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ICDT 2019 Editors

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ICDT 2019

Forward

The Fourteenth International Conference on Digital Telecommunications (ICDT 2019), held between March 24, 2019 and March 28, 2019 in Valencia, Spain, continued a series of special events related to telecommunications aspects in multimedia environments. The scope of the conference was to focus on the lower layers of systems interaction and identify the technical challenges and the most recent achievements.

High quality software is not an accident; it is constructed via a systematic plan that demands familiarity with analytical techniques, architectural design methodologies, implementation polices, and testing techniques. Software architecture plays an important role in the development of today's complex software systems. Furthermore, our ability to model and reason about the architectural properties of a system built from existing components is of great concern to modern system developers.

Performance, scalability and suitability to specific domains raise the challenging efforts for gathering special requirements, capture temporal constraints, and implement service-oriented requirements. The complexity of the systems requires an early stage adoption of advanced paradigms for adaptive and self-adaptive features. Online monitoring applications, in which continuous queries operate in near real-time over rapid and unbounded "streams" of data such as telephone call records, sensor readings, web usage logs, network packet traces, are fundamentally different from traditional data management. The difference is induced by the fact that in applications such as network monitoring, telecommunications data management, manufacturing, sensor networks, and others, data takes the form of continuous data streams rather than finite stored datasets. As a result, clients require long-running continuous queries as opposed to one-time queries. These requirements lead to reconsider data management and processing of complex and numerous continuous queries over data streams, as current database systems and data processing methods are not suitable. Event stream processing is a new paradigm of computing that supports the processing of multiple streams of event data with the goal of identifying the meaningful events within those streams.

We take here the opportunity to warmly thank all the members of the ICDT 2019 technical program committee, as well as all the reviewers. The creation of such a high quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and effort to contribute to ICDT 2019. We truly believe that, thanks to all these efforts, the final conference program consisted of top quality contributions.

We also thank the members of the ICDT 2019 organizing committee for their help in handling the logistics and for their work that made this professional meeting a success.

We hope that ICDT 2019 was a successful international forum for the exchange of ideas and results between academia and industry and to promote further progress in the domain of digital telecommunications. We also hope that Valencia, Spain provided a pleasant environment during the conference and everyone saved some time to enjoy the historic charm of the city.

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Likelihood to Recommend (L2R) Prediction using Quality of Experience (QoE) Measurements: A Longitudinal Study

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***Abstract*—Models that predict satisfaction with a service over time need to consider the impact of emotions and remembered quality of experience in creating attitudes towards a service. However, prior research on subjective quality of experience has typically focused on experiments conducted in a single session or over a short period of time. Thus, there is a gap between our understanding of instantaneous quality of experience and long-term judgments, such as overall satisfaction and likelihood to recommend and likelihood to churn. The goal of the study in this paper was to carry out a longitudinal study that would provide initial insights into how experiences of service quality over time are mediated through emotions and memory and accumulated into longer term attitudes about the service. The longitudinal study was carried out over a period of roughly 4 weeks with around 3 sessions per week. A specially constructed online service was used where participants could select YouTube videos to view, and the service would randomly add impairments to the videos before playing back the videos and then asking questions relating to Quality of Experience, Technical Quality and overall frustration and satisfaction. In this paper, we report on the results obtained from the first 8 sessions of data.**

Keywords–Video quality assessment; Quality of Experience (QoE); Comparison of rating scales; subjective evaluation; accessibility; retainability; longitudinal study; consumer satisfaction.

I. INTRODUCTION

In this paper, we focus on the quality of experience associated with streaming online video. While it seems possible that the results obtained here may also apply to other online services our discussion will focus on implications for judgments that are driven by online video experience, since consumption of online video is currently a dominant component of Internet services in terms of bandwidth utilization.

Internet Service Providers (ISPs) are typically private corporations that need to maximize profits by keeping costs to a minimum while preserving, and preferably increasing, their number of customers. However, in a competitive market just maintaining the current customer base can be challenging [1]. Internet service is a commodity and thus quality of service is a key competitive differentiator between ISPs. In this competitive environment, ISPs face a trade-off between the need for high quality service that will attract and retain customers, and the need for efficient use of resources to keep costs from getting out of control [2].

Since it is generally more costly to recruit new customers than to retain existing customers [1], it is believed that the best strategy for ISPs is to try to retain existing customers by heightening customer loyalty and customer value [3].

Quality of Experience (QoE) is an important contributor to the formation of attitudes relating to likelihood to recommend (L2R) or likelihood to churn (L2C) [4][5]. Although there are many different definitions on QoE, Callet et al. [6] explain it as follows: the degree of delight or annoyance of the user of an application or service.

Attitude towards a brand or service accumulates over time and is impacted by the interactions and experiences that a person has with the service. Specific experiences may get priority in terms of the amount of attention or resources that are dedicated to them based on emotional arousal or interest, resulting in stronger memories of those experience. Thus, we should not expect overall attitudes to a service to be based on a simple average of the quality of experience for all the videos viewed, or for all the viewing sessions. Instead, memories of viewing experience may be biased based on the psychology of how people remember experiences.

Since construction of psychological models of how memories of experience are accumulated into overall attitudes is challenging, it is not surprising that marketers typically dispense with this approach and simply ask customers overall questions about how satisfied or unsatisfied they are with their service. However, these judgments may not faithfully represent the true opinion of users [7]. Additionally, after the fact measures of overall attitude are not predictive and do not help ISPs in making decisions in a timely fashion [8]. In an ideal world IPSs might be able to redirect bandwidth to customers who were in danger of forming bad attitudes to the service, but currently ISPs tend to not have the capability to do this type of dynamic reallocation. However, knowing that a customer is probably becoming unhappy with a service might trigger several interventions (e.g., discounts on the monthly bill or other benefits to compensate for problems in service quality) and may also guide the ISP in where to invest in greater bandwidth capacity.

In this research paper, we report on a longitudinal study that looks at how different patterns of service quality affect cumulative experiences and attitudes. Earlier research showed that perceived QoE is affected by the sequence of good and poor videos that are seen within a single viewing session [9]. In the research reported below, we extend this analysis to patterns and variations in QoE occurring over extended periods of time (weeks as against the one-hour duration of a typical experiment).

In Section II, we provide a background on the types of service failures studied, the metrics used to measure the technical quality of the service, and the effects of emotions on memory encoding. In Section III, we discuss the methodology of the experiment, detailing the steps each participant had to go through. Next, in Section IV, we describe the groupings of the participants and the different questionnaire types used within the study. In the results section (Section V), we evaluate the three main hypotheses we have proposed in this research. Lastly, in the discussion section (Section VI), we provide arguments on why these hypotheses are true and provide recommendations on future research.

II. BACKGROUND

In the context of online video streaming, QoE is influenced by key criteria such as video quality, audio quality, speed of service access, and frequency of service interruption [10]. Two main dimensions of QoE are the Technical Quality (TQ) and Content Quality (CQ) [11].

The only manageable quality from the ISPs perspective is the TQ. ISPs do not have any input into the content that users choose and are not be able to estimate the importance or value of every instance of their service from the point of view of the customer. Thus, the only quality measure they can influence is the TQ [12].

There are two main types of TQ failures when it comes to assessing QoE in a session-oriented setting: Accessibility and Retainability. Furthermore, there is a third TQ problem, referred to as Impairments.

