that it is a part of the specific victims PNL. For a new user, starting dictionary is generated by using SSIDs connected to that user (ie. location / topic based). When executing the attack, depending on the channel quality, available time and other various parameters from our model, it is only possible to test a subset of all the SSIDs from the dictionary, making the recommender system a key component for increasing the success rate of the entire attack.

Within our research on Location privacy we have also collected SSIDs at an event hosting more than 50 000 people. Those SSIDs and various other databases can be used for revealing different information about the users and their whereabouts [5], [6], [7]. We highlight `SSID=Shelbourne Medical Clinic` from the collected dataset as an example on how big of an issue and how private such data can be.

IV. Conclusion

WiFi networks offer an interesting aspect to user's Location privacy. Simply monitoring the WiFi channel can reveal the user's previously used access points, contained in his PNL. Such data can then be used to reveal his previous whereabouts. By avoiding Active Service Discovery without Broadcast, device manufacturers have attempted to fix this vulnerability to passive attacks. In our work we have proposed, tested and simulated a model of an Active attack, making almost any

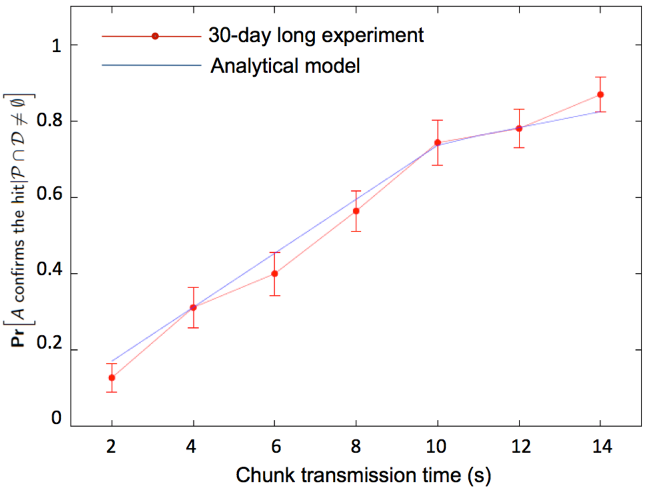

Fig. 3. Comparing attack success rate from the proposed model with results from executing the attack on Sony Experia Miro, while changing various model parameters

WiFi connected device vulnerable to location privacy leaks. An obvious countermeasure to our attack would be to set your device not to automatically connect to WiFi networks, which is unlikely considering the user experience aspect. We have also worked on passively collecting large quantities of SSIDs to be used to create a dictionary for our attack. In future work we will continue approaching location privacy in WiFi networks, tackling the MAC address deanonymization, WiFi positioning systems and drawing conclusions from PNLs.

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Visual Servoing for Mobile Robot Manipulators

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***Abstract*—Research goals in this doctoral program are development of the robotic manipulation module and development of new algorithms and methods for object recognition by robotic vision and hypotheses evaluation. So far, two low-cost vision guided robot arms have been assembled and robotic manipulation module based on visual servoing has been developed. Development of new methods for object recognition and classification were not considered in this paper.**

Keywords—robotic vision, 3D perception, robot arm, visual servoing

I. Introduction

This paper represents a brief description of the research and the results obtained so far in a doctoral study program, within the project *Advanced 3D perception for mobile robot manipulators*. Since the goal of the project is to develop and improve methods for 3D perception applied in mobile robot manipulation, it was necessary to build robot manipulation module which would serve as a testing platform for developed algorithms and methods. In this paper, a low cost vision guided robot arm setup along with the methods for hand-eye calibration and visual servoing are explained. The goal of this investigation is to find out what accuracy can be achieved with such a simple configuration. Experimental evaluation was performed and obtained positioning accuracy results are given.

II. Related Research

There exist many researches where visual servoing is applied for control of a robotic arm. In some of them [1], [3], [13] industrial robots were presented and used, while this research considers low cost solutions. This paper comprehends hand-eye calibration with a single camera in eye-to-hand configuration, while many other calibration methods such as Optimal [2], Global Polynomial Optimization [4], and [13-17] are designed for the eye-in-hand configuration. The eye-to-hand calibration was chosen because the camera used in this setup was too large to be mounted on the end effector without interfering with robot arm movement. Also, a wider overview of the robot environment is achieved by this configuration. Related research [1-4] proposes different calibration methods, which we tried to simplify.

Our setup consists of a low-cost robotic arm and an off-the-shelf RGB-D camera in eye-to-hand configuration. We wanted to build a system with 3D vision capability, since the results of recent computer vision research clearly demonstrate advantages of 3D vision systems [5–10].

The considered setup, which consists of significantly less expensive components in comparison to the hardware used in the aforementioned related research, together with an evaluation of the absolute positioning accuracy achieved by the proposed system represents the contribution of this paper.

III. Research

Even though robot arms are widely used in industrial automation, their high cost and dimensions are not suitable for household and education. Therefore, low cost robotic solutions are of the great importance for the further development of robotics, since they broaden the population of robot users and also expand the base of researchers in this field. Robot arms considered in our research are small and lightweight in order to be mounted on a medium sized mobile platform. Two robots are considered, Dobot Arm V1.0 and a custom made robot arm in SCARA configuration, named VICRA (Vision Controlled Robot Arm). Both robot manipulators are based on stepper motors and no absolute encoders or any other proprioceptive sensors are used in this research for measuring the absolute position of the robot's arm. The stepper motors are controlled by a series of impulses defining the relative changes in joint angles. Furthermore, the stepper motors could lose impulses, which could lead to wrong positioning. Off-the-shelf RGB-D camera, Orbbec Astra S is mounted on the top of the robot arms shown in Figure 1. Within this research, hand-eye calibration and visual servoing algorithms have been implemented and tested using both robot arm configurations.

Hand-eye calibration gives information about the relative pose between a camera and a robot. We developed a method for hand-eye calibration based on identification of the dominant plane in the camera field of view (FoV) and visual servoing using an RGB-D camera. Two methods were implemented and tested, one for absolute positioning and the other for relative positioning. The first method calculates transformation matrix between the robot and the camera reference frame (RF) based on three points obtained by moving the robot arm in three positions. The second method is designed for SCARA configuration where the first joint performs translation in vertical direction. The proposed approach is to use the dominant plane in the camera FoV to estimate the z-axis of the robot RF

Figure 1. Dobot Arm and VICRA

w.r.t. the camera RF, and one movement of the robot's arm to determine the axis of the second joint and the angle of the third joint. The second method might be of greater importance since it doesn't require the robot to be positioned in a known initial position and requires only one movement of the robot's arm, which makes it suitable for recalibration. The details of the discussed methods are omitted due to the space constraints.

In order to achieve precise positioning without proprioceptive sensors, visual-servoing using RGB-D camera is applied. Visual servoing iteratively verifies if robot achieved desired position and, if did not, calculates required joint differences and performs rotation and translation. Visual servoing is implemented by detection and localization of a marker mounted on the robot arm close to the end-effector. The marker detection and pose estimation is implemented using ArUco library for augmented reality [11] based on Open CV [12]. Visual servoing computes changes in joints variables in order to put the robot arm in a desired position. The applied method is based on the direct and inverse kinematics when using absolute positioning. When using relative positioning, geometry of the robot arm and known current and desired positions are used to calculate relative differences in joints variables.

IV. Experimental Evaluation

The developed algorithms were experimentally tested in order to determine the accuracy of visual servoing achieved by the proposed calibration methods. Both methods, for absolute and relative positioning were tested. A laser pointer was mounted on the end effector with a marker on top of it. Another marker, representing the object of interest, was put in 35 different positions for each method. The robot arm was supposed to position the laser pointer to points to the center of the marker representing the object of interest. When the positioning is completed, the distance between the center of the marker and the laser point was measured manually. The obtained results are given in Table 1. The analysis of the experimental results showed that the precision of the applied visual servoing algorithm is sufficient for many applications in everyday life. Some of the results of this research were presented on 40th MIPRO 2017 [18].

Table 1. Experimental results for Visual servoing

Calibration method	*Robot*	*Average measured distance*
Absolute positioning	Dobot	1.03 mm
Relative positioning	VICRA	2.36 mm

V. Conclusion and Future Work

Within the past nine months, a complete low cost vision based robot arm system, with new techniques for eye-to-hand calibration and visual servoing with high precision was developed. Such combination represents a new approach and has its contribution in making robotics, both research and application, widely applied. In the next three years and four months, accent will be put on the development of robotic vision methods for object recognition and object classification with application in mobile robot manipulation.

Acknowledgment

This work has been fully supported by the Croatian Science Foundation under the project number IP-2014-09-3155.

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Early Forest Fire Detection with Deep Neural Networks

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***Abstract*—Forest fires are natural phenomena that cause significant economic damage and have quite devastating effect to the environment all over the world. Early forest fire detection, but also both quick and appropriate intervention is of vital importance for forest fire damage minimization. In both cases, forest fire video monitoring system could be quite useful. In this paper, after a shorts survey of various approaches to forest fire monitoring, an advanced video monitoring system called iForestFire, developed at Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture University of Split and widely applied in Croatia, we proposed a novel approach for early fire detection based on deep learning algorithms.**

I. iFORSETFIRE SYSTEM

iForestFire (Inteligent Forest Fire) is integrated and intelligent video based monitoring system for early detection of forest fires. Forest fires are detected in incipient stage using advanced image processing and image analyses methods. Intelligent fire recognition algorithms analyze images automatically, trying to find visual signs of forest fires, particularly forest fire smoke during the day and forest fire flames during the night. If something suspicious is found, pre-alarm is generated and appropriate image parts are visibly marked. The operator inspects suspicious image parts and decides is it really the forest fire or not. The system is capable to work with both type of cameras: video cameras sensitive in visible and near IR spectra and real IR thermal imaging cameras. iForestFire is a Web Information System (WIS) and the only user interface is standard Web browser. The system is based on field units and a central processing unit. The field unit includes the day and night, pan/tilt/zoom controlled IP based video camera and an IP based mini meteorological station connected by wired or wireless LAN to a central processing unit, where all analysis, calculation, presentation, image and data archiving is done [1]. iForestFire is both integral and intelligent user friendly system. Its organizational structure is shown in Figure 4. iForestFire has three data bases: data warehouse with input images and alarm images, SQL database with meteorological data and temporal information of alarm images and GIS database with all relevant GIS data [2]. iForestFire has five working modes:Archive Mode Video and meteorological data archive retrieval using various user-friendly procedures, Simulation Mode Fire behavior modeling and fire spread simulation using meteorological data and various GIS layers, Fire Risk Calculation Mode - Micro location fire risk index calculation using, not only meteorological data, but sociological parameters connected with forest fires too. Structure of iForsetFire is shown on Figure 3.

II. RESEARCH TOPIC PRESENTATION

Main idea is to improve iForestFire system with adding detector for early forest fire based on deep learning algorithms. First step is creation of a large database with images collected from iForestFire system. The database contains images with early forest fire and also images with falls alarms (fog, clouds,..), divided in two classes fire and other.

Architecture of our deep neural network is based on LeNet [3], but with difference of the last full connected layer, since we have only two classes Figure 1. For training and testing we used deep learning framework Caffe, which is one of the most popular libraries for deep learning (convolutional neural networks in particular). It is developed by the Berkeley Vision and Learning Center (BVLC) and community contributors. Caffe is easily customizable through configuration files, easily extendible with new layer types, and provides a very fast ConvNet implementation (leveraging GPUs, if present). It provides C++, Python and MATLAB APIs [5].

The training phase will be done on Tesla K80 graphic card. Doctoral candidate's further research is integration of DNN in iForetFire system to test the accuracy of the trained network in the natural environment.

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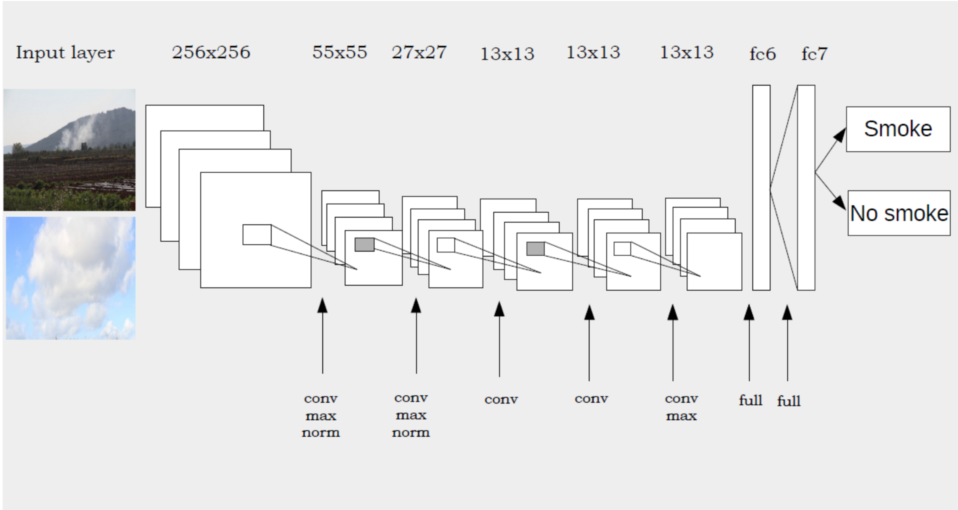

Fig. 1. Architecture of trained network

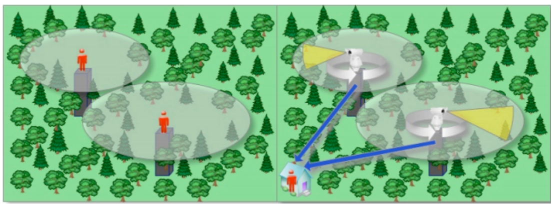

Fig. 2. The difference between human forest fires observation based on direct monitoring and distant monitoring using video cameras. In direct monitoring one observer has to be located on each monitoring spot, and in video based monitoring system the observer, located in monitoring center, could monitor wider area covered by few monitoring units.

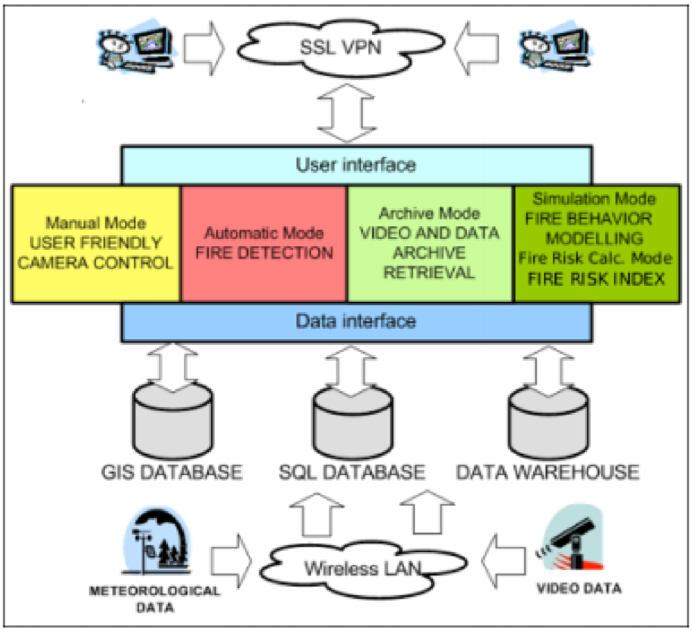

Fig. 3. Structure of iForestFire system.

