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MMTC Communications - Frontiers

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CONTENTS

Message from the MMTC Chair

Dear MMTC colleagues and friends,

It is my great pleasure to write the MMTC Chair's message for MMTC Communications – Frontiers. This issue includes two interesting topics, one on Social and Mobile Connected Smart Objects, edited by Prof Armir Bujari from the University of Padua, Italy, and another on Mobile AR/VR/MR and Haptics over 5G and Beyond, edited by Prof Melike Erol-Kantarci from the University of Ottawa, Canada. Thanks Armir and Melike for your commitment and contributions to MMTC!

It is almost one year since the current MMTC team was elected at the IEEE ICC, 20 – 24 May 2018, in Kansas City, MO, USA. I am honoured to serve as the Vice Chair of MMTC in this term (2018 – 2020) and serve for the MMTC community. I have been involved in the MMTC activities in the past 10 years, and have witnessed the fast growth of the MMTC community (now over 1200 members) under the leadership of many great MMTC chairs and officers (e.g. Haohong, Jianwei, Yonggang and Shiwen). For this term, under the leadership of Professor Honggang Wang from the University of Massachusetts Dartmouth, USA, we are determined to move MMTC forward further and to make MMTC an open, friendly and exciting research community on Multimedia Communications and related fields. Please access the MMTC website at http://mmc.committees.comsoc.org to find out more information about the Interest Groups (there are currently 17 IGs and it is free to join in), the Membership, and the MMTC Communications – Frontiers, including this one, and many others.

MMTC sponsors the Communication Software, Services and Multimedia Applications Symposium (CSSMA) at IEEE Globecom and ICC, two flagship conferences of the IEEE Communications Society. As the Co-Chair of IEEE ICC'19 CSSMA symposium, I have seen many excellent submissions this year on multimedia applications over cloud, mobile networks, and SDN/NFV, on advanced and intelligent multimedia services, and on Multimedia QoE etc. I encourage you to submit your original research papers to IEEE Globecom CSSMA symposium, which will be held in Waikoloa, HI, USA, 9 – 13 December 2019.

The next MMTC meeting will be held during the IEEE ICC 2019, in Shanghai, China, 20 - 24 May 2019. I encourage you to participate in the MMTC meeting, share your successful stories about your research/projects, meet old friends and make new ones, and contribute to the MMTC activities. I look forward to meeting you all in Shanghai.

Wish you all the Best!

Lingfen Sun

Vice-Chair, Multimedia Communications Technical Committee (2018 – 2010), IEEE Communications Society.

Associate Professor (Reader), School of Computing, Electronics and Mathematics, University of Plymouth, U.K.

SPECIAL ISSUE ON SOCIAL AND MOBILE CONNECTED SMART OBJECTS

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This special issue of MMTC Frontiers focuses on the experiences with the design, implementation, deployment, operation, and evaluation of novel systems for smart objects and the social aspects of these systems in the emerging cooperative environments. It is worth noticing that there are various research projects and activities aiming to devise a dynamic and cooperative infrastructure built upon objects intelligence.

The first paper presents the design, implementation and deployment details of a smart objects infrastructure in the rich context of Madeira, capable of sensing different environmental and urban conditions of the island.

The authors in second paper envision the use of social media platforms as a complement to the legacy 911 call service. The proposed framework allows victims to request help, enables local communities to initiate rescue efforts much earlier than waiting for FEMA to arrive, and facilitates communication between the victims and community response teams or official rescue operators.

The third paper presents a prototype of digital Augmented Reality (AR) mobile application designed and developed for revealing scientific information about a specific historical and cultural site to a broader and non-specialized audience. The case study taken into account is the Koguryo mural tombs, one of the oldest Korean kingdoms located in the northern and central parts of the Korean Peninsula.

The fourth paper in this special issue proposes a classification method over a vertically-partitioned dataset. In these settings, the data is collected at multiple locations each of which hold a non-overlapping set of features. The proposal leverages on randomly generated values and local information to collaboratively optimize the parameters of a logistic regression model.

Armir Bujari is an assistant professor of Computer Science at the Department of Mathematics, University of Padua, where he lectures the class of Concurrent and Distributed Programming of the bachelor degree in Computer Science. He received his PhD degree in Computer Science in 2014 at the University of Bologna, Italy and completed his M.S. in Computer Science, Summa Cum Laude, at the Department of Mathematics, University of Padua, Italy. From 2014 to 2017 he was a research fellow at the Department of Mathematics, Padua.
His research interests are primarily focused on the design and analysis of communication protocols for wired/wireless networks, Internet architectures, and mobile users, with an emphasis on distributed sensing, mobile applications and multimedia entertainment. On these topics, he is active in various technical program committees of the most prominent international conferences and is author of more than 50 papers, published in international conference proceedings, books, and journals. Among these publications, there are also an invited paper at the IFIP MedHocNet 2014, a STG award at the Wireless Days 2011 and two SRC awards at MobiCom 2015 and 2016 respectively. He has been TPC Chair of many conferences such as EAI/ACM GOODTECHS, IEEE NIME, IEEE DENVECT, EAI GoodTechs and ACM SmartObjects

A Sensing Infrastructure To Collect Data And Foster Citizen's Awareness About Urban And Environmental Issues

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1. Introduction

We live in a data-centric world where pervasive technologies and ubiquitous infrastructures continuously produce vast volumes of data, exploiting interconnected smart objects [1]. Smart objects are central to develop modern ICT paradigms, making possible the deployment of Internet of Things platforms and Smart City services. Such smart and interconnected infrastructures are exploited in different contexts, including the indoor scenario and the outdoor context. Considering the former one, smart objects can be used to create intelligent environments able to use the sensed data to enhance occupants' experiences (see, for example, [2] and [3]). Regarding the latter one, interconnected smart infrastructures can be used in the urban context with the aim of covering different issues, including societal challenges (see, for example, [4] and [5]).

Inspired by previous research studies, we designed, implemented and deployed a smart objects infrastructure in the rich context of Madeira, a subtropical archipelago located in the middle of the Atlantic Ocean. With 270.000 inhabitants, Madeira attracts more than 1.3 million tourists per year, with a significant impact in the economy (tourism accounts for approximately 20% of the region's GDP), but also on the environment. To note is that such area accounts for 80% of the biodiversity of the European continent and provides a unique testbed for testing pervasive technologies for sustainability and biodiversity issues.

In this context, infrastructures of smart objects have been deployed across the Madeira islands in order to sense different environmental and urban conditions, considering also a more-than-human approach in order to foster sustainable development. In particular, we designed the smart sensors to collect data aimed to investigate the following research questions:

<u>RQ1</u>. How to inform citizens about sustainability-related issues?
<u>RQ2</u>: How to engage citizens in monitoring biodiversity?
<u>RQ3</u>: How to motivate citizens in validating/exploring the collected data?

In this paper, we present the infrastructure and the different case studies we investigated to answer to the above stated research questions. In particular, Section 2 describes the infrastructure deployed to collect information about mobility flows and environmental condition (RQ1), and the platform we developed to engage citizens (RQ3); while Section 3 describes the smart objects developed to collect data about biodiversity for engaging users in biodiversity monitoring (RQ2) and in validating the collected data sets (RQ3). Finally, the paper concludes with final remarks and future directions.

2. Smart Objects for Sustainability and Environmental Monitoring

A sensing infrastructure has been deployed across the Madeira island in order to collect information related to suitability issues [6]. In particular, the goal of the infrastructure is twofold: (i) exploiting passive Wi-Fi tracking [7] to collect information in a non-intrusive way about the mobility flows of tourists and locals; (ii) monitoring air quality and other environmental conditions using low-cost sensors.
The final aim of the system is to collect huge volumes of data and make sense of them, providing a wider community of stakeholders with information and visualization about spatio-temporal patterns of the movement of people in touristic destinations and related data impacting the sustainability of the island.