1. Accessibility is the successful starting of the session.
2. Retainability is the capability to continue the session (with or without impairments) until its completion, or until it is interrupted by user action [13].
3. Impairments refer to the degree to which the session unfolds without excessive impairments. In this study, Impairments have multiple levels, suggesting different number and duration for the impairments within the videos watched [14].

The Mean Opinion Score (MOS) is a commonly used metric to measure subjective video technical quality. It was published by the International Telecommunication Union Telecommunication Standardization Section (ITU-T) (2008b) [15]. MOS has a unique rating model which starts from 1 (bad) to 5 (excellent) and since its introduction in 1969, it has been used for the purposes of evaluating radio quality of compressed speech in telecommunications world [16]. In this study, we use MOS scores as a metric to measure customer satisfaction, frustration, content quality and TQ. Two types of MOS scores are gathered in this study: expected MOS and perceived MOS scores which are reflected in terms of TQ.

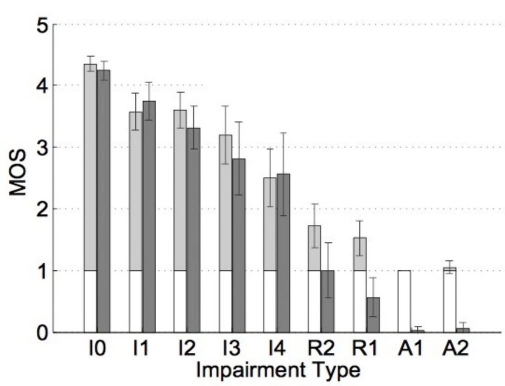

Figure 1. Trends in expected MOS scores measured in a single session setting. Results are calculated based on Li et al. [11].

The expected MOS scores are results based on experimental values gathered from the previous studies conducted by Li et al. [11]. In these studies, the same experiment was set up for only one session and the data gathered demonstrates the TQ levels based on different frequency and types of impairments. Figure 1 shows how individuals reacted to different types of impairments and what was their measures of perceived TQ. Amongst all the factors shown, only I5 was newly introduced, for which we have calculated its expected TQ based on the trend the expected MOS had in Figure 1. The MOS scores used to predict expected MOS score for this experiment are demonstrated in Table I. I0 starts from a 4.5 value instead of 5 since users are hardly giving a perfect score to a service. Also, the MOS goes as low as 1 since this is a 5-point scale model starting at 1 and ending up at 5.

TABLE I. DIFFERENT MOS SCORE USED ACCORDING TO DIFFERENT TYPE OF FREQUENCY OF IMPAIRMENTS AND FAILURES

I0	4.5
I1	3.8
I2	3.5
I3	3.2
I4	2.6
I5	2.2
NR	1.5
NA	1

1) Emotions and Memory Encoding: While emotions are typically of short duration (lasting a few seconds), there is also a cumulative emotional sense which leads to affective memories [17]. Emotional events often attain a privileged status in memory. The more negative an event, the more likely it is to be stored and remembered, and the more details will tend to be retrieved for the event [18]. Slovic described the affect heuristic where people consult their emotions in order to make judgments [19]. Individuals replaced the question of “What do I think about it?” with the question “How do I feel about it?” and answer that latter question since it is easier to recognize the feeling than to apply reason [20].

Aside from judgment based on only emotions, Greenwald [18] researched the possibility of cognitive systems that have two distinct representational stores: implicit and explicit attitude systems. The implicit attitude system is rapid and unconscious while the explicit evaluation is slow and conscious, generating more detailed evaluations [21]. More recently developed models have introduced the idea of multiphase computation of emotions. In this type of computing implicit and explicit appraisals are combined to create a final emotional appraisal that is grounded in previous emotional experiences. Thus, after the affective and cognitive appraisals, retrospective appraisal takes place and affective memories are generated, become available for retrieval and use in future situations [17].

III. METHOD

In designing the current experiment, we were concerned that the data gathered from previous studies did not replicate the real-world usage of mobile devices. Instead, participants were typically given tasks in lab environments that were significantly different from representative real-world scenarios. In order to create a somewhat more realistic experimental context, online software was created where participants could log in from any device and carry out the experimental tasks at their own convenience. The users were required to complete a video viewing session three times a week for a period of 4 weeks, simulating more closely the experience of browsing videos through different short video streaming platforms, while still maintaining some degree of experimental control. Sessions in this experiment were approximately 30 minutes long. During a session, users were able to search for short videos and the search results were then displayed on the screen. Once a video was chosen from the list of results (the videos shown in the list were filtered to be between 4 to 5 minutes long), experimentally assigned interruption or impairments would be applied to the video and then the video would play on the screen.

After the video was watched, users would be taken to a page where they were asked a few questions based on the video and its technical and content quality. This cycle would repeat until the session was over.

For the purposes of this paper, only data collected up to the end of the eighth session was included in the analyses.

IV. EXPERIMENT DESIGN

Users were divided into 4 main groups. The four groups represented four different sequences of good and bad experiences as demonstrated in Figure 2. According to figure 2, groups 1 and 3 end up on a rising trend of predicted MOS scores as of session 8, while groups 2 and 4 ends up with predicted MOS scores that are trending lower. It can also be seen that groups 1 and 4 start on a decreasing trend whereas groups 2 and 3 start on an increasing trend. Each group had 6-10 participants and the data for each participant was collected for 12 sessions over a period of 4 weeks, however, in this study, we only look at the data from the first 8 sessions. Each participant was asked to log in to the software a minimum of 3 times a week and with a 24-hour gap between sessions with reminders being sent to enforce this requirement. Participants received reminders every other day and those participants who were not able to complete three sessions a week were dropped from the study. At the end of each week, participants were asked specific descriptive questions about how they felt overall about their experience with the service in the past week or past 3 sessions (if fewer than 3 sessions had been carried out within the past week).

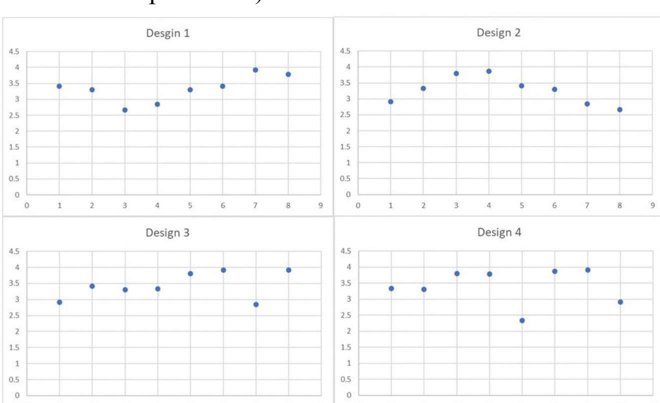

Figure 2. Different trends of experiences participants are exposed to during the 4-week long study.

Figure 2 gives a visual on how the experiment went across all four groups of participants. Each dot represents the average expected TQ rating of the session for that specific group.

Some of the other components of the study include sudden drops in quality in the service (from sessions 6 to 7 for group 3 and from sessions 4 to 5 for group 4, as shown in Figure 2) from one session to the next.

There were four questionnaires administered during the eight sessions. The first questionnaire asked users specific questions on how they felt about a video they had just watched, in terms of their level of satisfaction, frustration and acceptability of the service.