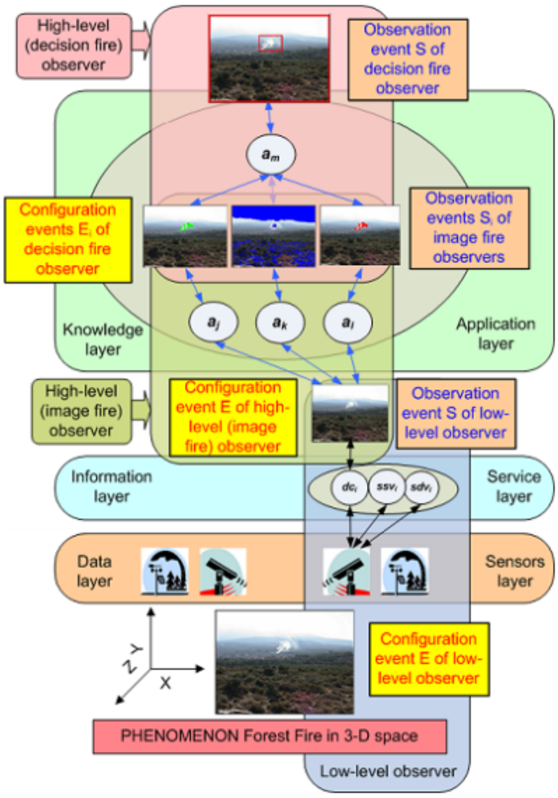

Fig. 4. Forest fire detection system seen as an observer network

Analysis of Evolving Software-Systems as Complex Networks

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Abstract **- Many real-world systems can be represented as a network. The same approach can be adopted for the software systems, which are constantly evolving and becoming more complex. In our work, we have analyzed evolving open-source software system, adopting the new approach in software engineering that uses a network theory. Statistical analysis of software networks has revealed some properties such as, power-law degree distribution, scale-free, small-world. Studying the structure of the system and its evolution in time by network theory, the results can be applied for predicting future trends, reliability, maintainability, defect predictions and other software characteristics. Our work is based on detecting these properties on an open-source software system in evolution.**

Keywords— software network; metrics; software evolution;

I. THE RESEARCH TOPIC PRESENTATION

In recent years, many complex systems have been examined according to the principles of the network theory, modelling them as complex networks where the components are connected by different relations. We can observe different systems around, as complex networks, for example social networks, biological networks, ecological networks, power grids, airline networks, web hyperlink network and others. From this analysis, it follows that even though the systems are very different, they present some common features, such as power-law degree distribution, small-world property, scale-free network, high level of clustering… It is this diversity of complex systems that encouraged the idea of modeling the software as a large and complex system such as a complex network. Having graph representation of a software system, allows us applying network theory in software engineering. Whereas, [6,7] software systems are considered one of the most sophisticated human-made systems, the application of complex network theory is an adequate approach for large software systems developed according to object-oriented structure.

This is not the first study conducted on the software systems while analyzing them as complex network, but our work is focused on a big set of statistical network metrics and has treated an evolution of an open source software system. For our case study, we have applied network theory in order to identify microscopic properties and proof of the existence of macroscopic properties, such as scale free and small-world properties. Moreover, network analysis enabled the determination of mesoscopic properties which indicate the presence of a structural modules and a deeper organizing structure for a software system. Having different software measures helps us to follow the process of software design and development [9]. Considering software system as a complex network, we can obtain different measures, called metrics, that gives us the opportunity to process them and get valuable conclusions. In recent years, particular importance in software engineering is analysis of the evolution and attempts to predict the trend of further development of the software systems. Although the importance of analysis of the evolutionary trend was obvious from the beginning of software engineering, different concepts of analysis and prediction have been used until today [2], but lately in special focus of researches is network theory.

In our research, object-oriented software is represented by a graph. For our software systems, we define a graph as an ordered pair G (V, E), where V are the nodes or vertices and E are the edges or links between those nodes. Our graphs are all directed. From source code files, we have obtained class dependency networks where nodes represent classes of software system and edges represent relations between them. Once having a graph, different set of metrics can be determined, such as: node degree (k), average node degree <k>, diameter (D), average path length (L), clustering coefficient (C), degree distribution exponent (γ), modularity. In our work, we have used Gephi[1] as a tool for exploring and manipulating networks.

It was already found [5] that many real-world networks, no matter how complex they are, have short average path length and high clustering degree. Networks with these properties are called small-world networks and their nodes, although they are not neighbor nodes, have a high probability of being reached in less than six steps [8]. We have proved in our analysis, that by using Gephi we have calculated L and C for all the versions of our software system and compared it with random graphs. The results are shown in Table 1. proving the rules of small-world networks for our networks.

[1] https://gephi.org/

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TABLE 1: METRIC'S VALUES OF TEN TESTED SOFTWARE SYSTEMS IN EVOLUTION

Version	N	E	E_{max}	D	<k>	L	C	γ
1.0	803	2650	644006	4	6,6002	1,6681	0,0613	2,07693
2.0	1429	5871	2040612	5	5,4334	1,6107	0,0404	2,06641
3.0	2463	11817	6063906	6	9,5956	1,6679	0,0632	2,05009
3.1	2787	13752	7764582	6	9,8704	2,5430	0,0538	2,04958
3.2	3305	16482	10919720	6	9,9739	2,5919	0,0491	2,04578
3.3	3460	17568	11968140	5	10,1549	2,5818	0,0486	2,04500
3.4	3614	18834	13057382	5	10,4228	1,6573	0,0520	2,04498
3.5	3736	19550	13953960	5	10,4657	2,5693	0,0525	2,04433
3.6	3780	19879	14284620	5	10,5180	2,5670	0,0520	2,04411
3.7	3808	19987	14497056	5	10,4974	2,5679	0,0504	2,04411

The most important feature of scale free network is that node degree distribution follows a power-law [1, 4, 8].:

$$P(k) \sim k^{-\gamma} \quad (1)$$

We have tested ten versions of evolving open source software system obtaining results shown in Fig 1, showing that all these graphs are examples of scale-free networks, and they have a degree distribution that follows a power law.

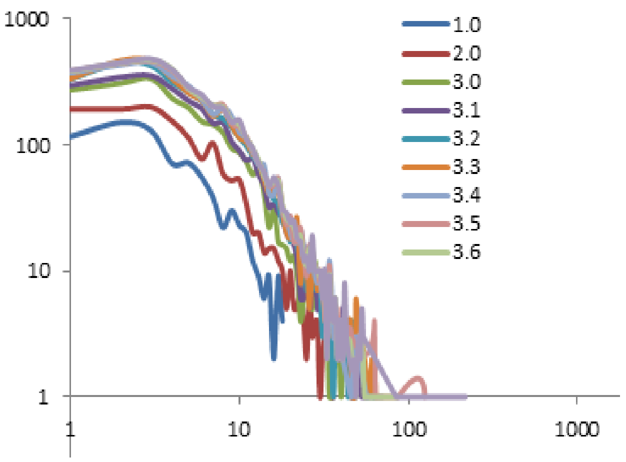

Fig. 1. Degree distribution during the evolution of software system in log-log scale

For describing community structure, a statistical metric is defined, called modularity. Modularity is one of the measures of the structure of network or a graph. It was designed to measure the strength of division of a network into modules. Each node gets assigned a module class, thus we have found the number of communities over the software in evolution. It's very interesting to see the distribution of nodes into communities for every version.

In this paper, we aim to show the results of graph-based analysis of an evolving software system, proving that scale-free property and the small-world phenomena for our graphs constructed from a source code of a complex software systems. We also examined the problem of detecting community structure in software networks and we show that the examined software systems reveal a significant community structure which confirms the presence of organized structure. It has been already proved that network software systems follow power law degree distribution, so they are scale-free networks and they reveal small-world properties [2, 5]. Network theory analysis allows us to obtain indicators for predicting future trends, reliability, maintainability, defect predictions and other software characteristics needed in software system engineering.

In the future, we will expand our analysis on new versions of these open-source software systems, and we will also consider other software systems. The analysis should also be extended to other graph's and community metrics.

ACKNOWLEDGMENT

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Teleoperation of Mobile Service Robots Over the Network: Challenges and Possible Solutions

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***Abstract*—With the ubiquity of service robots, various usage scenarios are developed for them, usually with a degree of autonomy. However, due to dynamic nature of the environment, algorithms for autonomous operation might fail. Besides that, there are tasks which are not meant to be completed during autonomous operation, and where the operator must take control of the robot to complete them. In order to efficiently and safely teleoperate the robot, the operator has to have a high degree of situational awareness. This can be achieved with the appropriate human-computer interface (HCI) so that the remote environment model constructed with sensor data is presented at an appropriate time and in an appropriate manner, and that robot commands can be issued intuitively and without much effort. Network latency problem is also addressed and a method for reducing its impact on teleoperation is presented.**

I. Problem formulation

Service robots are made to assist humans by completing tasks that are repetitive, dirty or are done in hazardous environments [1], [2] and are nowadays used for various applications in everyday life, both at home and in the industry. Some of them are designed so that they can perform their task autonomously, while others usually have limited degree of autonomy and require human intervention. Thus, occasionally it is necessary that the operator takes control of the robot from a remote location. This is referred to as teleoperation.

Teleoperation requires communication between the robot and the remote operator, usually using 2.4 GHz WiFi or 3G/4G mobile data network to connect to the Internet, so it can be reachable. There are situations when teleoperation is very difficult or even impossible due to the presence of high or changing network latency. This is because, in the presence of high latency, teleoperation performance degrades, making feedback of robot actions visible to the operator with a delay, which may result in a damage, both to the robot and the environment. Since all sensor data and robot commands are timestamped, the latency is measured as time difference between current moment and the moment of the timestamped data (either for user-to-robot or robot-to-user case). For efficient teleoperation of the robot, the operator must feel immersed, i.e. must be well aware of robot's state and state of its environment. This is often referred to as situational awareness, which is understanding of the conditions of dynamic environment and may be defined as "*The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.*" [3]. When teleoperating a robot, an operator has to be aware of the consequences of its actions both for the robot and for the environment. This can be achieved with an appropriate human-computer interface (HCI). HCI generally consists of two main parts: 1) output device (a graphical interface) which presents all necessary feedback from the robot about its state and the state of the environment, and 2) input device which is used to issue commands to the robot. The interface should be designed in a way that it offloads as much workload as possible from the operator and that makes robot control intuitive and easy. Generally, more (sensor) data about robot's state and it's environment improve situational awareness, but it has to be taken into account that too much information may distract the operator and overload network capacity. So, it's a matter of optimisation to choose which information should be presented to the operator while not congesting the communication channel.

The manner in which information from sensors is presented to the operator also affects the performance of teleoperation [4]. Graphical interfaces containing multiple information fused together in a single augmented reality (AR) frame, were shown to be more efficient than arrangement when they were presented in multiple frames, side-by-side. We even demonstrated in [5] that for simple tasks there is no statistically significant difference between visual and teleoperation scenarios when appropriate data is presented in the interface (see Fig. 1). It should be noted that inclusion of HCI control components that contain virtual reality elements [6], or haptic-based elements [7] might further improve the teleoperation experience.

II. Problem solution

We propose a two-pronged approach to the problem. First we chose the best HCI feedback and control elements so to achieve optimal use of available information channel capacity. Initial research has been carried on the topic in [5]. Gamepad and gaming steering wheel were used as input devices while graphical interfaces with and without depth information which made a total of 4 different HCI setups. In a user study, operators had to complete three steering tasks, and results showed no significant difference between used HCI setups and also no significant difference between teleoperation and visual control. However, it was noted that teleoperation parameters

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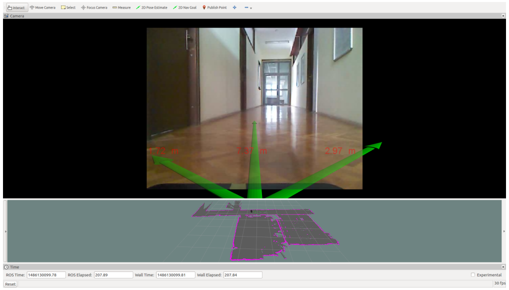

Fig. 1. AR graphical interface with depth information (green arrows) overlaid over live camera image and with 2D map of the environment, used in [5]

degraded somewhat, comparing to those of visual control. This can be further augmented with the inclusion of human in the autonomy control loop by means of explicit trajectory definition. Our proposal is to use an approach based on AR with a touch-panel of mobile phone or tablet (see Fig. 2), similar to the one proposed in [8]. This may be seen as a combination of teleoperation and autonomous navigation, since the operator is presented with feedback data on the screen, like in teleoperation, but does not steer the robot itself, it rather provides an input (goals or a whole trajectory) for the navigation which robot completes autonomously.

Fig. 2. A sketch of the proposed input interface

The second solution in the two-pronged approach addresses latency issues. We recognise that latency is difficult to control and/or minimise in public general purpose networks. Thus, we propose one of the possible solutions to the latency problem: in the case of high (or highly variable) latency robot switches to autonomous control seamlessly, and returns control to the operator when conditions are appropriate for efficient and safe navigation. This approach is depicted in Fig. 3. The switching threshold will be defined empirically and based on available literature like [9]. For this approach to be possible, the final goal needs to be known in advance. Also, some kind of human control model needs to be available. This approach can also be used to aid the operator in teleoperation tasks when long/tidies navigation from point A to point B is needed. The manner in which autonomous operation is to be executed is currently being researched. The method being developed is inspired by one described in [10], adapted for wheeled mobile robots. It features a self-supervised learning method. Data is collected in simulation by generating simple straight

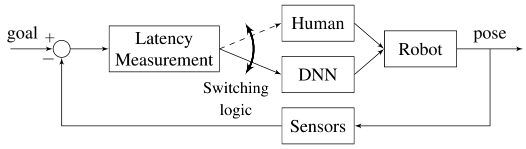

Fig. 3. Block diagram of the proposed solution

trajectories and treat ones that resulted in crashing a robot into walls as negative samples and ones that did not result in crashing as positive samples. The samples are then used to train deep neural network (DNN) that may act as robot controller in autonomous operation later, which will generate appropriate velocity commands that will steer the robot to the desired location, avoiding obstacles in the way. The idea looks promising (in initial testing) because this method does not require a map or any other knowledge about the environment the robot will operate in. Algorithm for human/autonomous switch also needs to be developed.

III. Conclusions

The paper describes mobile robot teleoperation and its prerequisites and presents parts of results of initial research that was conducted in order to find the optimal HCI configuration for teleoperation. The autonomous navigation system with the innovative approach based on self-supervised learning is presented, and ideas how to combine it with teleoperation are given. Some preliminary testing on it was done, and the idea looks promising.