More than 80 sensors stations have been spread across the Madeira and Porto Santo islands. In order to deploy our infrastructure, we invited citizens, including people working for public entities and owners of small businesses such as bars and restaurants, to install our sensors in their places. Each sensor station is equipped with a commercial TP-Link MR3240v2 home router (costing around 45€) to capture the data of people passing by it. In fact, due to active service discovery mechanisms enabled on most devices, Wi-Fi interfaces are periodically broadcasting frames, named probe requests containing their MAC address. As a result, a device with the Wi-Fi interface turned-on acts as an actual wireless beacon by periodically advertising a unique identifier in clear. This advertisement is also done while using the location services (GPS) in high accuracy mode that use the Wi-Fi network discovery to narrow down the device location in places where the location service takes longer to connect.

The low-cost router can run a Linux system and, since we were targeting multiple locations and wanted a robust solution, we opted for installing OpenWRT –Barrier Breaker 14.07. A custom script in Python was added to run at the start scripts of the router, setting the wireless interface in monitoring mode. This basic script uses the package Scapy to capture packets and filter them for the type 0 (management) and the subtype 4 (probe requests). It also takes into account the big number of repeated messages (same MAC address and SSID) from the same device and does not send to the database repeated captures to avoid data duplication. The detected probe requests are sent to a remote database through a web service with JWT authenticated messages in HTTP requests.

In some of the outdoor sensor stations, we also integrated low-cost sensors for environmental monitoring, including CO2, light, temperature, humidity, PM 5 and PM 2.5. In this way, we can monitor environmental conditions and correlate this information with the mobility flow patterns for a more strategic transportation demand management.

The collected data is aggregated and visualized through a web platform available to all citizens. The idea behind the system is to exploit data visualization strategy to make sense of big data related to sustainability issues and make people more aware of the impact of mobility in the Island ecosystem. Examples of interactive infographics are presented in Figure 1.

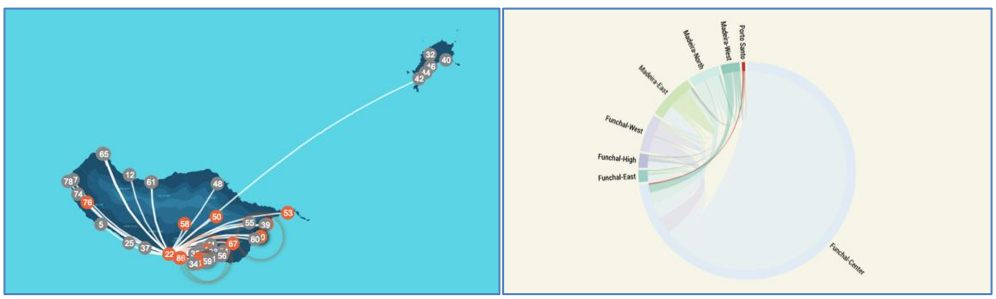

Figure 1: Interactive infographics representing mobility flows in Madeira.

3. Smart Objects for Biodiversity Monitoring

Considering the peculiarity of the Madeira archipelago, biodiversity preservation is one of the sustainable goals that need to be addressed. In line with that, we exploited low-cost bioacoustics sensors to create a smart object able to detect and record animal's calls based on the specific frequency.

We designed and built a low cost bioacoustic sensor able to detect animals' sound. The sensor station is composed of: i) a Particle Photon microcontroller, responsible for all the major computations; ii) a ultrasonic microphone (that has a frequency range depending on the animal's species); iii) a lithium polymer battery that can power the entire sensor (although it can also be powered via the USB entry of the Particle Photon); iv) a temperature and humidity sensor that collects temperature and humidity values of the proximity area; v) a SD card slot where the Photon writes all of the data it records; and vi) an antenna, that amplifies the sensor's Wi-Fi reception. The sensor works in the following way: every 250ms (configurable in the project settings), the sensor collects a set of sounds and calculates their frequency (applying fast Fourier transform, FFT, and quadratic interpolation to find the predominant frequency). If the frequency is in the interval of interest, the sensor collects a data-set 3 more times. If those data sets are in the frequency we are searching for, the sensor records the audio to the SD card, and, if connected to a Wi-Fi network, it sends the audio clip to the server. It is clear the relevance of such low-cost sensors for monitoring reasons.

In this scenario, to answer to RQ3 (how to motivate the users), we designed and implemented a game with a purpose (GWAP, [8]) taking advantage of the citizen science paradigm [9]. The game has been developed as Android mobile application and allows players to challenge them-self in classifying animals calls while learning about the biodiversity of the surrounding area (if used in location-based mode) or of a specific area (if used in remote-based mode). Examples of screenshot of the implemented GWAP are presented in Figure 2. In the first one is possible to see map-based interface that the user can explore; the second one is used to classify the animal's sound detected in that park in a specified day and time; in the third and last one, the creation of a mutant on the basis of the DNA sample collected validating and classifying the animal's sound.

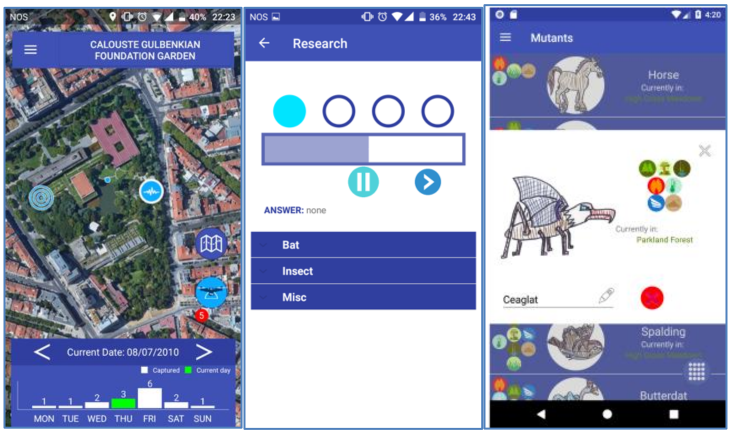

Figure 2: Example of game state progression.

4. Discussion and Future Work

This paper presents a low-cost infrastructure of smart objects designed, developed and deployed in the Madeira archipelago. Each node of the infrastructure can be equipped with different technological components and sensors to answer to the different needs.

Madeira accounts for the 80% of biodiversity of the European continent, making the archipelago a strategic test-bed for sustainable development and biodiversity preservation. For this reason, we build sensors to detect both mobility flow and environmental condition, and biodiversity monitoring through the recording of animals' calls. To deploy the infrastructure, we relied on citizens and the local government who plugged the sensors stations in their stores/restaurants/cafes (tourists and locals point of interests) and public spaces, respectively.

To engage users in changing behavior, becoming more aware of sustainability and biodiversity, we implemented i) a web platform that makes sense to the huge volumes of collected data; ii) a mobile game with a purpose to motivate users in classifying animals calls while learning about the biodiversity present in a specific area.

We tested both the solutions obtaining positive feedbacks from users regarding, in particular, the main goal, that is: increase awareness about sustainability and biodiversity exploiting a low-cost infrastructure of interconnected sensors. This encourages us to continue to collect data and maintaining the 80 nodes spread across the Madeira and Porto Santo islands.