The second questionnaire checked whether the user was paying full attention or not by asking questions concerning details of the contents of the video. It was administered after a randomly selected video (but not including the first video in the selection) in each session. A third questionnaire was administered at the end of each session and asked users about their general feeling about the session they just finished, asking them in detail about their current Likelihood to Recommend (L2R) and Likelihood to Churn (L2C), pricing, devices used and overall satisfaction or frustration level at the end of the session. The fourth and final set of questions asked about how well users remember their experience from the previous session. Items in this final questionnaire also check whether users remember any of the videos and asks for a rating of their overall feeling about their previous session. Using the questionnaire ratings, we analyzed the memory and sequencing effects and compared them to the pricing decisions and the L2R and L2C ratings.

V1	Q1	V2	Q2	V3	Q3	V4	Q2	V5	Q2	V6	Q3	Q4

Figure 3. A visualization of Participant 1, Session 1 demonstrating video and questionnaire types within it.

Figure 3 shows a representation of the videos and questions that a participant was exposed to in a session. The order of the questionnaires was also altered based on the group participants fell into. More specifically, figure 3 illustrates the questionnaire and video orders for session 2 and for group 2 participants. In this model, Q stands for Questionnaire Types and V stands for Videos within a session. Q1 asks about the initial feedback of the user from the video they have just watched and evaluates Technical Quality (TQ), Frustration Level and level of satisfaction on the content of the video (CQ). Q2 is the most common questionnaire and further asks the questions on TQ, CQ and Frustration level while comparing it to the previous video(s) they have watched. Q3 is a surprise questionnaire which asks questions about the content of the video to distract the experimenter from the regular questions they are answering and bring their attention back to the experiment. This questionnaire is asked at different stages across different sessions to make sure the user does not find a pattern for answering it and could always evaluate the users' responsiveness and level of attention according to the answers. Finally, Q4 asks about the overall sessions' acceptability, TQ, frustration level and pricing of services.

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V. RESULTS

A. Relationships between ratings

Table II shows the matrix of Pearson correlations between TQ, satisfaction, frustration, content quality, expected MOS, and TQDiff (the difference between the rated TQ and the expected MOS). The content (quality) score was a user rating of how interesting the content of the video was perceived to be. Significant correlations (p¡.05, two-tailed) were found for all possible pairs of TQ, Satisfaction, Frustration, and Content, which is consistent with earlier findings [21].

TABLE II. CORRELATION MATRIX FOR ALL THE VALUES MEASURED WITHIN THE FIRST SURVEY

Correlations

		TQ	Satisf	Frust	Content	Expected MOS	TQ Difference
TQ	Pearson Correlation	1	.920**	.869**	.476**	.376**	.692**
Satisf	Pearson Correlation	.920**	1	.904**	.537**	.310*	.666**
Frust	Pearson Correlation	.869**	.904**	1	.536**	.279*	.639**
Content	Pearson Correlation	.476**	.537**	.536**	1	.047	.433**
Expect MOS	Pearson Correlation	.376**	.310*	.279*	.047	1	-.667**
TQ Diff	Pearson Correlation	.692**	.666**	.639**	.433**	-.667**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Based on the analysis made on differences within TQ amongst all four groups, it was observed that certain groups such as group 1 had a more positive behaviour towards the experiment while group 3 having a more negative impression towards the experiment overall.

This result might be an effect of the trend of the data within the experiment [22]. Groups 2 and 3 are exposed to a more upward trend in data while group 1 and 4 participants are first exposed to a poor TQ then gradually moving towards a higher TQ rating. Based on this observation, it could be interpreted that initial exposure to a service determines a great significance on the followed perceive impressions of its failures. In particular, the better the initial interaction, the more sensitive to the participants are to poor quality and the greater the impacts of trends towards the negative.

B. Carryover effect of good and bad quality

The carryover effect is visible between different sessions of the experiment. For instance, Figure 4 shows that in Design 4, it could be observed that cumulative Expected and Perceived session MOS (SMOS) scores differ from each other, due to the difference in quality of experience that the person had over preceding sessions [23]. This result is very prominent in session 5. The SMOS is relatively low however, the general average of answers is about 2 ratings above the predicted average.

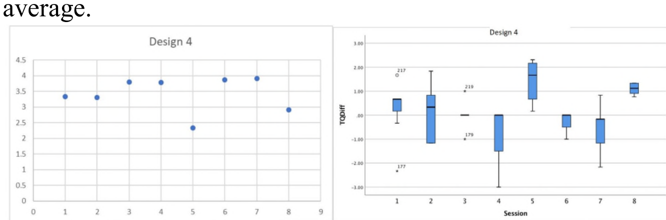

Figure 4. Carry over effect of Design 4.

It could also be observed from Design 4 that the carry-over effect is positive for a positive session and negative for a poor experience. In other words, the slight reduction of SMOS score from session one to session two in the design 4 experiment led to a more biased range of answers but more towards the negative side, however, a slightly more positive experience within session 4 compared to session 3, does not lead to an increase in likely to perceive TQ. Additionally, having the same TQ in two proceeding sessions does not mean that the perceived TQ would be the same. It could be seen from the data that most of the participants have more negative biases, perceiving the TQ as the same or worst if the TQ does not change within two consecutive sessions. Design 4 is one of the four results in the experiment, chosen at random.

C. General Group Behaviour

A significance change in TQ also has its effects, both towards good or bad perception. Figure 5 demonstrates this case by highlighting the differences between sessions 4 and 5 within design 4. The significant drop in TQ in session 5 compared to session 4 is towards the negative but the carry over effect impacts the perceived quality and participants mostly have a more positive impression of the service and are more forgiving of its failures. The same case happens between session 6 and 5 whereas here, session 6 is a significantly more positive experience compared to session 5 but the perceived quality is about the same or less due to session 5s carryover effect.

		Subset	
Group	N	1	2
3	5	-.3683	
2	8	-.2530	
4	8	.1711	.1711
1	8		.4062
Sig.		.069	.680

Figure 5. Difference in TQ of each subgroup within the study by looking at the Homogeneous Subsets of TQ differences.

VI. DISCUSSION

The results obtained from the preliminary analysis of the data from the Introduction Questionnaire (Q1), demonstrate three main findings. First, video Content is a determinant of video quality and could not be neglected. Second, expected and perceived TQ are different in value when we are looking at longer term interactions between service providers and users. Third, in usage of a service, initial interactions and trends of impairments are crucial to the perceived quality.

It has been previously proven that Content, is one of the main influencers of the perceived TQ. Here, we once again prove this relationship in a longitudinal study, demonstrating that aside from the real TQ and the number of impairments in a video, frustration and satisfaction levels are also heavily correlated with the content of the video watched.

In the previous studies, we were able to predict the perceived TQ based on the expected TQ [10]. However, in this study, our results show that the expected TQ to be having a lower correlation with perceived TQ compared to the single session study. One of the primary reasons for these results is possibly the effect of longitudinal study on the attitude towards the service, which is carried over a few sessions. Here, we have the carryover effect of the previous sessions, affecting the perception and attitudes of users towards the service even before starting a new experiment. A participant exposed to a poor service quality in the prior session, is more likely to perceived and report a poorer TQ for a session compared to a person exposed to a better prior service quality.

Lastly, the sequence that videos appear in is an important influencer of users' ratings of the quality of a service. How participants remember and evaluate the experience as a whole is what will influence their attitudes towards that service. It could be observed that the number of bad videos alone is not sufficient to explain how people retrospectively evaluate their experiences as a whole. The order in which the videos happen, as well are important factors of contributing towards how one perceives the quality of the video. The later the negative effect happens within a session, the more participants would tend to rate the session as a poor session. This result could be also shown from comparing the actual SMOS with the graphed SMOS throughout different sessions across all four groups of the experiment.