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YouTube QoE Classification Based on Monitoring of Encrypted Traffic

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***Abstract*—With the move to traffic encryption adopted by many Over The Top (OTT) providers of video distribution services, Internet Service Providers (ISPs) are now facing the challenges of monitoring application performance and potential end user perceived service quality degradations. With lack of direct feedback from OTT providers, ISPs generally rely on passive traffic monitoring solutions deployed within their network for the purposes of monitoring OTT service performance. The aim of this research is to develop tools and methodologies that enable the estimation of end user QoE when watching YouTube videos using different platforms and access networks, based solely on the analysis of encrypted network traffic.**

I. Methodology and current results

Prior to the widespread use of encryption in OTT traffic, network operators could gain insight into application performance by extracting packet header information. Today, the inability to monitor service performance at an application level poses a threat to network providers, as they are potentially unable to detect problems and act accordingly. Poor performance further imposes the risk of losing customers, as customers often tend to blame network providers for poor QoE. Given the current situation, ISPs commonly rely on passive traffic monitoring solutions deployed within their network to obtain insight into user perceived degradations and their potential causes.

To address these challenges faced by ISPs, we have been studying the feasibility of estimating YouTube QoE based on monitoring of encrypted network traffic, by using machine learning (ML) techniques. To do so, we are developing a system called **YouQ**. YouQ enables application- and network-level data collection, data processing and building ML models that can subsequently be used to estimate QoE of new YouTube streaming sessions based solely on network traffic features. To develop such a system, there is a need to understand how application Key Performance Indicators (KPIs) calculated from application-level data (such as stalling duration, initial delay, etc.) affect end users' QoE (QoE modelling problem)[1]. Another challenge lies in extracting the network traffic features that can be correlated to application-level degradations [2][3].

This research is conducted in the scope of projects "Survey and analysis of monitoring solutions for YouTube network traffic and application layer KPIs" and "QoMoVid: QoE Monitoring Solutions for Mobile OTT Video Streaming", both funded by Ericsson Nikola Tesla, Croatia. This work has also been supported in part by the Croatian Science Foundation under the project UIP-2014-09-5605 (Q-MANIC). The authors would like to thank Illona Popic, Petra Rebernjak and Ivan Bartolec for their help in running experiments.

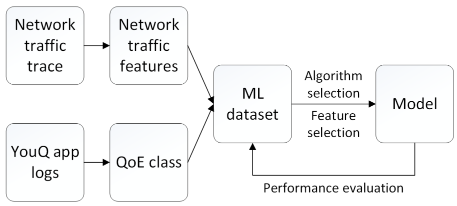

Fig. 1. Approach for QoE classification based on network traffic features

Our developed YouQ system consists of an Android application that plays a requested number of YouTube videos and logs events at an application level (e.g., video buffering, quality switch), amount of video in the buffer, and URLs from all HTTP requests. This data is collected using the YouTube IFrame API. In parallel to logging of application-layer KPIs, network traffic is also captured. After all the videos are played, both application-level logs and network traffic are uploaded to a YouQ server and processed. Processing includes calculating traffic features (e.g., average throughput, average interarrival time) for each of the videos in the experiment, calculating application-level KPIs from the collected logs (e.g., percentage of time spent on each quality level, stalling duration), and assigning a *QoE class* ("high", "medium", "low" QoE) to each video according to calculated KPIs and QoE models defined in [4]. The output of this phase is a dataset for training ML models. For each viewed video, we extract 33 traffic features (listed in [4]) based on the analysis of encrypted traffic, and classify the video into one of the three aforementioned QoE classes. The approach is depicted in Figure 1.

Our approach was tested in a laboratory environment shown in Figure 2. YouTube traffic between an Android smartphone (Samsung S6 with Android version 5.1.1) and YouTube servers is transmitted over an IEEE 802.11n wireless network and then routed through a PC running IMUNES (www.imunes.net), a general purpose IP network emulation/simulation tool enabling a test administrator to set up different bandwidth limitations and schedule bandwidth changes. Traffic is further sent through Albedo's Net.Shark device (a portable network tap used for aggregating and mirroring network traffic) where it

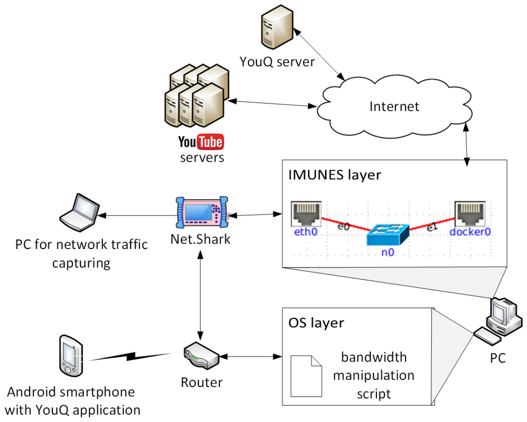

Fig. 2. YouQ lab setup

is replicated and sent to a PC designated for network traffic capturing. The PC running IMUNES also has an OS layer, accessed by the YouQ client application to run a bandwidth scheduling script according to defined experiments. The script resets the bandwidth envelope for each video in the experiment, which enables all videos to be played under exactly the same network conditions.

We collected a dataset corresponding to 1060 videos played under 39 differently defined bandwidth conditions, and trained models by using various ML algorithms. The models proved to be up to 84% accurate when 3 QoE classes were defined ("high", "medium", "low"). We also classified videos into 2 QoE classes ("high" and "low") and repeated the procedure. These models achieved an accuracy of 91%. The exact measurement procedure, definition of QoE classes, statistics of the collected dataset, along with a more detailed view of the results were published in [5], while [4] gives an even more detailed view of the test methodology used to train ML models for QoE classification, and provides a more detailed interpretation of classification results.

II. Ongoing Activities and Challenges

Our current activities aim to further develop the YouQ system so as to enable data collection, processing, and the training of QoE classification models for different usage scenarios. By this we refer to scenarios in which YouTube is delivered over different access networks (WiFi and mobile), using different clients (browser-based vs. YouTube App), using different transport protocols (TCP, QUIC), and with different types of user behaviour observed. As a standard for estimating QoE of adaptive streamed media has recently been published in ITU-T recommendation P.1203 [6], we plan to incorporate the defined model within the YouQ system instead of the simplified multidimensional model we are currently using.

A. Different client applications

Besides the YouTube IFrame API, that we used to develop the initial YouQ client application, YouTube also offers a native Android API. We have developed a version of the YouQ Android application based on this API, which enables us to observe YouTube KPIs and traffic behaviour in the case when a user access YouTube via the dedicated YouTube App. We noticed that in this case QUIC protocol [7] is used, as opposed to TCP, that was used in the IFrame case. Further comparison of the two applications also showed the differences in YouTube's adaptation algorithm. Considering these differences, models built using the data from the IFrame case are not applicable in this one, and new models should be built for this scenario. Another activity we plan, regarding the client applications, is building the YouQ application for iOS.

B. Different transport protocols

Using as a client device Samsung S6, we found that in all access network cases (WiFi, 3G, 4G) and using both the Chrome browser (version 55.0.2883.91) and the YouTube app (version 12.01.55), QUIC was used as the default protocol (Feb. 2017). As QUIC was formally proposed to the IETF as an Internet standard [7], it seems highly likely that QUIC will in the future be the base for YouTube functionality. Therefore, we plan to do an in depth study of the QUIC protocol and its impact on performance of the YouTube service. We already defined a set of QUIC traffic features that can be correlated to QoE, incorporated the calculation of these features into YouQ, and plan on running experiments to collect data and build classification models.

C. User behaviour

Finally, we are investigating different aspects of user behaviour and their effects on the service. We plan on running experiments and collecting training data involving different user interactions (e.g., using a playlist, autoplay, manually browsing through videos, seeking forward/backward, etc.), to determine the implications with respect to developing ML-based QoE classification models.

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Building an Agent-Based Model for Study of Product Development Team's Adaptability

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***Abstract*—Teams play a significant role in the process of product development, regardless of whether the product developed is a machine, software or service. As such, a number of studies have been conducted to determine factors influencing team effectiveness and performance. Due to flexibility, effectiveness and applicability of computational models, modelling and simulation approach has been used to aid research on teams, and simulations have been successfully utilised for studies on different aspects of teamwork. However, the full potential of computational experiments has yet to be achieved, as studies focusing on emergent properties of product development teams are seldom. One of team properties essential for product development's success is team adaptability, as teams have to constantly adjust to market changes, alterations in team structure, technology advancements, changes in product requirements, or upcoming deadlines. Thus, the development of a simulation framework which would enable studies of product development team's adaptation is of particular interest. This work presents the research aimed at the development of such framework.**

I. Introduction

A *team* is defined as a group of two or more people collaborating to achieve a shared goal [1]. In product development context, team members are utilising their knowledge, exchanging information and coordinating their activities in order to produce the description of, for example, a machine or software. As noted in [2], teams in product development promote organisational success in terms of acceleration of the product development cycle, increase in quality of developed product and reduction of development cost. However, more research is needed to determine the necessary and sufficient requirements for a team to perform successfully and achieve such advantages. A team property of special importance for a success of product development is team adaptability. Namely, teams have to cope with product requirements change, market fluctuations and technology advancements, as well as resolve conflicts and handle exceptions occurring during the project execution. Further, boundaries of product development teams are often fluid, and membership is temporary [2] and, as such, team members have to frequently adjust their processes to accommodate new members or substitute for those that have left.

Unfortunately, despite recognised importance of team adaptability [1], more research is needed to validate existing theoretical models, and gain an understanding of adaptation triggers, antecedents, mediators, outcomes and processes related to adaptation (e.g. team learning) [3]. Studies of teamwork and team adaptation are hampered by the difficulty of collecting team-related data due to complexity and unpredictability of relationships among team members and technology, as well as a large number of intangible elements influencing team performance. Therefore, additional research tools which would enable controlled, systematic studies of teamwork are needed to advance understanding and management of product development teamwork.

II. Research objective

Computational modelling and simulation can aid researchers in overcoming obstacles in teamwork studies described in the previous section. As stated in [4], computational models can serve to test various hypotheses, theories and ideas, therefore guiding the researchers' intuition, suggesting critical experiments and directing the future research. Building a computational representation of the real-world system and manipulating it to observe its behaviour reduces risks, time requirements and cost of real-world studies. Such method is particularly suitable for studying properties of complex systems (e.g. teams), as it enables controlled and repeatable experiments, as well as gradual refinement of the model, thus providing a means to isolate the influence of various processes which are indistinguishable in the real-world setting. Before utilising the model for research purposes, however, one must ensure that relevant elements and processes are appropriately represented in the model and that simulated behaviour provides a good approximation of the phenomenon of interest. In other words, a modeller must base the model assumptions on theory, calibrate model parameters based on theoretical and empirical findings, and ensure findings obtained through experimentation with the model are sensible.

In the context of product development teamwork, one would like to obtain a model which would enable simulation of team members' behaviour, and use it to study how team members' interactions with each other and with technology affect the team performance. Once teamwork model is defined (i.e. model elements and their relationships) and implemented, it could be used to study how team behaviour differs prior and as a response to the encountered changes in external or internal circumstances. Therefore, the main goal of the presented research is to develop and validate the theoretical

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and computational model of teamwork in order to enable simulation and study of team's capability to adapt to changes in external and internal circumstances occurring during the product development activities.

III. Research Methodology

As shown on Figure 1, a methodology used for obtaining the model described in the previous section is developed after [5] and consists of three cycles: Relevance cycle, Development cycle and Rigour cycle. A proposed research study commences with the *Relevance cycle* where the computational modelling environment will be linked with needs (i.e. circumstantial environment), stated in the forms of requirements and specifications for a solid understanding of the product development teamwork, setting the problem space, and informing the research with the associated requirements and constraints. Firstly, the phenomenon and variable of interest will be identified and defined, including the description of how to measure them in a reliable and valid manner. Secondly, the scientific principles and the nature of variables' relationships with the observed phenomenon (i.e. emergent properties of teamwork) in the context of the critical situations in product development will be examined. Thirdly, the computational methods (e.g. agent-based modelling) for exploring the relationships between variables and the studied phenomenon will be discussed and analysed. A literature review will be conducted, and a set of preliminary models will be developed to establish a valid basis for the research framework focusing on team's emergent properties. As an outcome, the primary variables and factors that are relevant for the analysis of team's emergent properties, particularly adaptability, will be identified and computational modelling paradigm will be defined.

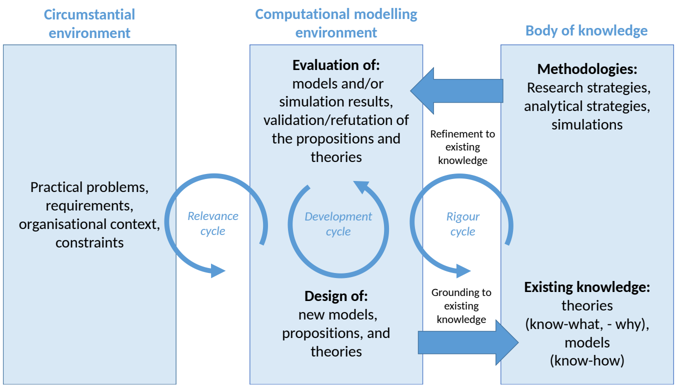

Fig. 1. Research methodology (based on [5])

In the *Development cycle*, findings from the previous phase will be implemented in the form of computational models. More precisely, this cycle begins with a definition and conceptual modelling of the system used for simulation of emergent team properties. System elements will be defined, and rules for their behaviour, evolution and interaction will be explicated. Models aimed at representing specific system behaviour of importance for teamwork simulation will be designed. Upon implementing designed models, experiments will be designed to iteratively test the models, to ensure internal validity, and enable refinement directed at an increase in consistency with the available theories and empirical findings.

Finally, in the *Rigour cycle* the models needed for teamwork simulation will be integrated into the coherent simulation framework. Findings based on a comparison of the outputs with the literature-based predictions and empirical data (i.e. the body of knowledge) will be used for calibration, refinement and remodelling. The combination of different data sources for calibration will produce different perspectives, and the subsequent interpretation of the simulation results should be based on the comparison of more than one view and as such will establish a basis for more reliable and valid results. Also, in respect to team adaptability, new research propositions will be created and evaluated to bring consistency and transparency to various aspects of teamwork. Newly obtained insights could lead to the formulation of models for the description of the adaptation process and adaptability of the team members when external or internal triggers are applied in critical product development activities (e.g. problem-solving, ideation, decision-making). As such, they will also serve as a link between managerial product development activities and theoretical contributions to new scientific knowledge.

IV. Expected Results

The research described is expected to result in the development of a theoretical and computational model of teamwork which is calibrated and validated and enables simulation and study of team adaptability. Once implemented, the simulation framework will be used as a computational laboratory enabling studies of various aspects of teamwork and providing a means to create numerous controlled experiments with the flexibility unattainable in the real world setting [6].

Acknowledgment

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Decision Support System for Managing Electric Vehicle Charging Infrastructure

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***Abstract*—Today, electric vehicles (EVs) market penetration is growing faster than ever before, and that is causing drastic changes in the transportation industry and, more broadly, in business, policymaking and society. As the number of EVs on the road increases, there is a higher demand for charging stations. This paper proposes the decision support system (DSS) for charging station infrastructure providers, based on the real-world data. One of the problems the proposed DSS can solve is described with the case study presented in this paper.**

Keywords—electric vehicles; green transportation; machine learning; big data; energy informatics; decision support system

I. INTRODUCTION

Fossil-fueled vehicles are considered to be one of the main contributors to the emission of CO_2, which is one of the main factors in global warming. Solution to that problem is higher acceptance of electric vehicles (EVs) as they provide clean transportation [1]. Although EV market penetration is growing (i.e. for four-year period, EV market share in Netherlands has increased nine-fold [2], while share of plug-in hybrid electric vehicles (PHEVs) has increased 20-fold), *range anxiety*, defined as a fear of running out of electricity far from charging stations, is still one of the top negative factors influencing drivers decision to buy an EV [3].