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Using Social Media for Crowd-Sourced Public Safety

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1. Introduction

With over 3.3 billion people using social media on mobile devices [1], we are observing an increased use of social media for situational awareness and information dissemination during disasters as was the case in 2010's Haiti earthquake [2]. During the 2016 Pulse nightclub shooting in Orlando, the club used Facebook to alert people to evacuate [3]. In 2017's Hurricanes Harvey and Irma, not only did people use social media for sharing their location and pictures of their surroundings, but also we saw them seeking help through social media as an alternate means to contact rescuers [4]. Platforms like AIDR have been developed to glean real-time disaster insights by feeding social media crowd-sourced information to machine learning algorithms [5]. Apart from emergency officials, we saw community volunteers actively engaging with victims through social media to help them. Hurricane Harvey saw Cajun Navy [6], a fleet of boat volunteers using the Zello app [7] to coordinate rescue efforts. However, such ad hoc volunteer efforts suffer from complex coordination with officials from multiple agencies, lack of overall prioritization of efforts, and incomplete feedback loops [2], [8].

We propose to use social media apps not just for rescuers and volunteers but also to provide a service similar to the legacy 911 call service. The traditional 911 service is prone to scalability issues during high call volume, resulting in increased call waiting times [9]. According to December 2017 NENA statistics, there are 5,783 call centers while annual 911 call volume is 240 million in the U.S. [10]. In addition to scalability, public safety communication networks need to be reliable. Hurricane Katrina response operations suffered from failure of infrastructure, delay in restoration, and lack of common framework between various agencies [11]. According to the National Center for Disaster Preparedness at Columbia University, disasters often have an impact on 911 service availability [4]. Sometimes the 911 network fails due to other unforeseen outages, for example, the Verizon outage in June 2018 [12] and the AT&T outage in March 2017 [13] prevented cellphone users from dialing 911 for an extended period of time. In situations where legacy infrastructure services are entirely or partially unavailable, social media can become the SOS network needed by victims to seek and reach rescue service in a manner similar to 911 call service.

We provide a framework over social media that allows victims to request help, enables local communities to initiate rescue efforts much earlier than waiting for FEMA to arrive, and facilitates communication between the victims and community response teams or official rescue operators. Specific contributions of this work include: a) Smart Public Safety Framework (SPSF) using social media as a communication platform, b) Twitter-based SOS protocol, and c) future research opportunities.

2. Smart Public Safety Framework

The key players in our proposed Smart Public Safety Framework (SPSF) include: i) a Public Safety Access Point (PSAP) agents, or PS Call Handlers or call-takers who receive, analyze and triage requests, and dispatch rescue teams; and ii) a Dispatch Units (DUs) or Response Teams who respond to the emergency and include officials from Police, Emergency Medical Service (EMS) and Fire Rescue as well as community volunteers registered with the SPSF system. Together, these people constitute the Public Safety Network (PSN). The SPSF also includes a web system and an integrated smart-phone app that can be used by DUs and volunteers to keep their skills and certificates up-to-date as well as automatically share location information. Specifically, the proposed SPSF architecture, shown in Figure 1, has the following key components:

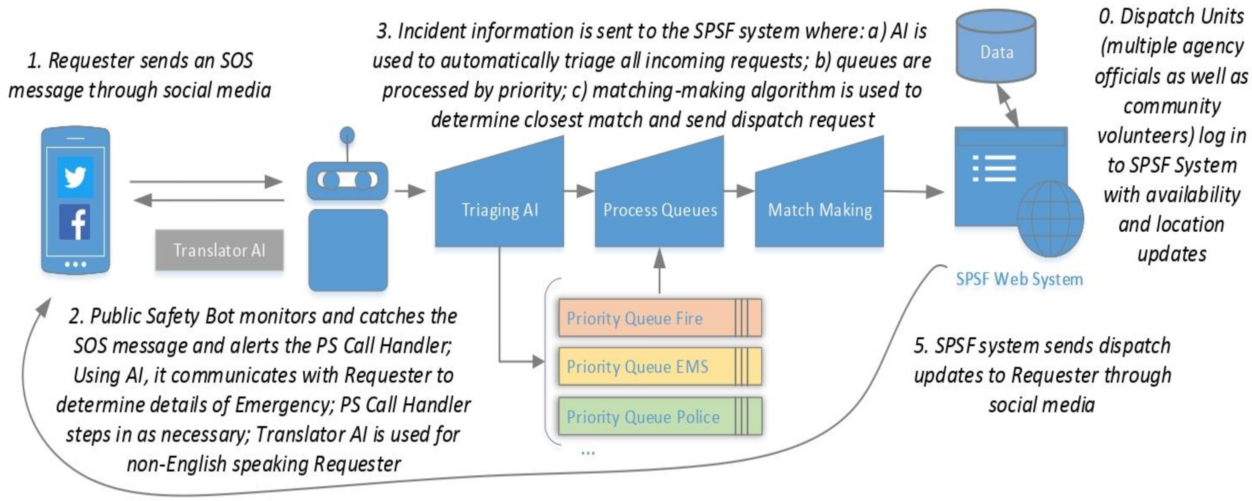


Figure 1: Smart Public Safety Framework.

2.1. Public Safety Bot

The framework includes a chatbot, called Public Safety Bot (PSB) that monitors social media streams for help messages and flags them for PS Call Handlers. This can be accomplished using APIs like Twitter Streaming APIs or tracking hashtags using Hootsuite, Tagboard, etc. If the PSAP is stormed with calls, the PSB can be trained to ask a series of questions as per call handling protocol to alleviate the PSAP's burden. In addition, PSB can be integrated with an AI translation service to automatically interpret messages exchanged between the PSAP agent and requester. This provides a clear advantage over traditional 911 service which may need additional personnel with specific language skills to act as liaisons between requesters and call-takers that do not speak the same language.

2.2. Victim Triangulation

To perform a successful rescue, the victim's location needs to be available and accurate. In traditional 911 calls made with landline, this information is available to the PSAP agent as addresses are registered with landline numbers. However, when a cell phone is used to dial 911, the cell tower receiving the GPS signal from a victim's cell phone can triangulate the victim's location and provide it to the PSAP agent, but it may not be accurate. In most cases, the PSAP agent would request confirmation of this location information from the caller. When social media is used, the victim's location can be even more of a mystery as less than 3% of tweets are tagged with geo-location [14].

Researchers at Penn State propose a "social triangulation" technique to infer a poster's location based on who they follow and what communities they subscribe to [15]. Some researchers at IBM developed an algorithm to analyze tweets' content using statistical and heuristic classifiers to predict a Twitter user's location [16]. Although social triangulation can be helpful for public safety officials to send tailored and targeted messages to people based on their memberships to specific communities, this method may not work for pinpointing the location of a specific user in real-time during an emergency. Similarly, the content analysis method does not reach the granularity of location identification needed for rescue and response operations.

More work needs to be done for pinpointing an online SOS Requester. Perhaps one approach is to use AI to analyze an SOS Requester's feeds on different social media platforms to discern their exact location. But this is time-consuming, it would involve determining the user's handles in various social media platforms, skimming their messages and pictures, then running some context analysis or image analysis on recent content to co-relate the background of photos, for example. In order to save time, should public safety officials run this analysis on people with social media presence beforehand? Clearly, there are socio-ethical concerns. One may argue that such proactive measures are necessary to avert dire situations, e.g., a proactive analysis on messages being exchanged before riots start, can help officials respond in time to prevent catastrophe [17].