In the future steps of this study, the carry-over effect would be measured over different weeks, helping us determine the duration of the positive and negative effects. Moreover, the results of this study could be used to build models that intentionally increase the service quality for some unsatisfied users at the times at which it is seen and predicted that these users are going to make impactful decisions about their service. For instance, increasing the quality of the service for users that are close to cut their service for keeping them as a customer.

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REFERENCES

[1] K. Moon-Koo, M. Park, and D. Jeong, "The Effects of Customer Satisfaction and Switching Barrier on Customer Loyalty in Korean Mobile Telecommunication Services," Telecommunications Policy, vol. 28, no. 2, pp. 145159, 2004.

[2] W. Li, H. Ur-Rehman, M. Chignell, L., Zucherman, and J. Jiang, "Frustration in Response to Impairments and Failures in Online Services, and Resulting Impact on Customer Attitudes," Tenth International Conference on Signal-Image Technology and Internet-Based Systems, pp. 1-7, 2014.

[3] F. Reichheld, "The One Number You Need to Grow," Harvard Business Review, vol. 81, no. 12, pp. 46-54, 2003.

[4] E. Paksoy, A. McCree, and V. Viswanathan, "A Variable-Rate Multimodal Speech Coder with Gain Matched AnalysisBy-Synthesis," IEEE International Conference on Cognitive Informatics, vol. 2, pp. 751754, 1997.

[5] S. Moller and A. Raake, "Quality of experience: Advanced concepts applications and methods," Heidelberg: Springer, pp. 1-8, 2014.

[6] P. L. Callet, S. Moller, A. Perkis, and Qualinet, "White paper on definitions of quality of experience," European Network on Quality of Experience in Multimedia Systems and Services (COST Action IC 1003), vol. 1, no. 2, pp. 1-7, 2013.

[7] B. Stauss, M. Schmidt, and A. Schoeler, "Customer frustration in loyalty programs," International Journal of Service Industry Management, vol. 16, no. 3, pp. 229-252, 2005.

[8] M. Chignell, D. Kaya, L. Zucherman, and J. Jiang, "Assessment of Technical Quality of Online Video Using Visualization in Place of Experience," Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 60(1), pp. 2014-2018, 2016.

[9] K. Brunnstrm et al., "Qualinet. White Paper on Definitions of Quality of Experience. Qualinet White Paper on Definitions of Quality of Experience Output,"The fifth Qualinet meetings, 2013.

[10] C. DeGuzman, M. Chignell, J. Jiang, and L. Zucherman, "Testing the effects of peak, end, and linear trend on evaluations of online video quality of experience," In Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 2015, vol. 61, no. 1, pp. 813-817, doi: 10.1177/1541931213601696

[11] W. Li, P. Spachos, M. Chignell, A. Leon-Garcia, L. Zucherman, and J. Jiang, "Impact of technical and content quality on overall experience of ott video," 13th IEEE Annual Consumer Communications Networking Conference (CCNC), vol. 13, pp. 930-935, 2016.

[12] T. Hoßfeld, M. Seufert, M. Hirth, T. Zinner, P. Tran-Gia, and R. Schatz, "Quantification of YouTube QoE via Crowdsourcing," IEEE International Symposium on Multimedia, vol. 1, pp. 494-499, 2011.

[13] W. Li, P. Spachos, M. Chignell, A. Leon-Garcia, L. Zucherman, and J. Jiang, "Understanding the relationships between performance metrics and QoE for Over-The-Top video," IEEE International Conference on Communications (ICC), pp. 1-6, 2016.

[14] G. Schroeder, International Telecommunication Union Telecommunications Standardization Sector, vol i-iv, pp. 1-42, 1995.

[15] R. N. Bolton, and J. H. Drew, "A Longitudinal Analysis of the Impact of Service Changes on Customer Attitudes," Journal of Marketing, vol. 55, no. 1, 1991.

[16] Wilson, K. Forbus, and M. McLure, "Am I Really Scared? A Multi-Phase Computational Model of Emotions," Proceedings of the Second Annual Conference on Advances in Cognitive Systems, 2013.

[17] S. K. Labar, C. Roberto, Cognitive neuroscience of emotional memory, Nature Reviews Neuroscience, vol. 7, no. 54, 2006.

[18] E. Kensinger, "Remembering Emotional Experiences: The Contribution of Valence and Arousal," Reviews in the Neurosciences, vol. 15, no. 4, 2004.

[19] P. Slovic, "Trust, Emotion, Sex, Politics, and Science: Surveying the Risk Assessment Battlefield," University of Chicago Legal Forum, pp. 59-100, 1997.

[20] S. G. Bharadwaj, R. Varadarajan, and J. Fahy, "Sustainable Competitive Advantage in Service Industries: A Conceptual Model and Research Propositions," Journal of Marketing, vol. 57, no. 4, pp. 83-99, 1993.

[21] D. Kahneman, "Thinking, fast and slow," New York: Farrar, Straus and Giroux, 2011.

[22] W. Li et al., "Video quality of experience in the presence of accessibility and retainability failures," 10th International Conference on Heterogeneous Networking for Quality, Reliability, Security and Robustness, Rhodes, pp. 1-7, 2014.

[23] W. Cunningham, and P. D. Zelazo, "Attitudes and evaluations: A social cognitive neuroscience perspective," Trends in Cognitive Sciences, vol. 11, no.3, pp. 97-104, 2007.

Introducing a Toolset for an easy Management of 3GPP Specifications

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***Abstract*—The standardization process in mobile communications technology, which is carried out by the 3rd Generation Partnership Project (3GPP), is a constantly progressing process. In particular, current technologies, such as LTE (Long Term Evolution) are frequently being expanded and enhanced. Upcoming technologies, such as 5G NR (5G New Radio) are still in an early specification phase and the number of specifications will grow, too. Due to the increasing abundance of specifications and ongoing changes, handling and managing of updates of existing specifications and getting aware of new specifications is quite difficult. This paper introduces a Python toolset for an easy management of a large number of 3GPP specification documents.**

***Keywords*–3GPP; Mobile Communications; Specification; LTE; 5G NR; Python**

I. Introduction

The task of the 3rd Generation Partnership Project (3GPP) is the worldwide specification of mobile radio technology. About 95% of the world's 7.8 billion mobile subscribers (Q4 2017) use these technologies [1]. Due to steadily growing user numbers, established technologies such as LTE (Long Term Evolution) are being improved and new technologies such as 5G New Radio (5G NR) are being newly developed. Existing specifications must constantly be adapted due to backward compatibility [2] and new specifications have to be created. The specification of mobile communication technologies is therefore a progressing process [3], whereby the amount of documents will increase. It is not a trivial task to manage the abundance of all these different specifications, which is simplified by the toolset presented in this paper. This paper is structured in four sections. In Section II, the problem statement is described in detail. After that, Section III shows, how the different scripts of this toolset work and what they accomplish. Finally, Section IV summarises the extent of this toolset.