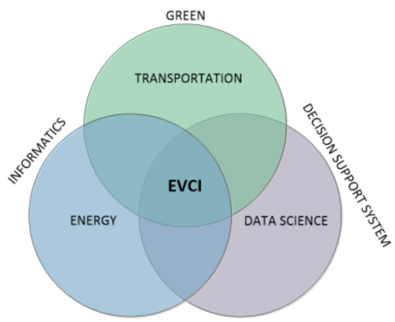

FIGURE 1 MULTIDISCIPLINARY RESEARCH CHALLENGE: INTERSECTION OF ENERGY, TRANSPORTATION, AND DATA SCIENCE FIELDS

In this paper we propose the generic framework (based on real-world data) as a support for EV charging infrastructure providers in their decision to optimize their charging network (EVCI Framework). If charging infrastructure providers could increase their profit with adding new charging stations (CS), there would be more charging stations, range anxiety would be lowered and therefore popularity of EVs would increase which would ultimately lower air pollution. Current research on described topic can be divided into three streams as depicted in Fig. 1: (**i**) *green transportation* [4], (**ii**) *energy informatics* [5], and (**iii**) *data science* [6].

II. THE EVCI FRAMEWORK

EVCI Framework is composed of four major modules as depicted in Fig. 2: (i) *Model Builder Module* that is used to fine-tune the machine learning algorithm and to provide the initial dataset; (ii) *Future Scenarios Predictor Module* is used to predict new utilization value when number of CSes in the dataset is changed, or when the number of places of interest (PoIs) is changed; (iii) *Business Analytics & Reporting Module* is used to report the descriptive statistics of the dataset (e.g. utilization per hour of the day, utilization of top-K chargers, or comparison of utilization through years); and (iv) *Charging Infrastructure Extender Module* is used to ultimately provide the answer about the location of new charging station based on the objective function provided (i.e. minimize utilization loss, increase number of CSes in CS low populated area, or hybrid approach). The framework itself is generic and can be easily applied to different problems, wherever there is a need to solve supply-demand location-based problem. User can manipulate various parameters of the EVCI Framework (e.g. clustering method, machine learning method, or objective function).

III. EVCI DATASET

The dataset with information about charging transactions is the core part of this research. Such dataset is provided by ElaadNL, one of the top EV charging infrastructure providers in Netherlands. The dataset consists of all transactions for their infrastructure for four consecutive years (from 2013 to 2016). Transaction is defined by all actions from the time EV owner plugs into the charging station until the EV is unplugged. Some of the variables in the dataset are: *Transaction ID*, *Charge Point ID*, *Transaction start/end Time*, *Connected time*, *Charge time*, and *Idle time*. Besides initial information, the EVCI dataset is enriched with information about PoI from the Google Maps API, distance between each two charging stations (fetched using the Nokia HERE API), and with information about competitors charging stations (fetched using the Opladpaalen API).

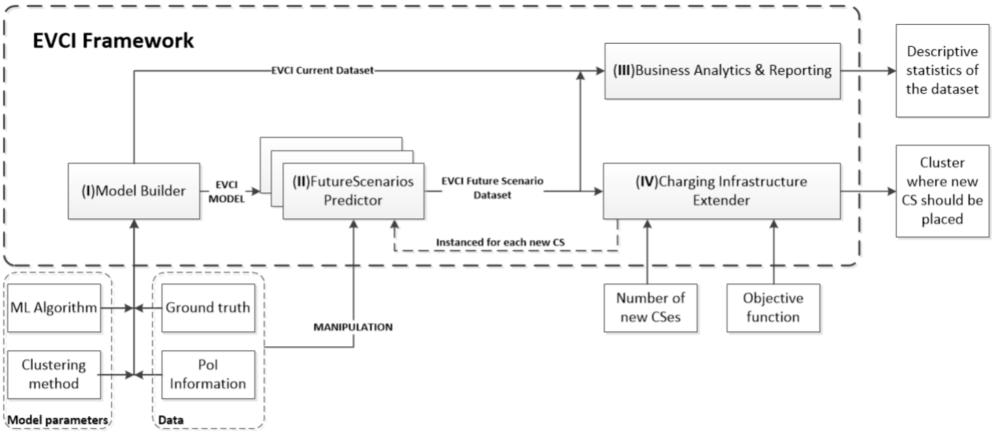

FIGURE 2 EVCI FRAMEWORK COMPOSITION

Since one transaction can span through multiple hours, each transaction is divided per hour for more precise time resolution (statistics-vise). To calculate utilization in certain region in Netherlands, charging stations need to be clustered into regions. We decided to use driving-distance based clustering, since it was calculated that this method improves accuracy for 31% in comparison to traditional air-distance based clustering. We assumed that an average EV owner has similar behavior as the owner of fossil-fuelled vehicle and is willing to travel between 5 and 10 minutes to reach next available CS. Taking into account similarity between owners of EVs and fossil-fuelled cars and the fact that an average speed in a populated area is between 20 and 35 km/h [6], our clusters are based on a 3 km distance.

IV. CASE STUDY: “WHERE SHOULD AN EV CHARGING PROVIDER DEPLOY ANOTHER CHARGING STATION?”

This case study is previously studied in [7] and [8]. Machine learning algortihm is the crucial part of the framework since it carries its main functionality – prediction of utilization. EVCI Framework uses two machine learning algorithms. First one is the Multiple Linear Regression (MLR). MLR has low prediction accuracy and cannot be used to predict utilization and therefore is used for better understanding of variables (e.g. how they influence utilization, or how they corelate with each other). Second algorithm, the XGBoost, has proven to be powerfull and versatile since with basic parameters it creates high accuracy model. Error measures of XGBoost against the baseline model, that is based on average value of utilization per hour of the day in a cluster, is presented in Tab. 1. The average error is around 5% while baseline model has average error of 7% and there is still a lot of place for improvement.

TABLE 1 ERROR MEASURE FOR XGBOOST PREDICTION MODEL

MEASURE	XGBoost	Baseline model
Mean absolute error	0.031840	0.046999
Root mean square error	0.051223	0.070570

Based on the previously described dataset, clustering method, machine learning algorithm, and objective function to minimize the utilization loss, new charging plug should be deployed in a 3 km radius from the center of *Schoorl village*. Another charger in that area would lower the utilization for $6.55 \cdot 10^{-6}$% which means that area has high demand for charging stations. Currently that area has 3 charging plugs and utilization of 17%.

V. CONCLUSION AND FURTHER WORK

EVCI Framework provides charging infrastructure providers with smart and efficient methods for deployment of new charging stations. Furthermore, EVCI Framework will also be able to answer questions like where to remove CS, or how to reallocate the existing CSes. This is not only important from the standpoint of infrastructure provider but from the perspective of environment and people as well, since everyone can benefit from practicing green transportation. For futher work, plan is to build the entire DSS system (EVCI Framework), obtain new data (i.e. different infrastructure provider), to improve machine learning precision (e.g. fine tune the parameters), and to introduce new context variables (e.g. is the cluster located in rural or urban area).

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Analysis of the New CMS Detector Design Properties

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***Abstract*—Basic research motivation is the improvement of CMS detector end-cap part which is being replaced with a newly designed one by using an advanced silicon sensor technology. Doctoral candidate's research work has the goal to define and implement algorithms for generation of basic objects, so called Trigger Primitive Generation. This requires some basic analysis of the new CMS detector geometry as a preprocessing step, taking into account the constraints and the specific properties of the detector that can later influence on the recognition process.**

Keywords — CMS, design, analysis.

I. Introduction

The Compact Muon Solenoid (CMS) detector is continuously being improved because of the development of new detection technologies and the need to replace parts of the detector which cannot resist very high levels of radiation [1]. Basic motivation for this research analysis comes from the previous context, by working on the design upgrade of the CMS detector whereas the most important part being replaced is electromagnetic calorimeter end-cap (Fig 1).

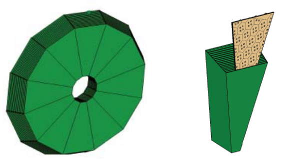

Fig. 1. The proposed electromagnetic calorimeter end-cap

II. Research Topic Presentation

A. Mechanical design constraints

Basic mechanical constraint is a definition of the new end-cap as an alveolar structure shown on Fig 1. The overall geometry contains twelve 30 degree sectors into which hexagonal sensor tessellated silicone cassettes are inserted. Readout cells can be of various shapes, and the choice of using hexagonal sensors for detector upgrade is driven by costs as hexagonal shape uses the largest fraction when produced from the circular silicon wafer. Technical report [1] foresees using cells of 1.05 cm^2 and 0.53 cm^2 area fabricated on six-inch and eight-inch wafer production lines. Modules are foreseen to have 256 communication channels, so the total number of hexagonal sensor cells inside the hexagonal module should be as close to 256.

B. Default requirements for the design analysis

Design of the hexagonal module embedded with hexagonal sensor cells is a challenging task. Namely, a hexagon cannot be composed of entire smaller hexagons but it has to be combined with using partial hexagons or non-hexagonal shapes. There are many researches that provide some ad-hoc usage of hexagons in a specific field, such as cartography [2] or sensor manufacturing [3], not concentrating explicitly on solving the problem of embedding hexagons into hexagons. Our research analysis is based on solving this specific problem from a mechanical point of view, as described in a previous section and provides a systematic approach in analyzing the possible solutions with a general hexagonal architectures definition. Basic goal of this analysis is thus to derive and visualize the possibilities of how smaller hexagons can be efficiently embedded into larger hexagon while having as few partial or distorted cells at the hexagonal module boundaries. Non-hexagonal shaped cells originate from constraint that module borders can be cut straight only. The total number of sensor cells inside the module has to be calculated together with the area of a cell and total module area based on the chosen wafer radius size. Silicon efficiency calculation is important as well, taken into account its cost per unit area. The module architecture chosen for the end-cap design should be of similar silicone efficiency as it is of a regular hexagon (83%).

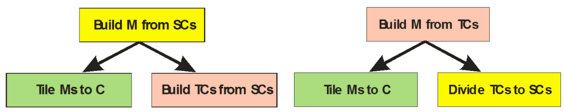

Fig. 2. System design approaches

About one billion proton-proton interactions will take place every second inside the detector. Not all the data can be read out, and even if they could, most would be less likely to reveal new phenomena. Trigger function is thus to select the potentially interesting events, and reduce the rate to just a few hundred events per second, which can be read out and stored on computer disk for subsequent analysis. Trigger cells are groups of hexagonal sensor cells as clustering the data and providing data reduction is a very important aspect in the CMS detector design.

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C. Module design approaches

There are two possible approaches that can be used for the module design, a sensor-cell centric and a trigger cell centric, as illustrated with the diagram on Fig 2. In our research the sensor-cell centric or bottom-up approach is used, since we first build hexagonal sensor modules from hexagonal sensor cells and then group them into trigger cells. We then further tessellate hexagonal modules to form the one layer of the full end-cap. Basic analysis questions are defined by the mechanical design constraints. Goal is to have minimal number of partial sensor cells at the module borders together with maximal number of full hexagonal sensor cells. There should be low fluctuation between cells in size and area, so maximum number of identical cells is required. This means that non-hexagonal cells at the borders can be acceptable if their area is the same as the area of a full hexagon. In addition, when tessellating the hexagon modules in the end-cap layer, minimal distortion of the sensor cell plane is preferable.

III. Module Design Analysis

As a result from our analysis, we identified different architectures which we divided in two basic classes. Hexagonal module architectures in the first class are regular and aligned with sensor cells, which are then divided in two subclasses; architectures with the central sensor cell and moved architectures in the sensor plane that do not have the central cell. We named these aligned centered (AC) and aligned up (AU) respectively. Each class of architectures has its specific topological properties, such as total number of full hexagonal cells as well as total number of different odd-shaped sensor cells at the module boundaries.

TABLE I. MODULE ARCHITECTURES COMPARISON

	Properties			
	Full Hexagon Cells	*Max. number of different border cell types*	*All sensor cells the same in area*	*Sensor cells plane distortion*
AC	yes	2	no	no
AU	yes	2	no	no
RE	yes	3	no	no
RO	yes	2	yes	yes
RES	yes	2	yes	yes
REW	yes	2	yes	yes
ROD1,3	yes	2	yes	no
ROD2	yes	2	yes	yes

Module architectures in the second class are rotated with respect to the sensor cells. They are divided in two subclasses; regular and the distorted ones. Regular rotated modules can form architectures with and without the central sensor cell, named rotated odd (RO) and rotated even (RE). Additionally, two new subclasses are derived from the RE architectures, called rotated even squeezed (RES) and rotated even widened (REW). Top and bottom edges are adjusted to contain full sensor cells. Distorted architectures are derived from the RO architecture, in order to maximize the total number of identical sensor cells inside the module. We named them rotated odd distorted ROD1-3 according to the difference in referent hexagon edge size. Short comparison between module architectures is given in Table 1.

IV. Visualization and Analysis Results

A drawing algorithm was developed to visualize the module design possibilities and to provide analysis results in a visual and numerical form. Design of the whole end-cap layer can be presented aesthetically to see where the cuts need to be applied. Example of the AC module architecture tessellation is given on Fig 3. From the numerical output file, information about particular sensor cell area as well as the total area of the module can be obtained. This is very important for the end-cap design analysis since the CMS technical report foresees having the sensor cells of 1.05 and 0.53 cm^2 areas inside a hexagonal module. In addition, module area is an important input to the silicone efficiency calculation.

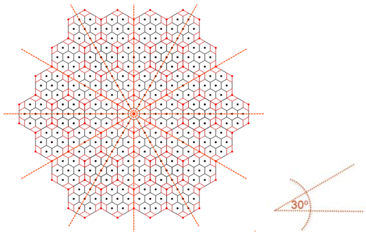

Fig. 3. Cassette borders in CL and EL visualization

Silicon efficiency is calculated for the distorted architectures which are compared on Fig 4. It can be seen that silicone efficiency is slightly reduced with the distorted architectures with respect to regular hexagons. However, the difference is actually negligible as it is below 10%. This shows that using distorted hexagonal module is cost effective. Effect of using distorted architectures compared to the non-distorted ones in terms of silicone efficiency is negligible.

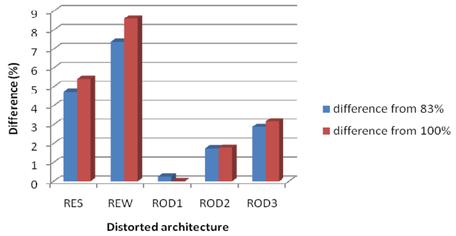

Fig. 4. Silicone efficiency comparison between distorted architectures

V. Future Work

When the whole end-cap layer plane is modelled with the hexagonal modules embedded with hexagonal sensors, further analysis can be worked out in terms of data reduction of the trigger system. A study of subdivision possibilities in the clustering sensor plane can be worked out and the idea of uniform trigger cells can be tested while grouping hexagonal sensor cells into various cluster types. This can be interesting in order to reduce the communication factor between modules and to keep the neighbour finding clustering algorithm as simple as possible.