2.3. Triaging AI and Queue Processing

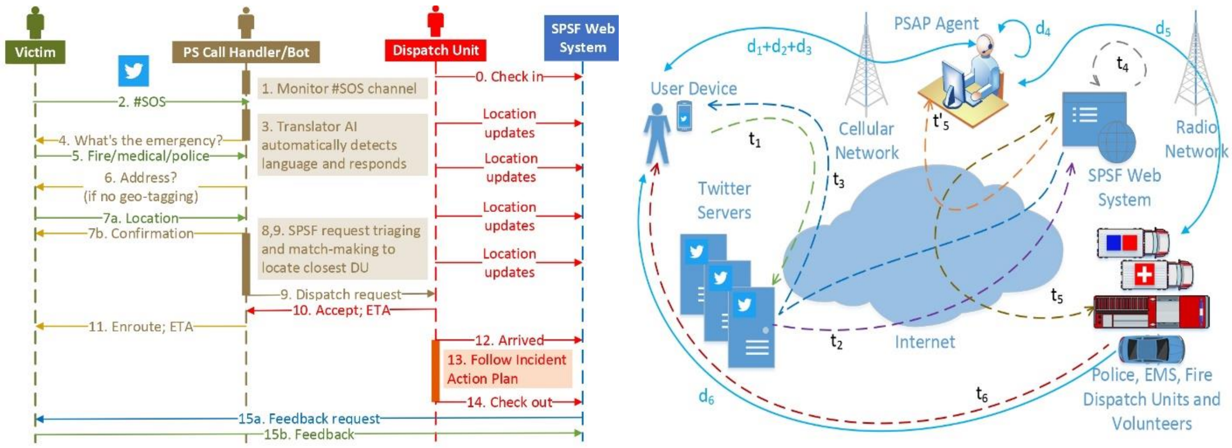
SPSF's chatbot can be trained to ask the questions necessary to triage incoming requests, discard fake ones, and flag requests with life-threatening emergencies. Thus, triaging using AI is a clear advantage in the SPSF framework as a) it can help filter out fake requests, which is an inherent issue in the use of social media due to the possible anonymity of posts; and b) it can automatically flag requests with different levels and types of emergencies. This can be achieved by asking a series of follow-up questions much like a human PSAP agent would. Such empathetic exchange is possible in today's chatbots [18]. Studies also show that machine learning algorithms can make better triaging decisions than humans [19], [20], e.g., AI-assistive tools like Corti can identify a caller suffering from cardiac arrest in 95% cases versus 73% by a human dispatcher [21].

Traditional 911 service breaks down during large scale disasters, where PSAP is inundated with phone calls and some people are unable to get through [9]. Augmenting traditional 911 with a social media based SOS service should help alleviate the PSAP's burden during disasters, but it may just as easily aggravate the issue when people flood the network by sending disaster photos and videos in their SOS messages, affecting network availability and response time. This could be resolved by sharing messages and data through a hybrid Internet-based and device-to-device network to extend connectivity [22].

The Queue Processing module is responsible for managing priority queues for incoming requests pre-flagged with the emergency type. It automatically processes the incoming requests and adds them to their relevant queues i.e. fire, police, and medical. Each emergency queue can itself be prioritized and all queues can be processed in parallel as response teams are generally different for different emergency types. This is another clear advantage of SPSF framework over manned PSAPs where calls are processed in the order they are received, and may cause a high-emergency call to be in the wait queue while a low-emergency call is being handled.

2.4. Volunteer Management and Match-making

SPSF enables crowd-sourcing for rescue and response operations by recruiting volunteers from impacted and nearby communities to quickly and effectively build response teams necessary to react to massive disasters. For these volunteers to be effective, they should either have prior experience, e.g., as a firefighter, lifeguard, etc., or they should be required to complete some rescuer training when they join the SPSF volunteer network to donate their time for improving public safety. We also propose a Volunteer Management module in the SPSF system where volunteers can register with the PSN, and upload their skills and certifications. PS officials can view all volunteer activities, ratings/feedback received, time logged, training acquired, as well as endorsements from other PS officials who may have worked with them on a job. The ratings are quantitative but feedback is qualitative, and comments can be private to the SPSF officials or accessible to public. This review/endorsement system can essentially help build credibility of volunteers and is also fed into the matchmaking process to find the best suited response team for a request in terms of skills, experience, availability and location. Through the web portal, a Requester can view ratings and reviews of dispatch units and choose who they would like to receive help from, if time permits. The question is, can we build enough credibility through SPSF to allow public to trust strangers with their lives during times of disasters?



(a) **(b)**

Figure 2: Sub-figure (a) shows the Smart Public Safety Framework's (SPSF's) protocol for sending distress signal to Public Safety Network via Twitter. Sub-figure (b) shows the various delays at play in SPSF vs. traditional 911.

3. A Twitter-Based SOS Protocol

A high-level description of SPSF's communication protocol between victims and PSN personnel is as follows:

1) PSB monitors channel for distress messages;
2) Requester posts an SOS message on channel; content may also include voice, picture, and/or video;
3) Translator AI auto-detects the language, interprets and translates the messages between the PSB and Requester;
4) PS Call Handler/PSB asks about the nature of the emergency or confirms what can be determined from the content;
5) Requester responds with emergency details, e.g. fire, chemical hazard, accident, intruder, or shooting;
6) PS Call Handler/PSB checks if geo-tags are available, and if not, requests exact location of the Requester;
7) If requested, Requester provides location and other information requested by PS Call Handler/PSB;
8) Triaging AI automatically categorizes and prioritizes requests, if deemed legitimate;
9) Match-making AI determines most apt Dispatch Unit and sends emergency code and location information;
10) Dispatch Unit accepts the task and provides ETA;
11) PS Call Handler/PSB assures Requester that help is on the way and provides ETA when available;
12) Dispatch Unit provides updates via SPSF system to the PSN to quickly disperse information;
13) Dispatch Unit executes Incident Action Plan;
14) Dispatch Unit checks out;
15) Requester has opportunity to provide feedback later.

In the case of Twitter, we propose to use Twitter for Business in SPSF with the Direct Message (DM) feature enabled to allow private message exchanges between requester and PSAP. This Twitter-based SPSF protocol is depicted in Figure 2a.

3.1. Delay Analysis

A key question is whether SPSF will reduce response time when compared to the traditional 911 service. With reference to Figure 2b: t_1 is the time to send an SOS tweet to the SPSF channel, t_2 is the streaming time from Twitter servers to the SPSF web system, t_3 denotes the communication time between PSB and victim to determine location and the nature of emergency, t_4 is the time for analyzing and triaging incoming requests and t_5 is the time for matching a suitable DU and sending them the request. If this request is not accepted or responded to, SPSF would find the next best match. It may also happen that the PSAP agent has to step in to gather more information, or respond to the victim while locating an appropriate DU, taking time t_5'. Let t_6 denote the travel time for DU to reach the victim. Total end-to-end worst-case delay will be $t_{max} = \sum_{i=0}^{6} t_i + t_5'$. In Figure 2b, the d series identifies the delays in the traditional 911 scenario where d_1 is the time to dial 911, d_2 is the time to answer the call depending upon current call volume, d_3 is the time taken by the PSAP agent to gather information from the victim, d_4 is the time to triage and d_5 is the time to find and assign a matching DU. The DU's travel time is d_6. The total end-to-end delay in the traditional 911 scenario will thus amount to $d = \sum_{j=0}^{6} d_j$. The National Fire Protection Association Standard 1710 requires a turnout time of 80 seconds for fire and 1 minute for EMS emergencies; and its guidelines state that in 90% cases, the first unit should arrive within 4 minutes and all units within 8 minutes [23]. Thus, for fire, $d < 12$ minutes.