II. Problem description

The 3GPP portal [4] allows downloading of all published 3GPP specifications. The term specification adresses technical specifications and technical reports as well. If the individual specification number is known, downloading is easy and unproblematic. It is possible to type in the number into a specific textfield directly. The search results area shows a glasses button in the last field on the right side, which refers to the download page of the corresponding specification. However, it is often the case that a certain specification refers to another document or other documents. In the rarest cases, it will be sufficient to download (or look into) only one specification. Further specifications have to be downloaded and taken into account then. If there is an interest of studying specifications of one complete series or technology, it is also possible to specify this in the search settings of the 3GPP portal, e.g., listing all 5G NR specifications. At the time of writing of this paper, such a query has already comprised over 390 different documents. The process of downloading these documents is very cumbersome, because it is - besides the individual download of each specification - only possible to download a list of the specifications found in the form of an Excel spreadsheet. In this Excel sheet, the corresponding download page can be opened by clicking on the specification number. A new browser window will open. The versions tab in the new window lists which versions are available for which release. By clicking on the underlined version number, the respective specification can be downloaded as a zip-file, which often contains one or more Microsoft Word doc(x)-files. This download procedure is a very tedious undertaking. If the downloaded Excel sheet contains several hundred specifications, the individual download of all contained documents is extremely time-consuming. Another problem with the Excel sheet is finding out what exactly a specification describes in detail. Usually, only the title of the specification, which is listed in the Excel sheet, indicates whether this specification is relevant for a particular scope or not. However, the exact scope can only be determined by looking into the specification. A keyword search that includes all specification scopes of a certain series or technology would therefore be very advantageous.

There already is a 3GPP toolset available provided by Netovate [5], which allows to search for 3GPP change requests and for written contributions ("TDocs") at meetings. However, the download of the specifications also has to be done manually.

III. Usage of the toolset

The toolset presented in this section allows the downloading and updating of many 3GPP specifications automatically, as well as a keyword search over the scopes of downloaded specifications. A bibTex-file can also be created for certain specifications. The toolset consists of four Python scripts. The programming language Python is freely available at [6]. Further requirements, such as installed Python packages for using the scripts, are shown at the corresponding download page [7]. There is also a detailed description of the usage of the scripts available. In the following, a short overview of the functionality of the toolset will be given.

A. *specificationsHandler.py*

This script automatically downloads specifications and checks if already downloaded specifications have been updated. First, an individual search must be carried out via the 3GPP portal at [4]. The result of this query can then be saved in the form of an Excel spreadsheet. This file must then be copied and both Excel files must be renamed: One file as `LATEST-EXCELFILE.xlsx`, the other file as `REFERENCE-EXCELFILE.xlsx`. Listing 1 shows how to run the script from command line. The script checks if there are specifications in the LATEST-EXCELFILE.xlsx that are missing in the REFERENCE-EXCELFILE.xlsx. All missing specifications are copied to the REFERENCE-EXCELFILE.xlsx. Additional columns are also created for later version management. Then, downloading procedure of all specifications in the REFERENCE-EXCELFILE.xlsx is divided into several threads. The corresponding download links taken from the REFERENCE-EXCELFILE.xlsx are requested and the most current version number and date are queried and compared with the information in the REFERENCE-EXCELFILE.xlsx. When running this script for the first time, there will not be any version information available in the REFERENCE-EXCELFILE.xlsx. Thus, every specification in the file will be downloaded. After finishing, the REFERENCE-EXCELFILE.xlsx is updated with the downloaded version number and date, which are used with further runnings to check for updates. Note that each specification can have different version numbers for each release. The script always queries the latest version number and date of the last and penultimate release (by passing the parameter *-3* the third to last release is also taken into account). If different versions are identified by comparing the online version number/date and the number/date in the REFERENCE-EXCELFILE.xlsx, a zip-file with the specification is downloaded into the subdirectory /Specifications. If there is only one single doc(x)-file within the zip-file, it is converted into a pdf-file using Microsoft Word (or LibreOffice, when using Linux) and renamed according to the following scheme: SpecNr_Version_Date_Release.pdf. This ensures that the same specifications are not overwritten by different release versions. Converting the doc(x)-files to pdf is done once for easier handling and, second, due to compatibility with the script pdfExtracter.py. There are two further options: By passing the parameter -wx, all doc-files are converted into docx-files (necessary for docxExtracter.py). If there is no conversion needed, the parameter -w can be used. This is the fastest approach to download a large number of specifications. For example, downloading all 5G NR specifications (about 390 at the time of writing this paper) took less than 15 minutes in several runs (depending on internet connection).

LISTING 1. USAGE OF specificationsHandler.py

```
python specificationsHandler.py LATEST-EXCELFILE.xlsx
    ↪ REFERENCE-EXCELFILE.xlsx [ -3 ] [ -w | -wx ]
```

B. pdfExtracter.py and docxExtracter.py

This script allows a keyword search over all scopes of specifications, which are in the folder /Specifications. All 3GPP specifications have the same chapter structure and the chapter *scope* describes what each specification defines in detail. By searching all the scopes it is easier to find relevant specifications for own purposes instead of just taking into account the specification title. After using the previously introduced script, the /Specifications folder should contain many specifications in the pdf/docx format. By starting the script as described in Listing 2 the *scope* of all specifications in the folder /Specifications will be extracted into a txt-file named scopeOfSpecifications.txt. For this purpose, the folder /Specifications is searched for pdf/docx-files, which are then processed by several threads. Each thread extracts the text of the section *Scope*. After all threads are finished, all extracted scopes are written into the mentioned txt-file. The created txt-file makes it possible to search through many different specification scopes (by opening it in a text-editor and using the search function) in order to find out what a particular specification defines in more detail.

LISTING 2. USAGE OF pdfExtracter.py / docxExtracter.py

```
python pdfExtracter.py | docxExtracter.py
```

C. specificationsToBib.py

This script creates a bibTex-file of specifications included in the REFERENCE-EXCELFILE.xlsx for using with LaTeX. For each specification contained in this file a bibTex-entry will be created. How to run this script is shown in Listing 3. The parameter -i is optional. It is possible to mark important specifications within the REFERENCE-EXCELFILE.xlsx. Therefore, it is necessary to fill out the corresponding field in the column *important* with the value *1*. By passing the parameter -i only the marked specifications are taken into account and are written into the OUTPUT-BIBFILE.bib. All generated bibTex-entries are of the type techreport. The individual bibTex-key is created by combining the specification number, the version and the publishing date, e.g., 38.201V15.0.0D03012018. The version number and the date are also transferred into the note-field in every entry. Thus, it is possible to reference same specifications with different version numbers.

LISTING 3. USAGE OF specificationsToBib.py

```
python specificationsToBib.py REFERENCE-EXCELFILE.xlsx
    ↪ OUTPUT-BIBFILE.bib [-i]
```

IV. CONCLUSION

This paper presented a toolset consisting of four Python scripts for easy handling of 3GPP specifications. The script specificationsHandler.py uses an Excel table as starting point, which can be downloaded from the portal [4]. All specifications contained are automatically downloaded, converted to pdf/docx and can be kept up to date. Another script (pdfExtracter.py / docxExtracter.py) extracts the respective section *scope* from the converted specifications into a single txt-file. This allows a simple keyword search over many specifications in only one file. Finally, the script specificationsToBib.py was introduced. Specifications contained in the Excel sheet can be converted into a bibTex-file by running this script.

REFERENCES

[1] E. Dahlman, S. Parkvall, and J. Sköld, Eds., 5G NR: The next generation wireless access technology. Academic Press, 2018, ISBN: 9780128143230.