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Objective Real-Time Video Quality Assessment

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Abstract—**There is currently an increased demand for video content delivery over the Internet. Therefore, monitoring video quality in real-time is becoming more important for different parties involved in video content delivery like content and service providers or network operators. This paper presents current state of research in the field of objective video quality assessment and points out possible research directions.**

Keywords— Video quality assessment; objective metrics; real-time quality assessment

I. INTRODUCTION

There is currently a growing demand for video content that is obtained over the Internet. This results in a growing competitiveness among the providers of these services. Providers need to guarantee Quality of Service (QoS) to justify subscription fee. Since the video content can be distorted in different phases of its delivery to the end users and therefore affect Quality of Experience (QoE) of the end-user, providers are interested in estimation of the perceived video quality. Such procedure is known as Video Quality Assessment (VQA). There are two types of VQA: subjective and objective. Subjective video quality assessment involves people that are watching videos in controlled environment and giving their opinion about video quality. Since this approach is quite time consuming and impractical, it cannot be applied for real-time VQA. On the other hand, objective VQA is based on computational models (metrics) which estimate perceived video quality [1]. Therefore, these methods can be automated and applied for real-time VQA. Naturally, the estimation of video quality with objective methods should be as close as possible to the people's opinion regarding video quality.

There are three types of objective VQA: full reference (FR), reduced reference (RR) and no-reference (NR). In full reference objective VQA original video is available so video quality of the distorted video is estimated based on a comparison with the original video. In reduced reference objective VQA only some of the representative features of the original video are available. However, in many applications (e.g. video streaming) the information about original video is not available and thus video quality is estimated without reference. Such approach is called no-reference VQA and is usually based on detection of different artifacts that can appear in video content due to the errors that occur during video content delivery [2].

In this paper, current state of the art regarding NR and FR VQA is reviewed. Based on the given overview, possible research direction with respect to NR VQA are given. More precisely, machine learning is pointed out as a possible approach to enhance NR VQA in terms of correlation with the users' opinion about video quality. However, current trend toward 4K video resolution has to be taken into account when developing such metrics.

Fig. 1. Example of a video frame with packet loss [3].

II. VIDEO ARTIFACTS

The errors that appear during video content delivery manifest in video as artifacts and affect perceived video quality. The most common artifacts are: blurring, blocking, ringing, noise, and temporal impairments such as jerkiness, frame freeze, jitter, flickering. Reason for occurrence of artifacts is high compression or information loss in transport like packet loss. Blurring can be described as loss of image sharpness. Blocking is discontinuity in neighboring blocks such as in color or brightness. Ringing can be described as outline around high contrast edged. This three artifacts appear due loss of high-frequency components caused by high compression. Due to the packet loss, random blocks of the video frame can be dropped and are replaced in certain way as shown in Fig. 1.

Efficient artifacts detection can be quite challenging in the case of NR VQA. For example, packet loss artifact (see Fig. 1) in video frame can be difficult to detect due to its randomness regarding time and spatial appearance, different concealment that can be implemented in decoder and so on. Furthermore,

TABLE I. NR METRICS COMPARISON

Approach	*Correlation coefficient*	*Database*
Bitstream [4]	0.945	EPFL-PoliMI [5]–[7]
	0.903	LIVE [8]
Pixel based [9]	0.78 to 0.91	LIMP [9]

TABLE II. FR METR ICS COMPARISON

Metrics	**Linear correlation coefficient**	
	LIVE database [8]	***VQEG database [10]***
PVM [11]	0.8157	0.8682
VQM [12]	0.7748	0.8673
ST-MAD [13]	0.8245	0.7053
MOVIE [14]	0.8112	0.8546

artifact influence on the perceived video quality depends on number of different factors and can be even more challenging to estimate. Therefore, NR VQA metrics are usually developed based on certain video database and thus are suited to video content with special type of artifacts (e.g. due to compression).

III. CURRENT TRENDS IN OBJECTIVE VQA

Table I. shows state of the art regarding NR objective VQA. Bitstream based metric [4] has relatively good Correlation Coefficient (CC) to subjective scores. Pixel based metric [15] results are correlation between results of this NR metric and FR VQM [12] results. Pixel based metric is based on Deep Learning methods. Bitstream based approach model was trained using FR model evaluation based on the VQM metric. In both cases VQA is done in real-time.

The FR metrics with the best performance are ST-MAD and PVM as shown in Table II where linear correlation coefficient shows correlation of the metric results and subjective scores on given databases.

Results from Table I and Table 2 suggest that there is a room for metrics enhancement with respect to correlation with the users' opinions about video quality. In practice, VQA metric result correlation should be as high as possible with users' opinion on different types of video content as well as in the presence of different video distortions or artifacts.

IV. CONCLUSION

Although FR metrics have high CC, they do not have practical importance for problems like network and service monitoring since referent (original) video is not available. Only viable options in that case are NR metrics with the accent on real-time application. Without referent video it is difficult to detect artifacts and their impact on video quality due to their randomness and diversity. Since the rules and algorithms for artifacts detection and their influence on perceived video quality is usually difficult to handcraft, machine learning (ML) emerges as an approach for solving this problem by automatic learning of the relationship between distorted video and perceived video quality in a way such that ML models are trained on FR metrics results for distorted video frames. Doing so, a more general NR VQA metric can be possibly developed which has high performance for different type of video content and video distortions. Another path of this research is how well current state-of-the-art NR metrics are suited for video with 4K resolution and development and optimization of NR models based on deep ML models for real-time VQA of 4K videos. However, since there is a lack of 4K video databases designed for VQA metrics development, a development of appropriate databases will be an important step in new VQA metrics research.

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Towards SDN-enabled Application-aware Network Control Architectures

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***Abstract*—The users' satisfaction with multimedia applications dictates the consumption of these services. Hence, the optimization of Quality of Experience (QoE) is a critical objective for application and network providers. Several works propose an interaction between application and network to appropriately decide on control actions to enhance QoE. Upcoming technologies towards softwarized networks, like SDN and NFV, leverage QoE management by providing capabilities for monitoring QoE influence factors and by facilitating a standardized, centralized control of the network. My PhD thesis envisions how QoE can be improved with these technologies by means of a joint control plane for applications and network.**

I. Introduction and Motivation

Software Defined Networking (SDN) overcomes several limitations of conventional network architectures by separating control plane and data plane. This SDN principle leverages the configuration, control, and implementation of functions on network devices in a standardized and centralized manner. It shifts the intelligence, which is conventionally distributed among the devices in the network, to one logically centralized unit with a global network view, the SDN controller. The controller decides about control actions in the network and communicates instructions to the network switches via standardized protocols like OpenFlow [1].

SDN enables to distinguish and differently treat applications, e.g. by technologies like DiffServ or IntServ. Further, Quality of Experience (QoE) measures for applications within a network can also be taken into account. Thus, the SDN controller can control the network resources based on these application-specific metrics and provide QoE for different applications. This is for example realized in [2], where a QoE-centric application-aware networking mechanism is presented. Depending on a YouTube client's buffer state and the bandwidth requirements of the corresponding flow, the controller chooses a less congested link for data transmission. A similar approach is presented in [3]. The proposed SDN-based video streaming architecture considers various video QoE metrics like initial delay and buffer to select an appropriate delivery node based on current network conditions and to dynamically select the network routing paths.

Current research widely covers mechanisms that target QoE-driven adaptation of the network, the application, or both. The various approaches differ in terms of collected application/network information, performed adaptations, and the way application and network interact with each other. As the proposed approaches are tailored and optimized for specific use-cases and often focus on a single application, the corresponding evaluations are limited to a set of application-specific metrics and only consider few selected scenarios. To date, there are no holistic evaluations that reveal and compare the impacts, advantages, and disadvantages of those approaches in different (multi-application) scenarios.

My PhD studies aim on filling this gap. Furthermore, the goal is to examine how the various techniques applied in those mechanisms can be employed on existing technologies, e.g. SDN or NFV, in a meaningful manner. Section II motivates the investigation on how a joint control of application and network can be designed within an SDN-environment to support application-aware network control. Section III presents past and current work in the context of application-network interaction.

II. PhD Thesis Outline

Several QoE-management mechanisms propose an interaction of applications and the underlying network. The information exchange facilitates to decide about control actions that enhance QoE. My PhD studies target a detailed investigation of the techniques applied in those approaches and how they can benefit from existing technologies like SDN. One key goal is to design and evaluate the performance of an application-aware network control architecture in the context of SDN. In particular, the following three main topics are covered. (1) Designing a network-aware application control plane that optimizes the overall QoE for a multitude of applications, (2) designing an application-aware SDN control plane, and finally (3) designing and evaluating a joint application and network control plane. There are certain design choices that need to be addressed for joining the application control plane and network control plane.

- Which information about network and application is needed at the control planes?
- At which granularity must information be present, e.g. network probing intervals, accuracy of buffer estimation.
- Where and at which level to collect information? For example, application information can be extracted from network packets (DPI) or can be signaled by the application itself. In the network, e.g., information can be gathered on flow-level or packet level.
- How to design decision algorithms for an optimized QoE?

In the course of designing a joint application and network control plane, it must be examined which information needs to be exchanged. Furthermore, the frequency of information exchange dictates how up-to date, and hence, how reliable information is. This also depends on the methods used for information exchange, e.g. pushing vs. polling. I also plan to evaluate possible technical and logical realizations of the joint control plane. On the one hand, information can be directly exchanged between application control plane and network control plane. On the other hand, a centralized entity with global knowledge could be introduced, eliminating a direct communication between applications and network. The design is driven by several impact factors, including technical feasibility, the induced complexity, and the resulting trade-off between overhead and performance gains.

Moreover, it is an essential to examine potential challenges of such a control plane. A joint optimization in the case of over-the-top applications, for example, involves several stakeholders. Hence, a solid business relationship must exist, providing incentives for each concerned party and agreements on the information exchange.

Within the scope of the thesis, I will provide a cartography on strategies that enhance QoE by supporting the interaction of application and network. Benchmarking and performing detailed evaluations of different mechanisms in relevant scenarios will reveal the applicability of certain strategies and their impacts on QoE influence factors. Thereby, I will consider several techniques, such as testbed-driven measurements, simulation, and modeling. Obtained results facilitate conclusions about pros and cons of the mechanisms under different conditions and reveal generic relationships. Finally, the PhD thesis studies new mechanisms, which shall consider a multitude of applications and combine the identified advantages of existing solutions.

III. Current Work on Interaction of Application and Network

Our first steps towards designing a joint application and network control include an extensive literature study on published works that propose an interaction between application and network for improvement of user-QoE. The different QoE management approaches differ greatly, e.g. with respect to their goals, as illustrated in Figure 1. Whilst some works target video quality fairness among users with heterogeneous device capabilities, others aim on smooth streaming by preventing stallings. However, they have in common that they all implement a certain control loop, which includes the following building blocks: *Application Monitoring (AM)*, which collects quality indicators related to the applications (e.g. buffer, initial delay) and *Network Monitoring (NM)*, which respectively collects information on network-related metrics. A centralized instance, called *Policy Manager (PM)*, collects the information and decides about actions that are implemented by the corresponding control entities *Application Control (AC)* and *Network Control (NC)*. We refer to this interaction as *Application-Network Interaction (App-Net)*, and

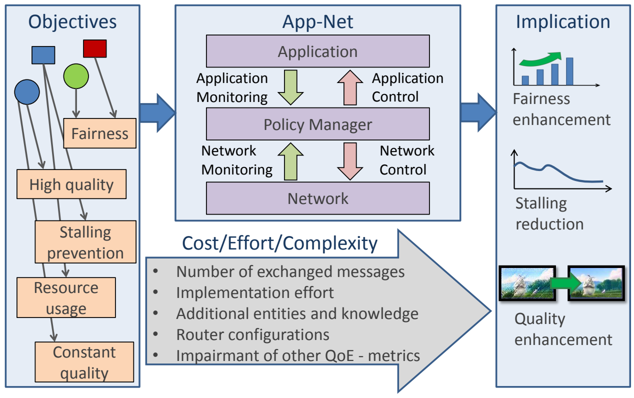

Fig. 1. QoE-management mechanisms vary with respect to their goals. The different implications are results of performing App-Net, which induces an additional complexity, that can be quantified in different ways.

also refer to mechanisms that implement it as App-Net solutions. Performing App-Net leads to implications like enhanced quality, less stallings, or higher fairness. However, this induces an additional complexity. To measures this overhead, e.g., a quantification of the implementation effort or the number of exchanged messages to realize App-Net may be considered.

In previous work [4], a classification of several App-Net mechanisms with respect to their monitoring/control support was presented. To investigate the impacts of those mechanisms on various QoE metrics like stalling, initial delay, video quality, or video quality fairness, we implemented three solutions to perform measurements for a quantitative, holistic comparison. As a first indication of the complexity, we considered the number of exchanged control messages.

The comparison of the different App-Net strategies with each other and against a baseline implementation reveals the potential of those mechanisms. The results show that the mechanisms' impacts on QoE influence factors and the applicability of certain solutions are diverse for different scenarios. This highlights the importance to perform a broad benchmarking.

Acknowledgement

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Energy efficient service provisioning in Machine-to-Machine systems

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***Abstract*—Internet of Things (IoT) systems have become ubiquitous, with many deployments spanning various domains. In settings where IoT devices are battery powered, energy-efficiency is an important aspect that needs to be taken into account. One of the key concerns is the fact that data from IoT devices is often sent in streams even when users do not have a need or interest for it. In our energy-efficient approach, the system is designed in a user-centric way, enabling control of IoT devices according to user needs or user-defined rules, thus conserving the energy when no interest in IoT data is expressed. Furthermore, the proposed system enables data analysis in the fog, and deciding on the node where it is more energy-efficient to perform analysis tasks. In the system more services can be executed on one IoT device, and decision on the best allocation is made with a goal to prolong the lifetime of services with higher priority. The results show how the allocation mechanism which takes advantage of the aforementioned features increases the lifetime of prioritized services.**

I. Introduction and motivation

Advancements in hardware and networking technologies brought new challenges to the area of sensor networks. Hardware improvements enabled execution of complex tasks on sensing devices. Such tasks include algorithms for data processing which were in earlier solutions always executed on a node within a back-end system [1]. Apart from the possibility to execute complex tasks, it is also possible for one sensing device to have more sensors attached to it. In that way, one sensing node can provide data to more than one service [2].

The possibility to access sensor nodes via Internet upgrades the notion of sensor networks and brings it closer to the notion of Internet of Things (IoT). With this connectivity, nodes can be controlled remotely, which enables a new possibility - to start and stop services based on user needs. In a traditional approach, services are running constantly and transmitting all of the acquired data [3]. However, the possibility to have a connection between users and sensors needed for their applications enables the control over sensors in relation to user needs. For instance, users might want certain data only in certain periods of time, and not all the time.

The focus of this research is allocation of tasks, that compose services, to sensor nodes and sinks. We use the term Machine-to-Machine (M2M) system because it considers the whole architecture for service provisioning based on sensor data - from application to sensor nodes. Our solution is compliant with oneM2M standard [4], which defines the architecture for M2M Communication and the Internet of Things. According to oneM2M, the terms M2M and IoT can be used interchangeably. In the standard, sensor nodes are referred to as M2M devices and sinks as M2M gateways.