The time it takes a victim to dial 911 or type an SOS tweet can be assumed to be the same, i.e., $t_1 \approx d_1$. In the SPSF framework, Twitter stream is being monitored in real-time, so an SOS tweet is handled promptly and we can assume $t_2 \approx 0$. However, in the traditional 911 case, call wait-times depend on the number of PSAP agents at the call center [24]and increase as call volume grows, i.e. $t_2 << d_2$ under load. A trained PSB can be assumed to take similar time as a PSAP agent to gather information from the victim, so we can assume $t_3 \approx d_3$. The Triaging AI can successfully triage the request and find an suitable dispatch unit in t_4+t_5 time units which is less than a PSAP agent in the traditional case, d_4. If we assume p to be the probability that SPSF's Triaging AI is successful with a strong enough confidence, then the probability that a PSAP agent has to be engaged in triaging is $1-p$. The time it takes for a PSAP agent to locate a DU in SPSF is similar to the traditional 911, i.e. $t_5' = d_5$ and the dispatch unit's travel time can also be assumed to be the same in both cases, so $t_6 = d_6$. Therefore, the average communication delay experienced in the SPSF framework can be expressed as $t_{max} = p\ (t_{max} - t'_5) + (1-p)\ t_{max} = t_{max} - p\ t'_5$. Thus, as long as $p > 0$, it holds that $t_{avg} < t_{max} \leq d$. Improvements in AI will increase the probability of successful triaging, and as $p \rightarrow 1$, the delay of SPSF will improve. The efficacy of this AI-based approach depends on the naturalness of the chatbot's interaction with the victim [25], precision of the AI-based triaging [19], and potential use of AI in the medical and emergency response fields [21, 26]. Some of these challenges are discussed in the next section.

4. Challenges and Opportunities

Several research opportunities arise from the SPSF concept. Can AI-enabled chatbots replace PSAP agents? Currently, AI’s potential is to assist the PSAP agents to make better decisions than machine or human alone [21], [26], [28]. Research in social chatbots [18] shows that both emotional quotient and intelligent quotient should be part of the chatbot design to help the user develop trust in the chatbot, essential during emergencies. Perhaps using a combination of deep-learning based technologies like AWS Lex and AWS Polly, sophisticated natural language-based online 911 bots can be built. On the positive side, not only are these automated techniques scalable, but would allow a victim access to 911 service without a language barrier by integrating with a real-time translation service like AWS Translate or Google Translation API.

We also raise the importance of accurate victim triangulation, especially in 911 over social media where most posts are not geo-tagged [14]. There is a need to evaluate existing social triangulation methods [15] for their real-time effectiveness during emergencies when every second counts. If the true victim is not at the location of the SOS requester, then additional data mining techniques need to be employed in conjunction with triangulation and they need to be near real-time.

We proposed an automatic Request Triaging AI in the SPSF framework to prioritize and flag calls properly. The Triaging AI will possibly need subject matter experts (SMEs) to improve accuracy, e.g., the D.C. Fire and EMS Department has registered nurses at PSAPs to detect true medical emergencies [29]. The efficiency and effectiveness of the priority automation with SMEs in SPSF needs to be explored in the context of SOS messages. Although social media empowers bystanders to freely report incidents while remaining anonymous and preserving their privacy, however, it can potentially lead to malicious diversion of genuine rescue efforts and more work needs to be done to develop and assess effective techniques to weed out fake callers.

We have proposed one simple approach in the SPSF Matchmaking module that finds a match based on DU’s skill, experience, availability and proximity. In reality, the match-making and queue processing modules will need to intelligently and dynamically re-route DUs headed to low-emergency site if a high-emergency call comes. SPSF also provides a credibility-building platform for engaging volunteers to become part of the Public Safety Network. The proposed ranking concept is similar to Uber ridesharing service, however, rescue operations have much higher safety and security concerns and better measures for credibility need to be explored. All communication channels between victim, PSAP, and DUs need to be secured. Twitter is currently testing Direct Messages encryption and when available, this feature would be key for the security of the proposed framework.

5. Conclusion

We have proposed a framework for "online 911" using social media platforms like Twitter to alleviate the challenges of traditional 911. It includes an automatic and scalable distress message handler to handle and process messages at a much higher rate than traditional 911 service. It also provides a platform for community/volunteers to engage with the Public Safety Network for emergency response. We outlined several research challenges and opportunities arising from the framework.

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On Discovering And Supporting Cultural Heritage Conservation Through Mobile AR

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1. Introduction

The current availability and the wide diffusion of ICT technologies are driving us into a scenario where objects and environments intelligence, together with their enhanced capabilities, can play a strategic role in different aspects and activities of our everyday life [1]. A significant one is represented by the case of cultural heritage, where ICT-based strategies can be exploited to disseminate and communicate information about a specific piece of art or a specific historical site [2]. Digital guides on mobile devices are already used during touristic visits in several museums and cultural institutions, but there is an additional and hidden treasure behind the scenes that could be discovered by the audience thanks to smart objects: understanding of the cultural heritage coming from diagnostic analyses. Information coming from that analyses cannot be easily accessed and exploited, but they can improve the understanding of a specific piece of art, giving information about the materials composition, the production techniques adopted by the authors, the state of conservation, etc. [3]. This information represents an interesting and significant part of the cultural heritage, but it is usually hidden behind the scene, even if it actually plays a strategic role for many aspects in this field. Hence, mobile and distance technologies can be intended as an exceptional opportunity to offer innovative and alternative approaches to individuals to interact with cultural heritage assets, which can accomplish not only entertaining, but also educational aims [4]. Moreover, digital technologies (in particular, the ones based on virtual and augmented reality) can greatly support the communication and the diffusion of information about specific cultural heritage when constrains and physical limitation prevent the visit in persons, for instance in those sites that admit just a limited number of visitors for conservation and sustainability purposes.

This paper presents a prototype of digital Augmented Reality (AR) mobile app designed and developed for revealing scientific information about a specific historical and cultural site to a broader and non-specialized audience [5]. The case study we took into account is the Koguryo mural tombs [6]. Koguryo was one of the oldest Korean kingdoms located in the northern and central parts of the Korean Peninsula and, at the height of its power in the 5th century, ruled over a vast territory. The hypogean environment, which is characterized by high relative humidity and carbon dioxide values, makes the mural paintings very fragile and covered by a thin layer of re-crystallized calcite. This affects the visual appreciation of the painted surfaces. Moreover, such mural paintings represent a precious source of information about the social and cultural aspects of the Koguryo kingdom (due to the absence of contemporary historical texts from that period [7]) and about technological aspects, which can be deducted thanks to painting material composition investigation. Finally, it is worth mentioning that the access to those tombs, which are located far away from the capital city of Pyongyang, is difficult and in many cases strictly forbidden.

In this paper we present a mobile AR application prototype (mainly based on the tombs Jinpa-ri I and Jinpa-ri IV), which represents a tentative of exploiting smart devices in an enhanced indoor environment, simulating the tomb, equipped with ad-hoc markers. This prototype has been designed with the aim of letting the user appreciate a cultural heritage site that could not be visited in person and understand the reasons that preclude a real visit. Our objective is getting the idea that such an historical site is very fragile in terms of materials composition and that the presence of humans visitors would damage such a delicate and precious environment.

2. Background and Related Work

The Koguryo mural tombs are historical relics, which had a large influence on the development of Eastern culture in the medieval ages, thanks to their outstanding architecture and astonishing painting techniques. In the absence of contemporary historical texts from the Koguryo kingdom [7], we can gain an insight into the social and cultural aspects (including also technological aspects of Koguryo) through the mural paintings of the tumuli. In fact, the Koguryo mural paintings vividly reflect the life of the Koguryo civilisation: they are still rich in colour and tone, and they were retaining their distinct colors for about fifteen hundred years. The state of conservation in the tombs Jinpa-ri I and IV from the Complex of Koguryo Tombs is not stable and further conservation interventions will be desirable. In order to guide any future intervention, an extensive research aimed at understanding their state of conservation and the painting technique adopted was carried out. This has motivated the use of digital technologies to disseminate scientific information to a general audience, including archaeological and artistic values, material composition, and the general conservation problems of the Koguryo Jinpa-ri Tombs.