[2] "About 3rd generation partnership project (3gpp)," 2019, URL: http://www.3gpp.org/about-3gpp/about-3gpp [accessed: 2019-01-28].

[3] "3gpp ongoing releases," 2019, URL: http://www.3gpp.org/specifications/releases [accessed: 2019-01-28].

[4] "3gpp portal," 2019, URL: https://portal.3gpp.org/ [accessed: 2019-01-28].

[5] "Netovate 3gpp tool," 2019, URL: https://netovate.com/3gpp-tools/ [accessed: 2019-01-28].

[6] "Python programming language," 2019, URL: https://www.python.org/ [accessed: 2019-01-28].

[7] "Toolset for an easy management of 3gpp specifications," 2019, URL: https://github.com/cs7org/3GPPtoolset [accessed: 2019-01-28].

On the Introduction of 5G Networks in Romania

A novel architecture for spectrum occupancy evaluation

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***Abstract*—In the context of the upcoming 5G networks, the current paper reviews several aspects regarding the New Radio (NR) physical layer: the radio technologies that were proposed for the implementation of the air interface, the frequency bands foreseen to be used and access in unlicensed spectrum areas. The current situation regarding the introduction of 5G networks in Romania is also discussed. Finally, we propose, in the framework of an ongoing research project, a preliminary architecture for a spectrum occupancy evaluation system.**

Keywords-5G; NR interface; frequency allocation; software defined radio; spectrum occupancy.

I. INTRODUCTION

As the requirements in terms of data rate are ever increasing along with the expansion of the multimedia and wireless communications markets, the forthcoming fifth generation of mobile communication networks (5G) will have to provide significantly higher values for capacity, data rate and number of connected devices as compared to the current generation (4G). Moreover, several major user scenarios are defined for 5G, including enhanced Mobile Broadband (eMBB), Ultra-Reliable and Low Latency Communications (URLLC) and massive Machine Type Communications (mMTC) [1].

However, several challenges will have to be faced in order to obtain the above-mentioned performance goals. A key problem that must be solved is related to the limited frequency resources that are currently available, because of the fixed allocation policy and the large number of wireless communication standards that require spectrum resources.

The current state of 5G New Radio (NR) standardization includes a first version of the standard developed by 3GPP (Rel. 15), both in terms of non-standalone network operation (specifications were concluded in December 2017) [2], and in the case of standalone network operation (the specifications in this case were concluded in June 2018) [3]. The development of a new release (Rel. 16) already started and is expected to be concluded before the end of 2019.

The current paper focuses on the physical layer of the forthcoming generation of mobile communication networks. The main contributions of the article are a review of the unlicensed spectrum access elements in case of mobile communication networks and a proposal of a spectrum occupancy evaluation system. The proposed system is based on the use of Software Defined Radio (SDR) platforms and brings novelties over state-of-the-art by combining SDR platforms with different characteristics and by using optimized spectrum sensing algorithms.

The rest of this paper is organized as follows. Section II contains a review of the various radio technologies that were considered for the implementation of the radio interface in 5G networks. Section III discusses the frequency bands that are foreseen to be used for 5G networks. In Section IV, several aspects regarding the use of unlicensed spectrum resources in the context of 5G networks are presented. A preliminary architecture of a spectrum occupancy evaluation system is proposed in Section V. Section VI concludes the paper and contains future research directions.

II. RADIO TECHNOLOGIES CONSIDERED FOR THE RADIO INTERFACE IN 5G NETWORKS

As with all the other generations of mobile networks, the requirements imposed for 5G networks are ever increasing. In Table I, a comparison between the performances that can be obtained using the current 4G networks and the ones that are expected for the upcoming 5G networks.

As it can be noticed, the requirements in case of the upcoming 5G networks are significantly higher compared to the ones for the existing 4G networks.

TABLE I. PERFORMANCE COMPARISON BETWEEN 4G AND 5G NETWORKS [14]

Indicator	Significance	4G	5G
Peak data rate (Gbit/s)	Total traffic for a single device in a cell	1	20
User experience date rate (Mbit/s)	Total traffic constantly perceived by the user	10	100
Spectral efficiency (bit/s/Hz/site)	Data rate per unit of bandwidth	10	15-30
Mobility speed (km/h)	Maximum speed for which certain quality parameters can be maintained	350	500
Latency (ms)	Time in which the data packet travels through the network	10	1
Density of connection (per km^2)	Number of connections in an area for which certain quality parameters can be maintained	100000	1000000
Area traffic capacity ($Mbit/s/m^2$)	Total traffic for a certain area	0.1	10

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Several radio technologies are considered for the implementation of the air interface within the future 5G networks. These technologies, which are seen as appropriate in order to achieve the performances specified in the 3GPP standard (see Table I), can be grouped into several categories as follows:

• Multi-carrier technologies such as CP-OFDM [4], Windowed OFDM (WOFDM) [5], Unique-Word OFDM (UW-OFDM) [6], Discrete Fourier Transform-Spread OFDM [7];

• Single carrier technologies such as Continuous Phase Modulation - Single Carrier - FDMA (CPM-SC-FDMA) [8] [9], Differential Quadrature Amplitude Modulation (DQAM) [10];

• other technologies such as Bi-Orthogonal Frequency Division Multiplexing (B-OFDM) [11], Filter Bank Multi-carrier (FBMC) [12], Generalized Frequency Division Multiplexing (GFDM) [13], Universal Filtered Multicarrier (UFMC) [14].

III. Frequency Bands Forseen to be Used in 5G Networks

The current allocation of frequency resources for the existing mobile communication networks (2G, 3G, 4G) comprises of various frequency bands, all of them being located below 4 GHz. In Figure 1, the allocation of spectrum resources for the case of Romania is presented, as given in [15] by the National Authority for Management and Regulation in Communications of Romania (ANCOM).

In terms of frequency bands expected to be used in future 5G networks, two main categories are defined as follows:

- Frequency bands below 6 GHz (FR1);
- Frequency bands between 24.25 GHz and 52.6 GHz (FR2).

For the particular case of Romania, the same national strategy for 5G [15] also mentions the frequency bands to be used in future 5G networks for which a call for tender will be held in the second half of 2019:

• The 3.4-3.8 GHz frequency band, which is considered by the RSPG (public consultation group on radio spectrum allocation policy at European Commission level) to be the most suitable for immediate use by 5G networks [16] [17];

• The frequencies in the 700 MHz band, which are suitable for the development of 5G network coverage over extended areas, due to lower radio frequency attenuation. For this band the existing infrastructure is expected to be used;

• The 24.25-27.5 GHz frequency band, which can offer bandwidths of the hundreds of MHz required to achieve the performance specified in [2] and [3] (speeds up to 20 Gbps under stable conditions for mobile users).

IV. Aspects Regarding Access in Unlicensed Frequency Bands in 5G Networks

Considering the fact that several wireless communication systems appeared in the last decades and they all required frequency resources, spectrum allocation became a critical aspect in recent years. However, several measurement campaigns that were conducted worldwide [18] clearly shown that most of the spectrum is currently used in a very inefficient way. We also conducted measurement campaigns in Romania [19] and obtained spectrum occupancy values going all the way down to less than 15% in rural areas. One possible approach for improving the efficiency of spectrum usage would be to allow the access of different wireless communication systems in unlicensed bands or in bands licensed to other systems, as long as the licensed (Primary) system/User (PU) is not active.