The solution proposed in this research allocates tasks, which compose services, to nodes of the field domain within M2M architecture (M2M devices and M2M gateways) where M2M devices are battery powered. The novelty of this approach is in the following: i) it enables user-centric deployment of services, based on user needs; ii) data processing tasks can be executed in fog network on M2M devices or on M2M gateways, the decision is made according to energy efficiency of possible solutions; iii) it puts services in focus, each service has its priority, and the goal is to extend the lifetime of the services with higher priority.

Existing solutions in this area tackle some of the aforementioned novelties [2], [5]. However, they are not all considered within a single system.

II. Model and algorithm for service provisioning in M2M systems

To enable service provisioning, i.e. task allocation to appropriate nodes within field domain of oneM2M architecture, energy model is defined which specifies parameters that need to be taken into account. Energy model includes following subtypes: service model, task model, device model and gateway model. Both M2M devices and M2M gateways are referred to under the expression *node*, defined by parameter N.

Service is composed of tasks, that are allocated to M2M devices or M2M gateway. The important parameter of the service that we introduce is $priority$, and can have values $high$ or low. Task has $en-cons$ parameter containing energy consumption for one execution, based on which service lifetime can be estimated. Device contains $battery-state$ parameter, containing information about the current battery state, and $priority-threshold$, which initiates dynamic reallocation, a term to be presented later on.

The main goal of the task allocation mechanism is to find a task mapping scheme that maximizes the lifetime of high priority services subject to available energy resources on M2M devices. The allocation mechanism needs to find a mapping

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$f : V \rightarrow N$ such that each task $v \in V$ is allocated to a node $n \in N$ where it is executed. A task mapping scheme is denoted as $M^x = M_1^x, M_2^x, ..., M_n^x$ where x is an index of a task mapping solution.

The problem can be formulated as follows:

Find M^{best} where

$t(M^{best}) = argMax\{t(M^1), t(M^2), ..., t(M^x), ..., t(M^m)\}$

M^{best} is the task mapping scheme which maximizes lifetime of high priority devices within all possible task mapping schemes $\{t(M^1), t(M^2), ..., t(M^x), ..., t(M^m)\}$ before next battery recharge. High priority devices are M2M devices executing high priority services. Lifetime of high priority devices within one possible allocation can be found as follows:

$t(M^x) = argMin\{t_{d_1}, ..., t_{d_j}, ..., t_{d_z}\}$ where t_{d_j} is the estimated lifetime of a high priority device within a particular allocation M^x, subject to $f(E_{s_k}, priority_{s_k}, battery\_state_j)$.

Task mapping scheme is found based on energy consumption E_s of each service k and its priority ($priority_{s_k}$).

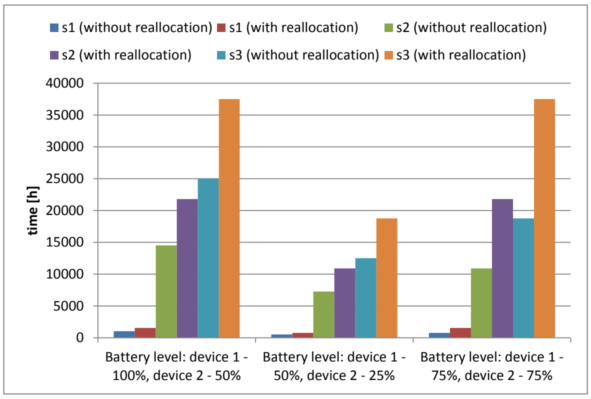
Task allocation mechanism is executed whenever a new service needs to be deployed on nodes, when an existing service needs to be stopped, or upon reaching the $priority - threshold$. This parameter is defined as a battery level at which it is needed to execute dynamic reallocation, i.e. to reallocate services because the battery of the M2M device is nearly drained. This process enables that services continue its execution if other devices are available to host them.

III. Evaluation

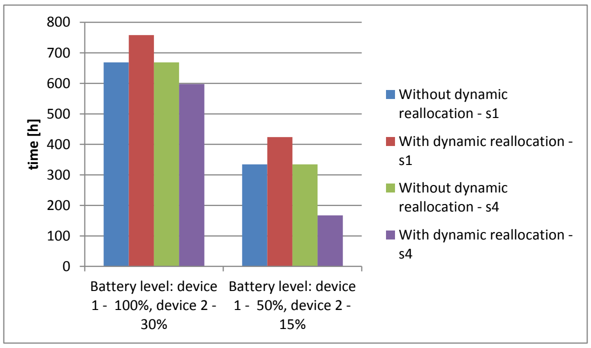
Figure 1 shows how dynamic reallocation as one chosen feature of the proposed mechanism prolongs lifetime of selected high priority services running on its own on one M2M device (shown in Subfigure 1a), and for a high priority service when running in parallel with low priority service on the same M2M device (shown in Subfigure 1b).

In Subfigure 1a) lifetimes for three services are shown: activity detection, luminosity fluctuation detection, and window state monitoring. When using dynamic reallocation in all of the scenarios concerning device battery state, the service lifetime is prolonged for 50-100% because tasks are reallocated from device 1 to device 2 when the device 1 on which they have been running drains the battery.

Subfigure 1b shows lifetimes for activity detection as a high priority service when running on the same device with a temperature monitoring as a low priority service. Due to the service prioritization, a mechanism which ensures that M2M devices with low battery levels are being drained only by high priority services, low priority services should be reallocated to some other device or stopped when reaching a priority-threshold. In the shown case, both devices can execute both services. However, because of the $priority - threshold$, only high priority service can drain the battery, at the expense of a low priority service which is stopped. As a result, high priority service can consume the battery of both devices until the end, which prolongs its lifetime. Low priority service is stopped after reaching a $priority - threshold$ of both devices, which is set at 25% in this experiment, and has its lifetime reduced.



(a)



(b)

Fig. 1: Service lifetime when a) one high priority services is running on one M2M device, and b) when a high priority service and low priority service are both running on one M2M device

IV. Conclusion and Future Work

The algorithm proposed in this paper extends the lifetime of high priority services. The total lifetime of those services depends on the parameters which are defined within the model (measurement and sending intervals), and are not discussed within this work. In future work, the scalability of this approach will be tested, i.e. the time needed to allocate tasks of a larger number of services to a larger number of devices.

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Quality of Experience Driven Video Encoding Adaptation Strategies for Cloud Gaming under Network Constraints

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***Abstract*—Cloud gaming is a highly interactive service that allows on-demand streaming of game content onto non-specialized devices (e.g., PC, tablet, smart TV, etc.). With available network resources varying over time, there is a need for efficient and dynamic service adaptation strategies on the game server to meet different bandwidth availabilities. The main objective of this research is to specify video encoding adaptation strategies to optimize end user QoE for cloud gaming under variable system and network conditions. The research hypothesis is that the novel and context-aware video encoding adaptation strategies can be exploited to improve end user QoE in comparison with state-of-the-art approaches for cloud gaming service adaptation in light of constrained system or network resources.**

I. Motivation

The cloud gaming paradigm has been recognized as a promising shift towards enabling the delivery of high-quality games to nearly any end user device, thus alleviating the need for devices with high-end graphics and processor support. With powerful servers being responsible for executing the game logic, rendering of the 2D/3D virtual scene, video encoding, and streaming game scenes to client devices, the result is a significant increase in downlink bandwidth requirements to secure a good level of Quality of Experience (QoE) as compared to traditional online gaming. A challenge faced by cloud gaming providers is configuration of the video encoding parameters used for game streaming with respect to different available network bandwidth conditions. The cloud gaming server has very limited control over network latency, apart from reducing its own sending rates to avoid filling up router queues during congestion. Hence, codec reconfiguration decisions made by the cloud gaming server (in terms of chosen target bitrate and frame rate values) are driven by measured available effective bandwidth. Additionally, current developed QoE models [1], [2], [3] can for the most part be applied to only one specific game for which they were primarily derived for due to significant differences (in terms of graphics detail, gameplay pace, input rate, etc.) between games that are assigned to the same game category based on present game genre classification. Therefore, there is a need to design an appropriate game categorization for cloud gaming based on objective game characteristic that can be later used as a tool when aiming to develop accurate QoE models for derived game categories. Consequently, such a categorization could then be used for determining optimal adaptation strategies for categories of games, which could in the future automate the process of deciding on the best encoding adaptation strategy for a particular game.

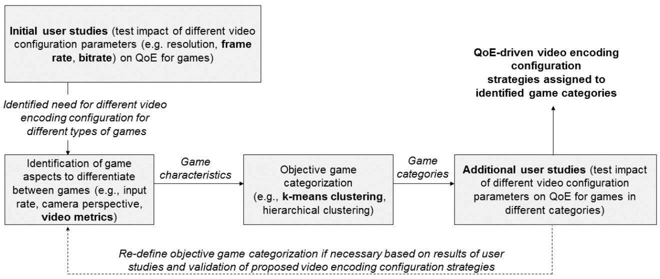

Fig. 1: Research methodology

II. Methodology and current results

Overall methodology of the research presented in the paper is shown in Figure 1. The results of two initial user studies involving 80 participants and three tested games reported in [4] indicate that different video encoding adaptation strategies should likely be applied for different types of games when aiming to maximize QoE. In the mentioned paper, we investigated the impact of video encoding parameters on QoE, i.e. we manipulated video frame rate and bitrate, consequently controlling image quality and smoothness of gameplay. Based on the subjective results (shown in Figure 2) and statistical analysis reported in the paper, main findings were that different codec configuration strategies may be applied to different types of games in light of bandwidth availability constraints so as to maximizes player QoE (this was clearly shown using two games belonging to different genres (Serious Sam 3 and Hearthstone)), and in certain cases, the same codec configuration strategy may be applied to games belonging to different genres (Serious Sam 3 and Orcs must Die). Hence,

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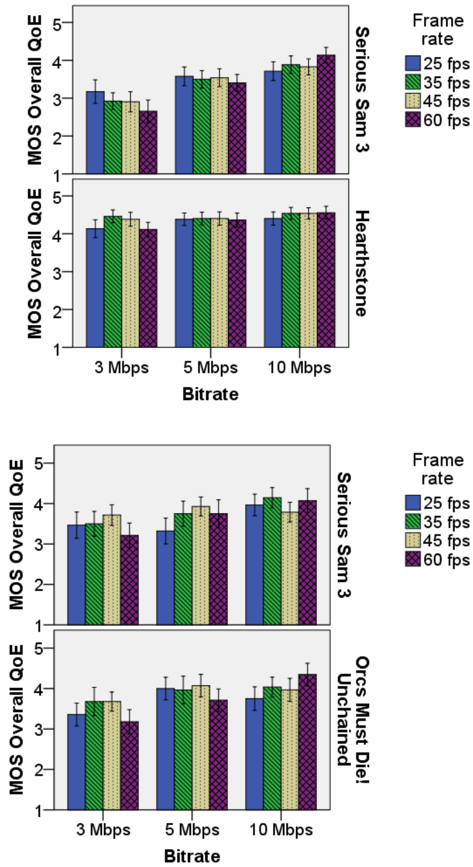

Fig. 2: Subjective ratings of overall QoE (95% CI) for tested games (taken from [4])

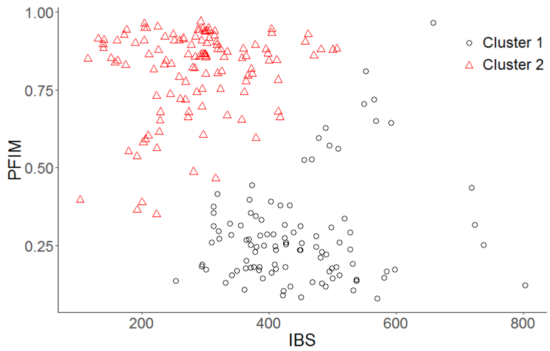

Fig. 3: Video metrics scores for the clusters (taken from [4])

we concluded that the game type tested clearly needs to be taken into account when evaluating the QoE of cloud games.

As a result, a detailed analysis of digital game characteristics was conducted to identify game aspects which can be used to identify the differences between video streams of different games in cloud gaming. We gathered a large number of video game play traces and collected player actions from 25 different games. For each of the tested games, we recorded between 5-10 gameplay video traces that lasted exactly 30 seconds each in order to obtain a large enough sample of gameplay for each game. Alongside gameplay recording, we also measured the intensity of user interaction, thus collecting mouse and keyboard input during gameplay. Based on a k-means analysis of obtained data (also reported in [4]), we found that games may be grouped into 2 clusters characterized by objective video metrics. To visualize the obtained clusters, a scatter plot of analysed objective video metrics (Figure 3) is given. It can be observed that Cluster 2 contains games with high video motion that contains a smaller amount of video information. On the other hand, Cluster 1 contains games with low video motion, however when the objects in the screen move, the coding block size is quite large. The results could serve as a basis for proposition of a novel game categorization that could be utilized for selecting appropriate video configuration strategies for different types of games.

III. Conclusion

While cloud gaming represents a promising paradigm shift in the domain of online gaming, challenges arise in meeting the strict bandwidth and delay requirements of game streaming. Such challenges inherently call for codec configuration and adaptation strategies capable of meeting strict player QoE requirements and adapting the service to variable network conditions. Given the wide diversity of games and their corresponding QoE requirements, it is clear that different strategies may be applied to different categories of games. Two subjective laboratory studies have been conducted which provide valuable insights into the impacts of different codec configuration strategies on three different games. Consequently, using as a basis the subjective results, we proposef a novel game categorization based on objective video metrics that could be utilized for deriving appropriate video encoding configuration strategies for cloud gaming. The proposed game categorization could be used for determining adaptation strategies for clusters of games, which could in the future automate the process of deciding on the best video encoding strategy for a particular game, alleviating the need to conduct subjective studies for additionally considered (or newly emerging) games.

Acknowledgment

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Choosing application layer protocols for IoT devices

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Best Presentation Award

***Abstract*—Choosing an appropriate application layer protocol in IoT can be done by defining a context in which an IoT device operates and by defining the purpose and priorities of said device. In this paper a proposal for the definition of context for IoT devices will be given, and the proposed context definition will be used to show how to choose the proper application layer protocol.**

Keywords—IoT, application layer protocol, context

I. INTRODUCTION

Over the past few years, the number of IoT devices has been growing rapidly – from devices used for medical purposes, over HVAC devices to devices used for military purposes. Main characteristic of all those devices is their communication capability, which enables them to communicate with each other and with various services on the Internet. In addition, many of those devices also have limited resources, so many of the protocols which are part of the TCP/IP stack and commonly used for communication over the Internet are not well suited for use in IoT. Main differences between the regular TCP/IP stack, and the IoT protocol stack can be seen on the physical and application layers.

On the physical layer IoT devices use Ethernet, WiFi, radio access networks, and additional protocols specifically designed for low-power devices, such as IEEE 802.15.4, Zigbee (based on the aforementioned IEEE 802.15.4), and NarrowBand IoT (NB-IoT) which is a Low Power Wide Area Network (LWPAN) built on top of LTE. Network layer still uses IPv4 and IPv6, with the addition of 6LowPan, which allows IPv6 headers to be shrunk from 40 bytes to between 2 and 20 bytes. The transport layer is unchanged from the regular TCP/IP stack, and TCP and UDP protocols are used.