Several museum virtual heritage applications use immersive and interactive virtual reality technologies to give visitors access to computer reconstructions of historical sites. As an example, the Digital Koguryo project has been developed to create a learning environment that can support young children in understanding the past and the history, life and values of the Koguryo cultural heritage [7]. The virtual and interactive heritage environment encouraged users to immerse and engage in the cultural experience [8]. In the same project, the researchers found out that the existing surfaces of the original mural paintings are damaged in various places, and do not provide enough detail. Therefore, they had to perform a digital restoration of the 2D mural painting images to create the texture maps for Digital Koguryo. The authors scanned the photographs taken from the murals and the books, created the illustrations for the base to reconstruct the restored image. Then they corrected color, hue, and intensity in the digital images and filled the damaged parts. This process has been based on the historical research and documents on the polygenetic pigments of Koguryo and on studies about how the colors would change with moisture and how the texture of the painted walls would interfere with the colors [7]. Finally, in this study, it was concluded that the virtual reality application was difficult to develop without knowing the material constituents and painting techniques. Thus, we have included in our prototype information about contemporary scientific research results on material composition, because in our case the historical documents are not available or not existing.

Smart objects and virtual/augmented reality technologies can be used to provide additional digitalized information while users are looking or approaching the actual object or piece of art placed in a specific location, improving the user's learning and/or entertaining experience [9]. In the cultural heritage field, many applications of augmented reality have been explored to "bring back to life" archaeological sites that have been lost [10] or to which it is impossible to access for some reasons [11]. Another example of AR employment in the cultural heritage context is its inclusion in museums and in cultural institutions where thousands of historical artefacts are carefully preserved. An excellent example of augmented reality usage is to recreate an object in its original form above the object actually exhibited in the museum to facilitate understanding of what is being watched. The interpretation of cultural heritage through the use of additional information, initially imparted on paper or by voice through a guide, was an ideal way to preserve cultural material, but also to spread knowledge in a captivating way [12]. In addition to archaeological findings, the museums can also present reconstructions of archaeological sites that are located in places not comfortable to reach, where visitors cannot enter in order not to affect the delicate environmental balance or sites that no longer exist, and this is the case of our project.

3. Our Prototype

There are several categories of Augmented Realty (AR). Our prototype is based on Marker-Based AR, which uses a Recognition through which the elements can be visualized on the graphical entity screens. The marker can be a simple piece of paper with black and white marks on it (see the Hiro marker in Figure 1). There are different types of markers that can be seen by the camera as the centre of positioning virtual resources on the scene. By concentrating the device's camera on the marker, the application can retrieve the stored information to correctly render the three-dimensional virtual objects.

In order to design an effective mobile AR application, a clear understanding of what is inside the Jinpa-ri Tombs is needed. According to that, an appropriate digital tool should be selected to reflect the information in a feasible way. The tombs are still keeping their distinct artistic features, at the same time the surfaces are very fragile and with the risk of great degradation. In order to let users understand why strong preservation measures are taken and why the access to the tombs is prohibited, it is necessary to explain the material composition of the artistic surfaces of the tombs and the degradation processes. To reach this, results of the high-end scientific research have be presented to the public. Moreover, the way of presenting the results should be the one that allows an easy understanding for the general audience. Researchers in the field of cultural heritage digitalization let us understand that little is known about the structure of the tombs and their mural paintings. It is a quite challenging task to reproduce the tomb in virtual reality [7]. This work may serve as an experiment of how combining results of scientific research in cultural heritage diagnostic analyses with new mobile technologies and applications.

We decided to develop a Web app, which can be access and enjoyed by a browser installed on a laptop or on a mobile device. The application has been designed and developed thanks to the collaboration of cultural heritage restoration and conservation scientists and of computer scientists, with three main goals in mind: (i) letting the user enjoy a virtual reconstruction of the tombs; (ii) letting the user understand the fragile ambient within the tomb, which is the main reason that prevent a visit in person; (iii) engaging users expert in the field, with scientific content. Hence, the storytelling and the interaction flow have been studied in the form of questions-answers, trying to provide technical information (i.e. material composition, painting techniques, degradation phases) to a larger audience, by means of hypermultimedia and interactive contents, based on images, animations, and textual descriptions. As a general approach, the interaction flow always starts from the general view of the selected wall, which will be the background for the entire duration of the visit. Then, it will appear the question or the title of the content that the visitor will be dealing with. After the appearance of the animation, automatically, an image will be displayed showing the painting in its original appearance (representing a hypothetical reconstruction), enriched with textual description, explaining the meaning, the origin and the techniques in which it was depicted.

Figure 1 to 4 depict screenshots taken from our prototype, showing, respectively, the composition of a wall in the form of stratification, the explanation of a painting technique which has been adopted and the pigments used by the artists, and a 3D graphical reconstruction of the various layers of materials applied to the stone, with an animation showing what happens when carbon dioxide and water molecules meet the superficial part of the painting (providing information about the state of conservation of the wall).

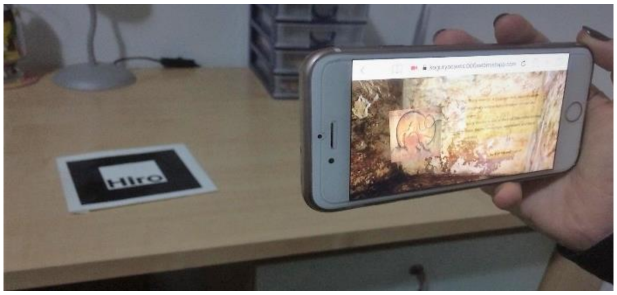

Figure 1: Marker tracking of our prototype from a mobile phone.

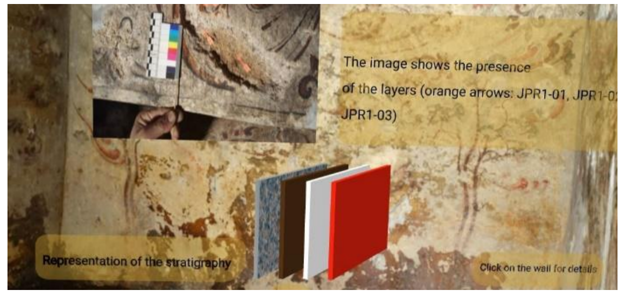

Figure2: Animation of the stratigraphic composition of the wall.

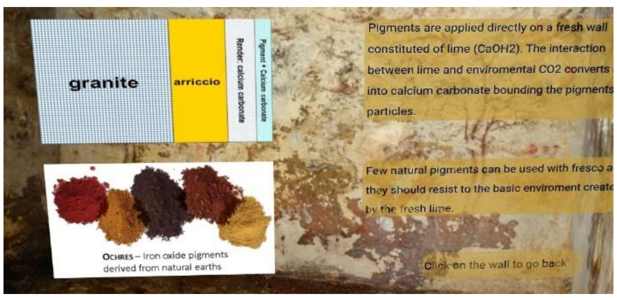

Figure 3: Explanation of the Fresco technique.

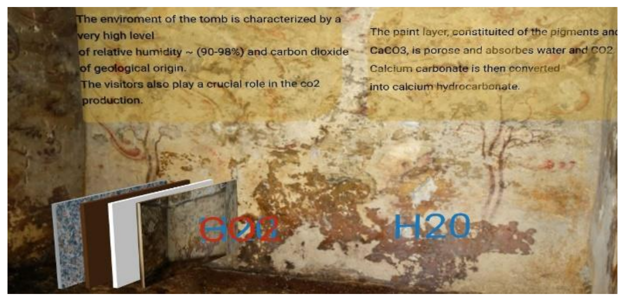

Figure 4: Animation of the interaction of water and Carbon Dioxide.