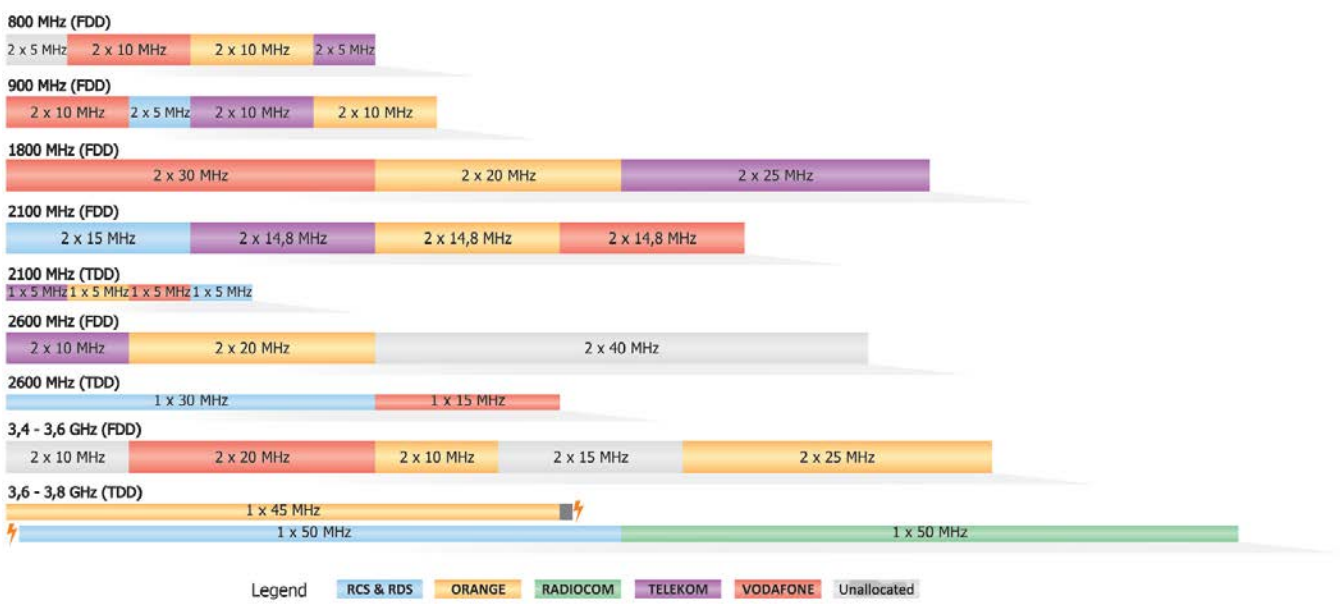

Figure 1. Allocation of spectrum resources for 2G, 3G and 4G in Romania [15]

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Such an approach, known as Dynamic Spectrum Access (DSA) or Dynamic Spectrum Sharing (DSS) requires that each equipment that accesses such a frequency band continuously scans the spectrum, process known as Spectrum Sensing (SS), in order to detect a possible activity of the PU. As soon as such an activity is detected, the unlicensed (Secondary) User (SU) should immediately cease its activity in that frequency band, in order to avoid any interference with the PU.

Starting with the fourth generation of mobile communication networks (4G), standardization efforts focused on the possibility of allowing users to access both licensed and unlicensed spectrum under a unified network infrastructure. The LTE-Unlicensed (LTE-U) technology was initiated as part of LTE Release 13 in order to obtain the above-mentioned goal [20].

Another LTE-based technology which operates standalone in unlicensed and shared spectrum is MulteFire [21]. The MulteFire specification was developed by the MulteFire Alliance, an independent, diverse and international member-driven consortium. Based on 3GPP Release 13 and 14, MulteFire technology supports Listen-Before-Talk for fair co-existence with Wi-Fi and other technologies operating in the same spectrum. It supports private LTE and neutral host deployment models and targets industrial IoT, enterprise, cable, and various other vertical markets.

A study regarding NR-based access to unlicensed spectrum was started by 3GPPP in 2018 [22] and has as goal the development of a single global solution for NR-based access to unlicensed spectrum, which should be compatible with the NR concepts.

Several regulatory requirements for the 5GHz frequency band are being mentioned for all the different ITU Regions, including Dynamic Frequency Selection (DFS). DFS is a spectrum-sharing mechanism that allows the coexistence of wireless LANs with radar systems by automatically selecting a frequency that does not interfere with certain radar systems while operating in the 5 GHz band. The DFS concept was first introduced in 2001 and is a feature that is present in the ETSI BRAN HIPERLAN/2 and IEEE Standard 802.11h.

For the case of the upcoming NR-Unlicensed (NR-U) standard, it appears that a DFS conformance testing would only have to be performed for the Base Station (BS), as full DFS functionality doesn't have to be implemented in all devices, but only in those controlling the transmission.

Different unlicensed bands or shared bands have been discussed for the NR-U, such as 2.4 GHz band, 3.5 GHz band, 5 GHz band, and 6 GHz band. Some of these frequency bands are available globally, whereas some of the bands are only available in some specific regions.

Although in [22] only the case of the 5GHz band is discussed in detail, the same principles will be applicable to a set of frequency ranges to be further defined, without any prioritization for any particular unlicensed band. However, unlicensed bands below 1GHz are not targeted, due to the lack of spectrum in that range, which would make an efficient NR-U operation impossible.

V. Preliminary Architecture of a Spectrum Occupancy Evaluation System

In the following year, in the framework of the Spectrum-5G research project, our research team intends to conduct several measurement campaigns in order to evaluate the spectrum occupancy in urban and rural areas of Romania. We intend to collect RF data for a frequency range up to 6 GHz and for long time periods, in order to obtain a relevant picture of the current spectrum occupancy status. A preliminary architecture of the system that we intend to design and use for performing the measurements is presented in Figure 2.

As it can be noticed, the system is based on the use of several SDR platforms as capture devices. The radio frequency signal is captured by means of a broadband antenna (frequency range of at least up to 6 GHz), which is then distributed to multiple SDR platforms via a broadband radiofrequency power splitter. The SDR platforms will monitor different frequency bands, selected through filtering circuits.

For higher frequency bands, Low Noise Amplifiers (LNA) will be added to increase the level of detected signals in order to obtain improved performance in the spectrum sensing process. As it can be seen in Figure 2, the SDR platforms targeted for the system implementation will be:

- USRP X310 (with UBX-160 RF daughterboard) – Frequency range 10-6000 MHz; Maximum instantaneous bandwidth 160 MHz; Host interface – 10 Gbit ethernet;
- USRP N210 (with WBX RF daughterboard) – Frequency range 50-2200 MHz; Maximum instantaneous bandwidth 40 MHz; Host interface – 1 Gbit ethernet;
- USRP B200mini – Frequency range 70-6000 MHz; Maximum instantaneous bandwidth 56 MHz; Host interface – USB 3.0;
- HackRF One – Frequency range 1-6000 MHz; Maximum instantaneous bandwidth 20 MHz; Host interface – USB 2.0.