On the application layer IoT devices use HTTP, CoAP, MQTT, MQTT-SN, HTTP/2 and XMPP. The protocols vary in several areas, which include type of the protocol (text vs binary), whether or not the protocol supports REST, built-in quality of service, etc. General overview of the aforementioned protocols is shown in Tab. 1.

II. RELATED WORK

While seemingly similar, the behavior of the application layer protocols varies between different uses. Research done in [1] and [2] has shown that MQTT is a better choice than CoAP when reliability is more important than bandwidth. On the other hand, if bandwidth usage and lower latency are of greater import, CoAP is a better choice than MQTT. In [3] a comparison between MQTT-SN and CoAP has shown that MQTT-SN gives better reliability, but CoAP offers lower energy consumption. HTTP and MQTT were compared in [4], where it was shown that MQTT uses less bandwidth and less energy for location sharing if the device is idling, or if the number of devices the location is shared with is lower than 3. However, when the number of devices is greater than 3, HTTP uses less energy and less bandwidth. In [5] it was shown that CoAP uses less energy than HTTP.

III. RESEARCH TOPIC PRESENTATION

Based on the current body of work, it can be concluded that choosing the right application layer protocol for the IoT device depends on various parameters. These parameters can be identified as follows:

TABLE I. OVERVIEW OF APPLICATION LAYER PROTOCOLS IN IOT

	TYPE	REST	TRANSPORT LAYER	MODE	SECURITY	QUALITY OF SERVICE
HTTP	Text	Yes	TCP	request/response	TLS	-
CoAP	Binary	Yes	UDP	request/response publish/subscribe	DTLS	fire and forget confirmable
MQTT	Binary	No	TCP	publish/subscribe	TLS	fire and forget delivered at least once delivered exactly once
MQTT-SN	Binary	No	UDP	publish/subscribe	DTLS	fire and forget delivered at least once delivered exactly once
AMQP	Binary	No	TCP	publish/subscribe	TLS	delivered at most once delivered at least once delivered exactly once
HTTP/2	Binary	Yes	TCP/UDP*	request/response	TLS	-
XMPP	Text	No	TCP	request/response publish/subscribe	TLS	-

*Experimental support through QUIC [6]

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- P – the purpose of the IoT device
- D – characteristics of the device, which available various hardware parameters such as CPU and memory, power supply type and capacity, e.g. is the device plugged in, or is it using its' battery
- N – network characteristics and status, where the former includes what type of network is the device connected to, how it accesses that network, while the latter is measured by round trip time, latency, and rate of packet loss
- S – services available to the device
- E – physical environment of the device, which includes the location of the device, various climate conditions, such as temperature, pressure, wind speed, etc.

Four of the parameters can be used to define the context in which the IoT device operates as:

$$\text{IoT-C} = \{D, N, S, E\} \quad (1)$$

Thus, by knowing the purpose of the IoT device, and the priorities of that device (e.g. conserve bandwidth, ensure message delivery, or ensure secure communication over unsecure networks), and by knowing the context the device operates in, we can rank the existing application layer protocols by their fitness, and finally, choose the best suited protocol that is supported by the device.

For example, we have a device with the purpose of monitoring the environment temperature, and priorities of the device are to keep low energy consumption when operating on a battery, and to be able to reliably raise an alarm if the temperature becomes high. With the context defined as tuple {D, N, S, E}, where *D = {power=battery; protocols=CoAP, MQTT; default_protocol=HTTP}*, *N = {packet_loss=low}*, *S = {}* and *E = {temperature=high}*, the chosen application layer protocol would be MQTT. On the other hand, if *E* changes, and becomes *E = {temperature=low}*, then the chosen protocol would be CoAP. Figure 1 demonstrates how the proposed context can be used to choose an appropriate application layer protocol based on the previously given purpose and priorities of the IoT device

IV. FUTURE WORK

Future work will first focus on fully working out what each part of the IoT device context entails. This will be done by building a testbed where the behavior of IoT devices and various application layer protocol can be measured and compared. Afterwards, an exhaustive comparison of the existing application layer protocols will be done. The final goal of this research would be a context model for choosing an appropriate application layer protocol.

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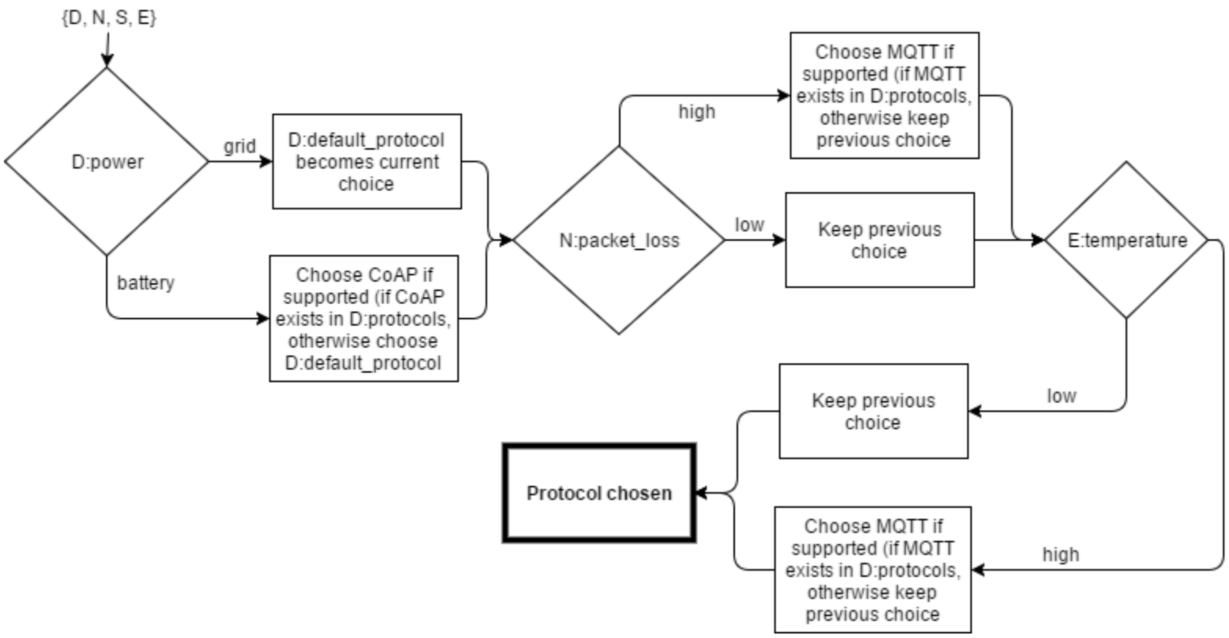

Figure 1 - Choosing an application layer protocol based on context

Stochastic approaches in computational electromagnetics and bioelectromagnetism: the inclusion of stochastic parameter variability

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***Abstract*— The models used to simulate the interaction of electromagnetic fields with physical objects and the environment are mostly deterministic thus giving the result only for a specific setup of input parameters. However, the nature of these parameters is uncertain, which is why they should be represented as random variables and/or random processes. As a consequence the uncertainty is propagated to the output values. The scope of this research is to develop an efficient stochastic computational model with applications in bioelectromagnetism and electromagnetic compatibility of thin wire structures, which will provide statistical description of the uncertain output values and thus a more realistic and complete description for a given problem.**

I. Introduction

The use of electromagnetic (EM) fields has grown tremendously and it is hard to imagine everyday life without electromagnetic devices. Furthermore, the presence of EM fields in the environment gives a rise to constant public concern regarding their potential harmful effects on human health. Thanks to the advancement of computer processing power, efficient numerical methods have been developed to solve various practical configurations that include EM fields. However, the computational electromagnetics (CEM) models are mostly deterministic i.e. they provide the results for a single scenario. In the real world the parameters used to describe the environment and the physical objects are partly or entirely unknown. This requires the development of stochastic models that provide the means for the inclusion of parameter uncertainty in the computational models.

II. Research Topic Presentation

A. General description

The scope of the research is the development of an efficient stochastic model for the problems that arise in two categories: bioelectromagnetism (human exposure to EM fields and biomedical applications of EM fields) and electromagnetic compatibility of thin wire structures (e.g. ground penetrating radar antennas and grounding electrodes). The aim is to obtain a stochastic description of the output of interest, which includes the calculation of stochastic moments, the estimation of confidence intervals, the reliability analysis for the case when there is a need to estimate the probability of failure of a system and the sensitivity analysis (SA) of the input parameters.

The general procedure displayed on Fig.1. consists of two parts: the first one, uncertainty quantification (UQ), refers to a stochastic description of the random input variables (RV) while the second one, uncertainty propagation (UP), implies the propagation of uncertainty from the input variables to the output of interest by means of chosen stochastic method [1].

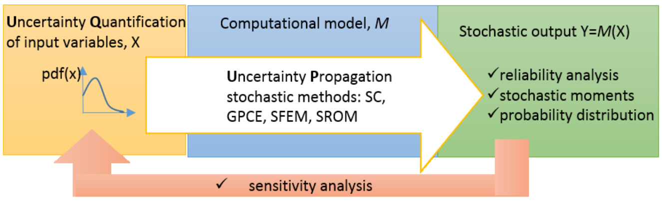

Fig. 1. Uncertainty quantification (UQ) and propagation (UP) framework

B. Results

In the present work the Stochastic Collocation (SC) method has been applied to several problems [2-7]. The chosen stochastic approach is non-intrusive and treats the existing deterministic models as a "black box". The results exhibit good efficiency of the method. The deterministic codes are based on Galerkin-Bubnov's scheme of Finite or Boundary Element Method (GB-FEM or GB-BEM). The SC method is suitable for the calculation of statistical moments and it is also a useful tool in the framework of Global Sensitivity Analysis (GSA).

The first example is the SA of thermal parameters in the homogeneous human brain model [2]. The thermal parameters are input variables in the Pennes' bio heat equation which is solved in order to determine the temperature distribution inside the brain. The parameters are the convection coefficient h_{eff}, tissue thermal conductivity λ, volumetric perfusion blood rate W_b, heat produced due to metabolic process Q_m, ambient temperature T_{amb} and arterial blood temperature T_a. The goal is to investigate their influence on temperature rise in human brain which is being exposed to high frequency EM field. The

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distributions of temperature and temperature elevation are depicted on Fig.2. Obtained confidence margins show if the prescribed limits are approached. The impacts of each thermal parameter's variance on certain temperature values are shown on Fig.3. The most dominant thermal parameter is volumetric perfusion blood rate W_b while the influence of the variability of Q_m, T_{art} and T_{amb} is negligible for the analysis of temperature elevation. Based on this information these parameters can be excluded from further analysis.

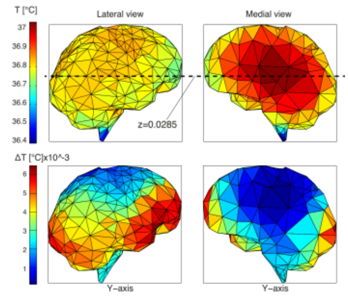

Fig. 2. Distribution of temperature and temperature elevation in homogeneous human brain model in case of exposure to HF EM field

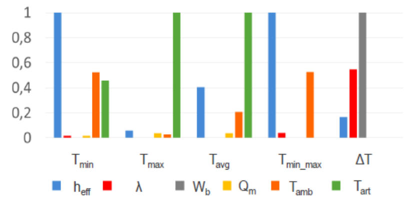

Fig. 3. The impact of thermal parameters on certain temperature values

The second example is the stochastic analysis of transient impedance of the horizontal grounding electrode used in lighting protection systems (LPS) [5]. Random input parameters are soil conductivity and two parameters used for mathematical description of lighting strike current: lightning front time and lightning time-to-half. The mean value with the confidence margins is obtained for the entire simulation period (Fig.4.). The ANalysis Of VAriance (ANOVA) approach applied in [6] is used to obtain first and second order indices (Fig.5.). The first order indices enable the ranking of parameters from the most to the least influential one, while the second order indices provide information regarding interactions between RVs taken by pairs. The importance of the interaction by pairs of RVs is almost negligible from 0.1 μs which emphasizes the first-order influence and the overwhelming impact of soil conductivity.

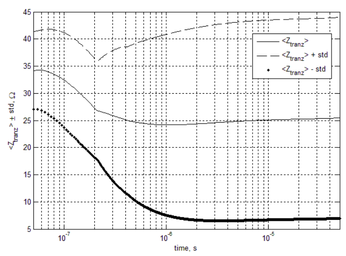

Fig. 4. Mean value ± standard deviation of transient impedance

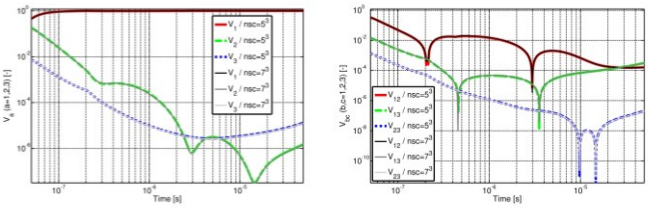

Fig. 5. First (left) and second (right) order sensitivity indices for the analysis of stochastic transient impedance

C. *Future work*

Since the deterministic models developed for mentioned applications are based on Finite Element or Boundary Element Method, the natural extension is the implementation of Stochastic Finite (Boundary) Element Method [8, 9]. Contrary to the SC method this approach is intrusive and demands the change of the existing equations and codes which makes it more complex for the implementation. However, this enables running only one simulation instead of repeating deterministic simulations of a "black box" model for number of times. Also, the fact that the code is being changed offers more control. The calculations and findings obtained with SC method will serve as a benchmark. In particular, the sensitivity analysis carried out in pervious examples can be used to exclude less important parameters form more complex simulations, which becomes significant for a large number of random input variables.

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Adaptive streaming algorithms used in MPEG DASH – QoE problem

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***Abstract*—In order to provide the end user with the best possible quality of requested content, the HTTP protocol based standard called MPEG DASH was developed. MPEG DASH defines a way of notifying the user that a variety of transmission streams of different qualities exist together with the information needed to select the appropriate transmission path. The bit rate adaptation algorithms used in MPEG DASH clients can be divided into several major groups: bandwidth-based algorithms, buffer-based algorithms, and algorithms that take into account the available buffer size and the bandwidth. In order to analyze the quality of service provided to users, both QoS and QoE parameters should be taken into account. From the available research it can be concluded that when preparing content for transmission, it is necessary to analyze the content itself in order to improve its segmentation which results in better selection of the most favorable adaptation scenario.**

Keywords—MPEG DASH; adaptive streaming; QoE; adaptive algorithm

I. INTRODUCTION

Considering the changing conditions in the network, adaptive streaming technique is used to constantly adjust the bit rate. Dynamic Adaptive Streaming over HTTP (MPEG DASH) standard defines the method for notifying the user that there are several transport streams with different quality available. It also defines media file formats suitable for adaptive streaming. The existence of a variety of file formats enables efficient and unobtrusive switching between different streams, enabling them to adapt to changing network conditions without stopping the playback. Adaptive streaming aims to optimize and adapt the video configuration that ensures the best video quality that can be delivered to the end user depending on network conditions [1]. The MPEG DASH specification provides a standardized description of content stored on the HTTP server. Content that is stored on the server can be divided into two parts: Media Presentation Description (MPD) and segments. MPD is an XML manifest file based on XML that describes the available content and its features. By parsing the MPD the DASH client learns about programming time, media types, accessibility features, availability of media content, resolution, minimum and maximum bandwidth, etc. Then the client based on the obtained data selects an adaptation set. Within each adaptation set one specific representation is selected. Having selected specific representation within the adaptation set, a list of available segments is selected. Client accesses to content by requesting the entire segment or sequence of segments for certain bit rate. The client requests the media segments from the selected representation by using the generated list of segments. The rendering starts when the Stream Access Point (SAP) is identified for each of the media streams in all available representations. The structure of a system that implements MPEG DASH is given in Fig. 1. [2]. In traditional signal transfer services, the fixed transmission rate directly determines the quality of the video. However, if video signal streaming uses high transmission rate that does not adapt to network conditions, the viewing experience of end-user video may be unacceptable due to limited network bandwidth. The limited network bandwidth results in frequent interruptions in playback, which reduces the quality of experience (QoE). Adaptive streaming provides a better balance between the QoE and the possibility of fluently streaming the video content. However, there are still a number of adaptive streaming issues, such as how the change of bit rate used to improve the flow of video content affects the end-user experience. It is also necessary to explore which factors have the greatest impact on user experience and in what way. Methodologies for video content network conditions evaluations as well as metrics for network performance analysis used to accurately estimate QoE of end-user should be developed. Such evaluation model of evaluating the QoE could increase efficiency and optimize bit rates used in adaptive streaming [3].