Our prototype has been developed by exploiting a Marker-based Augmented Reality with a web-app. The idea is to place each of the four walls of the tomb Jinpa-ri I or IV as the background of the scene in a way to make the visitor imagine that s/he is actually facing the wall. Subsequently, the information regarding this wall will appear above it. The user can interact with some scenes, moving on to other types of information or to deepen what s/he is currently viewing. The prototype has been developed by exploiting well-known libraries and framework (A-frame, AR.js, ARToolKit).

Summing up, the entire composition of the internal environment has been reproduced thanks to textual and visual representations. The user is provided with all the information, textual and iconographic, necessary to understand in a simple way how the process of degradation of the paintings takes place. It was decided to work step by step by first presenting the visualization, in layers, of the composition of the wall with textual description of the internal environmental situation of the main chamber.

4. Conclusion

In this paper we have presented a mobile AR application prototype (mainly based on the tombs Jinpa-ri I and Jinpa-ri IV, two Koguryo tombs, where historical and artistic mural paintings can be found), which represents a tentative of exploiting smart devices in an enhanced indoor environment, simulating the tomb, equipped with ad-hoc markers. This prototype has been designed with the aim of letting the user appreciate a cultural heritage site that could not be visited in person and then understand the reasons that prevent a real visit. Our objective is getting the idea that this historical site is very fragile in terms of materials composition and that the presence of humans visitors would damage such a delicate and precious environment. Future work will be devoted to test other AR approaches, such as the marker-less ones, so as to compare them. Moreover, an adequate group of target users will be identified, so as to involve real users in an evaluation campaign, with the aim of testing the usability of the user interface and the effectiveness of the proposed approach in terms of users' involvement while learning and enjoying cultural heritage related content.

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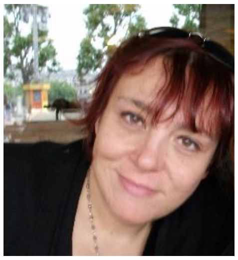

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Learning a Classification Model over Vertically-Partitioned Healthcare Data

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1. Introduction

Advances in sensing and communication technology have allowed the deployment of an extensive amount of various sensors. It is common to store and process the data attributes separately near the information sources, i.e. at the data collectors. This setting can be called vertically-partitioned data [1] or feature-wise data distribution [2]. Storage, bandwidth, and energy constraints obstruct the transmission of all data to a single central location. Furthermore, locally collected data may contain private information that should not be shared with other collectors.

Let consider a healthcare scenario (Figure 1). The system can analyse distributed data to predict whether a patient would be hospitalized (readmission) in near future or not. In the figure are shown five data collectors that hold their own data without disclosing to each other due to privacy issues. The patient holds her personal attributes (e.g. weight and age). She arrives at a clinic or a laboratory to do the tests, for example the hemoglobin A1c test on the average level of blood sugar over the past months. These test results are only stored at these sites. Similarly, the information of physician and hospitals is not shared with the other data collectors. The ground-truth labels are protected at the coordinator, which can access the patient's readmission status. All data collectors contribute processed data through combination of raw data and their parameters to learn a shared diagnostic model, which can benefit other patients in the future.

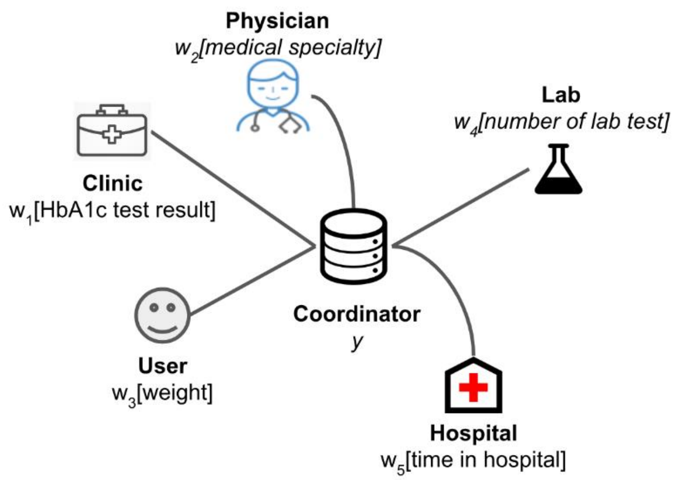

Figure 1: Learning with features distributed across the data collectors

In this paper, we consider a setting in which entries of feature vectors are vertically partitioned over distributed data collectors (for instance, patient, physician, hospital etc.). Consider a sample with K attributes $x_i = [x_1, x_2, \dots x_K]^T$. For example, in case of diabetes diagnosis, the attributes include such measurements as patient's age, insulin level, and blood pressure. Each collector holds a partition P of sample attributes $P \in \{1, 2, \dots K\}$, as $\mathbf{x}_P = \{x_{j\in P}\}$, and the corresponding parameters $\mathbf{w}_P = \{w_{j\in P}\}$. Its partition is not overlapped with those of others. When executing the task (e.g. classifying the environment situation), each collector transmits one scalar value $\mathbf{w}_P * \mathbf{x}_P$, instead of multiple values $\mathbf{x}_P = \{x_{j\in P}\}$. The corresponding labels y_i are known to the coordinator that collects processed information $\sum_{i=1}^{K} x_i\, w_i$ from the data collectors to make predictions and provide binary feedback if necessary. In this setting, the collectors can not access the full feature vectors or the ground-truth labels while the coordinator has no access to raw feature data. Our approach approximates parameter updates with local information at each collector. More specifically, at each step of the proposed optimization process, a random value is generated and leveraged to calculate the update step. Then, the new parameter is combined with new attributes of the environment observed by the collector. This value is transmitted to the coordinator.

The latter in turn collects and analyses processed data $\sum_{i=1}^{K} x_i\, w_i$ to verify whether the new parameters improve the classifier. Based on the result, the coordinator informs the collectors whether their parameter updates increase or decrease the performance of the classifier under training. Depending on values of the binary feedback, the collectors choose their corresponding actions. The chosen actions iteratively optimize the model parameters without requiring the collectors to communicate to each other, except to the coordinator. Figure 2 illustrates the protocol in which a collector transmits the combination of its parameter and local attribute to the coordinator. The latter analyses information from collectors to evaluate the model quality and provides the feedback to control the optimization procedure. The protocol iteratively improves the learned model.

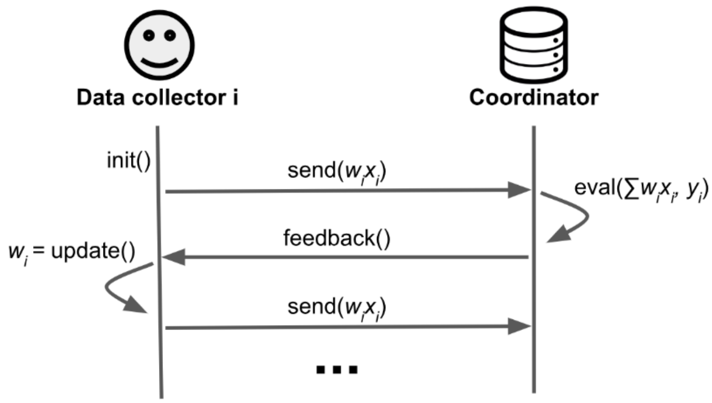

Figure 2: The iterative protocol to learn the optimal parameter at each datacollector with binary feedback from the coordinator.