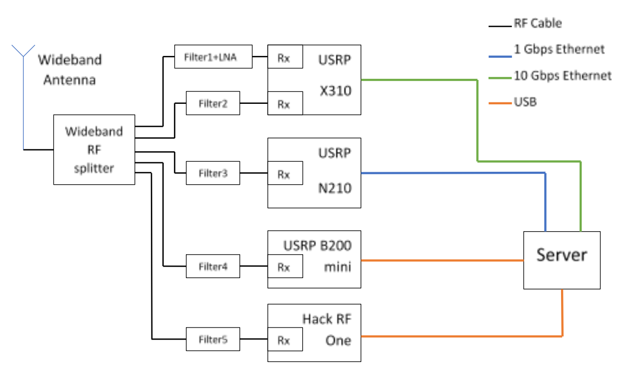

Figure 2. Preliminary architecture of the proposed spectrum occupancy evaluation system.

The information from the SDR platforms will then be centralized using a high-performance server, this approach enabling the simultaneous acquirement of data from different frequency bands. From a software point of view, we intend to use the GNU Radio environment to control and capture the data from SDR platforms, and the MATLAB environment for estimating the degree of occupancy of the spectrum based on collected data using different spectrum sensing algorithms. We already developed several algorithms based on energy detection [23], which will be used alongside classical algorithms like [24]. Although in the current paper the case of Romania is discussed in detail, the flexibility of the proposed system will allow its use for analyzing the spectrum occupancy for any other country.

VI. CONCLUSION AND FUTURE WORK

The paper presented several aspects regarding the physical layer of the upcoming fifth generation of mobile communication networks. The candidate radio technologies that are considered for the implementation of the air interface were mentioned, together with the frequency bands that are foreseen to be used for covering all the different use scenarios covered by 5G networks. A review of the different aspects related to the access in unlicensed frequency band is also performed. A preliminary architecture of a spectrum occupancy evaluation system, based on several software defined radio platform, is finally proposed. As future work, we intend to implement, in the framework of the Spectrum-5G research project, the previously described architecture and we intend to use it for performing measurement campaigns in several urban and rural areas in Romania.

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REFERENCES

[1] M. Shafi et al., "5G: A Tutorial Overview of Standards, Trials, Challenges, Deployment, and Practice," in IEEE Journal on Selected Areas in Communications, vol. 35, no. 6, pp. 1201-1221, Jun. 2017.

[2] 3GPP First 5G NR Standard Approved, available at: http://www.3gpp.org/news-events/3gpp-news/1929-nsa_nr_5g, retrieved: Jan. 2019.

[3] 3GPP Release 15, available at: http://www.3gpp.org/release-15 , retrieved: Jan. 2019.

[4] H. Steendam and M. Moeneclaey, “Different guard interval techniques for OFDM: Performance comparison,” in Multi-Carrier Spread Spectrum, vol.1, pp.11–24, 2007.

[5] B. Muquet, Z. Wang, G. Giannakis, M. de Courville, and P. Duhamel, “Cyclic Prefixing or Zero Padding for Wireless Multicarrier Transmissions” in IEEE Transactions on Communications, vol. 50, no. 12, pp.2136–2148, Dec. 2002.

[6] M. Huemer, C. Hofbauer, A. Onic, and J. B. Huber, “Design and analysis of UW-OFDM signals,” in International Journal of Electronics and Communications, vol. 68, no. 10, pp. 958 – 968, 2014.

[7] T. Svensson et al., “Block interleaved frequency division multiple access for power efficiency, robustness, flexibility, and scalability,” in EURASIP Journal on Wireless Communications and Networking, pp.13, Sep. 2009.

[8] G. Huang, A. Nix, and S. Armour, “Impact of radio resource allocation and pulse shaping on PAPR of SC-FDMA signals,” in Proc. IEEE 18th Int. Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), pp. 1–5, Sep. 2007.

[9] M. Wylie-Green, E. Perrins, and T. Svensson, “Introduction to CPM-SCFDMA: A novel multiple-access power-efficient transmission scheme,” in IEEE Transactions on Communications, vol. 59, no. 7, pp. 1904–1915, Jul. 2011

[10] N. Svensson, “On differentially encoded star 16QAM with differential detection and diversity,” in IEEE Transactions on Vehicular Technology, vol. 44, no. 3, pp. 586–593, Aug. 1995.

[11] M. Kasparick, G. Wunder, P. Jung, and D. Maryopi, “Bi-Orthogonal Waveforms for 5G Random Access with Short Message Support,” in Proc. European Wireless Conference (EW’14),Barcelona, Spain, pp.1-6, Jun. 2014.

[12] J.-B. Dore, V. Berg, and D. Ktenas, “Channel estimation techniques for 5G cellular networks: FBMC and multiuser asynchronous fragmented spectrum scenario,” in Transactions on Emerging Telecommunications Technologies, vol. 26, no. 1, pp. 15–30, Nov 2014.

[13] G. Fettweis, “GFDM - Generalized Frequency Division Multiplexing", VTC Spring - IEEE 69th Vehicular Technology Conference, pp. 1 - 4, Jun. 2009.

[14] V. Vakilian, T. Wild, F. Schaich,, S. ten Brink, and J. F. Frigon, “Universal Filtered Multi-Carrier Technique for Wireless Systems Beyond LTE,” in Proc. 9th Int. Workshop on Broadband Wireless Access @ IEEE Globecom’13, Atlanta, pp. 223-228, Dec. 2013.

[15] 5G Strategy for Romania, available at: http://www.ancom.org.ro/uploads/links_files/Strategia_5G_pentru_Romania.pdf, retrieved: Jan. 2019.

[16] Strategic Roadmap Towards 5G for Europe – Opinion on spectrum related aspects for next-generation wireless systems (5G), available at: http://rspg-spectrum.eu/wp-content/uploads/2013/05/RPSG16-032-Opinion_5G.pdf, retrieved: Jan. 2019.

[17] Strategic Roadmap Towards 5G for Europe – RSPG Second Opinion on 5G Networks, available at: https://circabc.europa.eu/sd/a/fe1a3338-b751-43e3-9ed8-a5632f051d1f/RSPG18-005final-2nd_opinion_on_5G.pdf, retrieved: Jan. 2019.

[18] D. Das and S. Das, “A Survey on Spectrum Occupancy Measurement for Cognitive Radio”, in Wireless Personal Communications, vol. 85, issue 4, pp. 2581-2598, Dec. 2015.

[19] A. Marțian, R. Crăciunescu, A. Vulpe, G. Suciu, and O. Fratu “Access to RF White Spaces in Romania: Present and Future”, in Wireless Personal Communications, vol. 86, issue 3, pp. 693-702, Apr. 2016.

[20] R. Zhang, et al., "LTE-unlicensed: the future of spectrum aggregation for cellular networks," in IEEE Wireless Communications, vol. 22, no. 3, pp. 150-159, Jun. 2015.

[21] MulteFire Release 1.0, available at: https://www.multefire.org/wp-content/uploads/MulteFire-Release-1.0-whitepaper_FINAL.pdf, retrieved: Jan. 2019.

[22] 3GPP Study on NR-based Access to Unlicensed Spectrum, available at: http://www.3gpp.org/DynaReport/38889.htm, retrieved: Jan. 2019.

[23] C. Vlădeanu, C. V. Năstase, and A. Marţian, “Energy Detection Algorithm for Spectrum Sensing Using Three Consecutive Sensing Events,” in IEEE Wireless Communications Letters, vol. 5, pp. 284-287, Jun. 2016.

[24] H. Urkowitz, “Energy detection of unknown deterministic signals,” in Proceedings of the IEEE, vol.55, no.4, pp. 523-531, Apr. 1967.