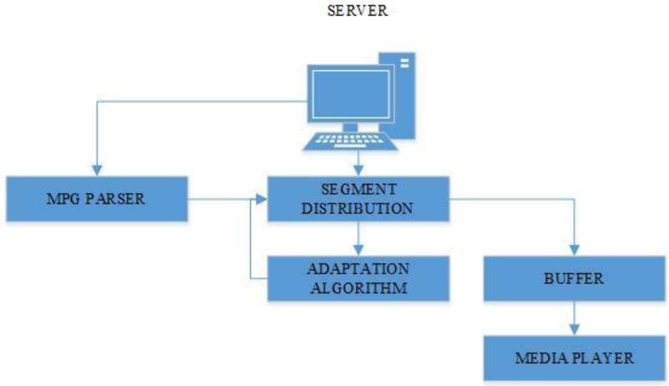

Fig. 1. Structure of video streaming management

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II. Adaptive streaming algorithms

The bit rate adaptation algorithms used in MPEG DASH clients can be divided into several major groups:

A. Algorithms based on availible bandwdth

Algorithm proposed by authors in [4] is an example of algorithms that as the input value accept the time used to retrieve the previous segment. It also calculates the factors used to decide whether to switch to a higher or lower level of the segment's quality and compares them with the metric for time adaptive segment acquisition (calculated based on the available average bandwidth of the previous segments) and determines whether the change of segment quality level is required.

B. Algorithms based on buffer level

Algorithm proposed by authors in [5] is based on information about the throughput dynamics that was available in the past. The algorithm recognizes two phases that are time-multiplexed. The first phase is a phase of rapid startup that provides the ability to switch to a higher representation in the more liberal and more aggressive way than in normal phase. Once the fast startup phase is completed, as long as there are necessary conditions, the algorithm enters the standard phase in which it stays until the end of the session.

C. Algorithms based on both bandwidth and buffer level

Authors in [6] propose the Segment Aware Rate Adaptation Algorithm (SARA). This group of algorithms includes the effect of segment size on measured bandwidth in adaptive algorithms. SARA chooses the most suitable representation for the next segment. Based on buffer fullness at any time, the bit rate adaption is performed in four phases: the fast start phase, the phases of gradually and aggressively increasing of bit rate, and the phase of segment download with increased delay.

III. QoE in adaptive streaming algorihms

In [7] authors performed subjective experiments in a way that they measured effects of transient occurrences on the QoE. It was discovered that the insertion of intermediate level between cases of high signal quality degradation was more favorable for perceived quality compared to the direct switch to the target quality level. In [8] authors perceive that end users can observe if a certain behavior of the system is unjust. For example, transition to a lower quality level, frequent quality level switching, periods when the bit rate is below a certain level, etc. It was also concluded the users are more critical to the degradation of video quality and less satisfied with the increase of the same. Besides the transient occurrences also the initial delay and congestion that can occur during playback should be taken into consideration. The adaptive algorithms balance their initial delay which if it's too long may reduce the QoE but at the same time increase the initial delay affects the beginning of management of bit rate levels. The authors in [9] show that about 90% of users consider that higher initial delay has less impact on the QoE than subsequent delays in reproduction. Also in the impact of initial delay on perceived quality depends only on its length, but has no correlation with the total video clip length. Delays that occur during a video playback due to insufficient buffer occupancy occur when the bandwidth fullness is less than the video upload speed, which is why the buffer can become empty. Playback is in this case interrupted until the certain amount of video content is reloaded. In [10], the authors show that the increased duration of the reproduction downtime reduces the QoE, but a longer standstill is more acceptable than frequent short outages.

IV. Conclusion

Depending on the content, the transition from one to another quality level will more or less affect the perceived quality. So, when preparing content for streaming, it is necessary to analyze the content to improve the video segmentation and so that the most suitable adaptation scenario can be selected. Algorithms that take into account the segment size as well as aforementioned parameters have less transition between different bit rates which results in better QoE. However, there is still room for improvement in terms of increasing the bit rate in networks which have a high available bandwidth. Also there is room to further analyze the impact of the duration of the segments on QoE and designing a new algorithm which enables better adaptation to network conditions thus helping customers increasing their QoE. The open issue remains the fact that there is no metric for analyzing QoE which would unite the existing ones.

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Towards QoE-driven service configuration strategies for multi-party mobile video conferencing

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***Abstract*— Video conferencing is becoming increasinglyy popular in both leisure and business contexts, offering opportunities to increase productivity, reduce costs, and share information in real time. High resolution displays, front and rear cameras, high speed wireless networks and new technologies, such as WebRTC, make video conferencing free and available anywhere at any time. Dynamic wireless networks and limited mobile end user devices require dynamic service adaptation strategies to achieve acceptable perceived quality. The main objective of this research is to identify and quantify the impact of various encoding, system, and network influence factors on QoE during multi-party mobile video conferencing, with the aim to work towards QoE-driven service adaptation strategies.**

I. Introduction

In October 2016, mobile and tablet Internet usage was reported to exceed desktop usage for the first time worldwide [1]. While video conferencing was previously both expensive and often quality impaired, nowadays video conferencing services are expected to be secure and easy to manage, reliable, available for every user, network connectivity, end user device, and context. In a mobile environment, with limited and variable resource availability, video conferencing applications should be capable of adapting the real-time audiovisual content streaming to current network and device conditions so as to secure a high level of Quality of Experience (QoE).

Standardized subjective quality assessment methods for relevant elements used in two-way communication are well establish in [2]. In [4], [5] are summarized QoE challenges of video conferencing services, and addressed special characteristics such as mobility, interoperability, additional functionalities and privacy. However, methods for multi-party conversational and interactive video service quality assessment in mobile environments are not completely standardized up to day [3]. To reach acceptable QoE, service providers have to be able to manage and control resources efficiently. Therefore, we conducted five studies with experiments involving subjective end user assessments and address the following research questions:

What is the degree of impact of different smartphone configurations on QoE (with devices differing in CPU, display size, and resolution)?

How significant are additional functionalities available on the conferencing web page to end users?

When considering a three-way video call where each participant sees three video, what video resolutions are needed to achieve satisfactory QoE under different bandwidth constraints and taking into account screen size?

What is the impact of bandwidth restrictions on conversational interaction in a three-way video call established using smartphone devices?

How does the GCC (Google Congestion Control algorithm) handle packet loss in WebRTC (Web Real-time Communications) and what effects does this have on QoE?

What is the influence of packet loss on audio and visual quality in a three-way mobile video call?

The main objective of the studies is to define a relevant QoE model for mobile multi-party videoconferencing and to provide the basis for improving service quality with service adaptation strategies.

II. Methodology and Current Results

Experiments, summarized in Table 1, included subjective end user assessments with the goal being to investigate the impact of different smartphone configurations, topology and video parameters setup on QoE under symmetric (to eliminate the impact of certain parameters) and asymmetric (trying to create more realistic scenario) conditions. Results of the first two studies are published in [6] and [7], while the results from case studies 3-5 are still being analyzed.

In each experiment participants used the same multi-party video conferencing service in a realistic home environment, leisure context under controlled network conditions, (Figure 1).

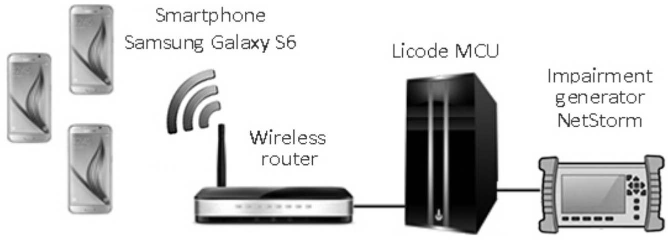

Fig. 1. System set-up over LAN in Case Study 4.

TABLE I Overview of conducted subjective studies for three-party mobile video conference

Case study	Participants	Number of tests	Topology	Media Server	End user devices	Operating system	Browser	Parameters variation	Goal
1. March 2015 [1]	18 male 12 female	120	P2P	Kurento Appear.in Talky vLine	Samsung S5, S3, LG G3 3 x laptop	Android 4.1.2 Android 4.4.2 Windows 7, 8.1	Chrome 40.0.2214.109	None	Explore possibility of three-party video on smartphone
2. April 2016 [2]	14 male 13 female	108	MCU	Licode	3 x Samsung S6	Android 6.0.1	Samsung internet browser 4.0.10-53	Video resolution, bitrate	Influence of different video parameters on QoE and traffic load
3. October 2016	13 male 11 female	96 for S5 96 for S3	MCU	Licode	3 x Samsung S5 3 x Samsung S3	Android 6.0.1 Android 4.3	Samsung internet browser 4.0.30-24	Video resolution bitrate	Smartphone configuration impact on QoE
4. March 2017	16 male 14 female 1 fixed user per each group	120	MCU	Licode	3 x Samsung S6	Android 6.0.1	Chrome 55.0.2883.91	Video resolution, bitrate, frame rate, packet loss	Analyze GCC behavior in case of a packet loss
5. May 2017	21 male 6 female	72	MCU	Licode	3 x Samsung S6	Android 7.0	Chrome 57.0.2987.132	Video resolution, bitrate, frame rate	Determine lowest QoE acceptable configuration

The selected participants had no special AV knowledge. Participants were acquaintances, therefore a natural conversation was chosen for a task. The test schedule consisted of groups with 3 participants under different conditions, each lasting 3 minutes. With respect to limited smartphone processing power, results in Study 1 showed that P2P topology in multi-party scenarios impose too much burden on the end user device. To obtain acceptable QoE, a Multi-control Point Unit (MCU) was subsequently used. Furthermore, higher video resolutions and bitrates might bring better video quality but also require, in this case unavailable, processing capabilities. On the other hand, higher resolutions and bitrates generate significantly more traffic, flooding the network with unnecessary load. Scenarios with highest resolution in case Study 2 scored the lowest QoE in all cases. Since it is possible to achieve high QoE with a setup lower than 600kbps bitrate, resolution 640x480, we recommend such a setup as an upper threshold for three-way video calls on smartphone devices, (Figure 2). As a next step, we aim to determine threshold service configurations (in terms of video encoding parameters: resolution, bitrate, and frame rate) for achieving acceptable QoE.

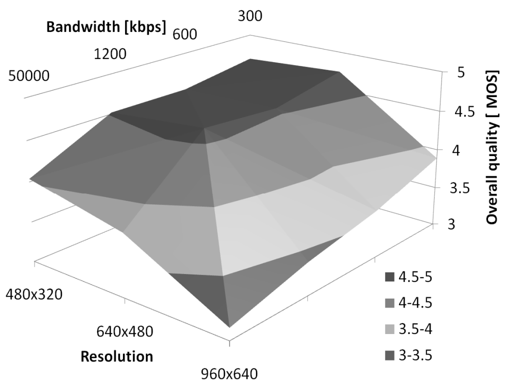

Fig. 2 Overall quality for each combination of bandwidth and resolution settings in Study 2.

III. CONCLUSION

Providing high QoE for multi-party video conferencing remains challenging, with a need for service adaptation strategies considering mobile device resources and current network conditions. Results obtained in Study 1 showed that MCU is necessity in multi-party mobile environment. Study 2 showed that higher video resolutions and bandwidth contribute only to some point to better video quality, because of unavailable processing power which ultimately leads to service congestion. Our methodology is based on conducting empirical user studies to correlate objective network and device QoS factors with subjective QoE scores, thus aiming for deriving QoE-aware service adaptation strategies.

ACKNOWLEDGMENT

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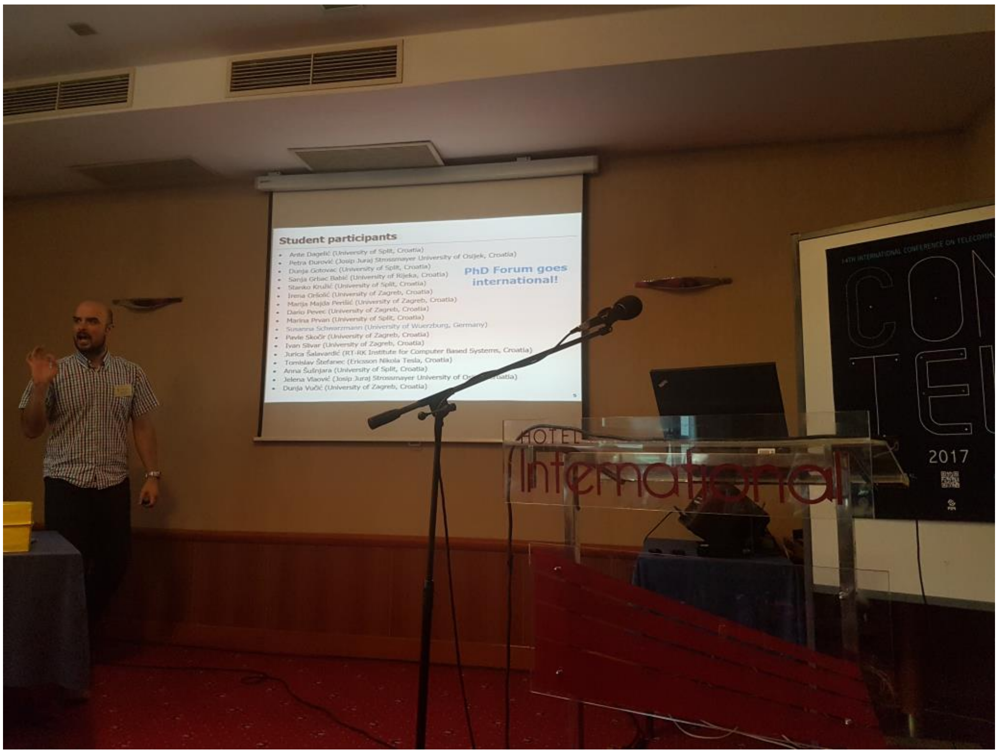

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