2. Methodology

Optimization algorithms comprise one of the central topics in machine learning. They find the optimal parameters of models during the training process by optimizing an objective function $f(\theta)$ where $\theta \in R^d$. Popular techniques have been surveyed by Bottou *et al* [3]. One of the widely-used approaches for differentiable functions (e.g. gradient descent algorithm [4]) is to iteratively update the parameter vector θ with a step vector $\Delta\theta$:

$$\theta_i = \theta_{i-1} + \Delta\theta \tag{1}$$

where $\Delta\theta$ is computed with a function π over the objective function. For example, in case of the gradient descent method, $\pi = -\gamma \nabla f(\theta)$. In this paper, we select logistic regression [4] because it has been analysed thoroughly and is widely used in applied sciences [5]. In the binary classification case, where $x_i \in R^d$ is a feature vector (or sample), $y_i \in \{0, 1\}$ is the corresponding label, and $w \in R^d$ is the parameter vector that is obtained during the training process, logistic regression models a probability distribution $P(y_i \mid x_i; w)$:

$$\begin{gathered} h(x_i) = \frac{1}{1+e^{-w^T xi}} \\ P(y_i = 1)|\, x_i; w) = h(x_i) \\ P(Y_I) = 0 \mid x_i; w) = 1 - h(x_i) \end{gathered} \tag{2}$$

When training with the gradient descent technique [4], we aim to gradually optimize the log likelihood function over n training samples:

$$l(w) = logL(w) = \sum_{i=1}^{m} y_i \log h(x) + (1-y_i)\log(1-h(x_i)) \tag{3}$$

The stochastic gradient descent algorithm can be applied to gradually update each parameter w_i toward the optimal value:

$$w^j = w^j + \lambda \frac{\delta}{\delta w_i} l(w) = w^j + \lambda(y_i - \mathrm{h}(x_i))x_i^j \tag{4}$$

where λ is the learning rate, which controls the update speed of the model parameters w. If each parameter can be updated separately, based on all n training samples, the method becomes coordinate descent (or ascent) [6]:

$$w^j = w^j + \lambda \sum_i^n (y_i - h(x_i)) x_i^j \quad (5)$$

In order to update the parameters w in Equation 5, data collectors require $y_i - \mathrm{h}(x_i)$ for prediction over each sample x_i. However, they can not access the ground-truth label or data from other collectors. Hence, we sample a uniformly-random value $r \in [-1; 1]$ to mimic the update. Equation 5 becomes:

$$w^j = w^j + \lambda \sum_i^n r\, x_i^j \quad (6)$$

Note that the learning rate λ and the local attribute of each sample x_i^j are available at each collector. Since r is generated randomly, it can reduce the performance of our classification model, i.e. it may change the parameters to the wrong direction farther from the optimal values. We, thus, need a mechanism to correct the erroneous updates. A binary feedback can be applied to handle this requirement. After receiving all inputs $w^T x_i$ from the data collectors, the coordinator can compute the loss function in Equation 3. Based on the loss value, it can evaluate the learning model regarding the convergence towards the optimal parameters. To deal with the variance of loss values, we assess the model after collecting a number of processed feature vectors $w^T x_i$. The idea is based on the mini-batch stochastic gradient descent [3]. The value n in Equation 6 is the size of each mini-batch of samples.

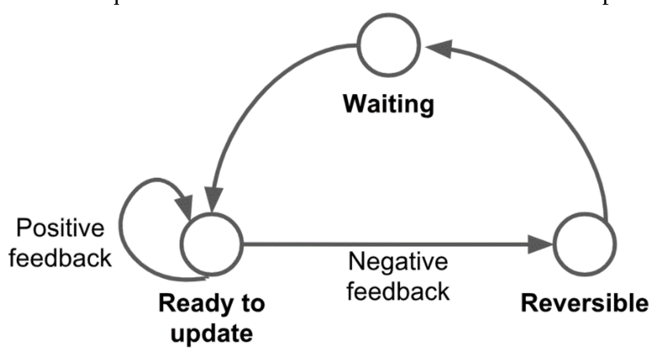

Figure 3: The state transition of each data collector.

We visualize the state transition of data collectors in Figure 3. Each of them can have one of three states, which affects how it reacts to feedback broadcast by the coordinator. When receiving a feedback value, a *ready-to-update* collector randomly picks $r \in [-1; 1]$ to calculate the update quantity at a probability of $\frac{1}{m}$ where m is the number of data collectors. If it is updated, its state becomes *reversible*. When receiving a feedback notifying that the change does not reduce the loss function, a *reversible* collector rolls back the update, i.e. its parameter is reversed to the previous value. Its state is transformed to *waiting*. This mechanism prevents many data collectors from updating at the same time. Algorithm 1 summarizes the state transition of each collector according to the feedback it receives. Line 4 - 6 add an update that combines a random quantity and a local feature to the current parameter; then changes its state to *reversible*. Line 8 - 10 reverse the update if it does not improve the model quality. The remaining case forces the collector to change from waiting to the *ready-to- update* state. Algorithm 2 describes how the coordinator generates feedback values when receiving processed data from the data collectors. Note that to simplify the notation, these algorithms are applied on a single sample. It calculates the loss value at Line 1 before detecting the loss trend. Then, the feedback is generated from Line 3 to Line 7. In the case of mini-batch updates, the function IsLossDecreasing at Line 2 should be customized appropriately, as well as the update part in Algorithm 1.

```
Data: A binary feedback value b ∈ {0, 1}
Result: Parameter w_j of the data collector j and its
        state s_j
if b = 0 then
    // Previous update does not improve the model quality
    begin
        switch s_j do
            case 0 do
                // Possible to update
                w_j = w_j + r x_i^j
                s_j = 1
            end
            case 1 do
                // Undoing the parameter update
                w_j = Reverse(j)
                s_j = 2 // Waiting state
            end
            otherwise do
                s_j = 0
            end
        end
    end
else
    if s_j = 0 then
        // Possible to update
        w_j = w_j + r x_i^j  s_j = 1
    else
        s_j = 0
    end
end
```

Algorithm 1: Update rule for each collector

```
Data: A set of values w_j x_i^j from each data collector j
      over the sample x_i
Result: A binary feedback value b ∈ {0, 1}
// Calculate the loss value
l(w) = y_i log h(x_i) + (1 − y_i) log(1 − h(x_i))
// Detecting the trend of loss values
t = IsLossDecreasing(l(w))
if t = True then
    b = 1
else
    b = 0
end
```

Algorithm 2: Feedback generation at the coordinator

3. A Case Study on Healthcare Data

First, we evaluate our approach on the Pima Indians Diabetes Database [7]. This dataset is contributed by the National Institute of Diabetes and Digestive and Kidney Diseases. It includes data from 768 women. Its objective is to predict whether a patient has diabetes or not, based on analysing eight diagnostic measurements: age, the number of pregnancies the patient has had, glucose concentration, blood pressure, triceps skin-fold thickness, serum insulin, body mass index, and diabetes pedigree function.

Then, we perform an experiment on the Diabetes 130-US dataset submitted on behalf of the Center for Clinical and Translational Research, Virginia Commonwealth University [8]. It aims to analyse factors related to readmission and other outcomes pertaining to patients with diabetes. It represents 10 years (1999-2008) of clinical care at 130 hospitals in US and integrated delivery networks. There are 49 features as well as ground-truth of patient outcomes. The latter can have either one of two values (labels): readmitted if the patient was hospitalized again and no readmission at all. Note that the labels can be recorded at any hospital that the patient was admitted to and can be stored at the database of the coordinator. The 101766 samples were extracted from the database for encounters that satisfied the following criteria: (1) it was an inpatient encounter (a hospital admission), (2) it was a diabetic encounter, that is, one during which any kind of diabetes was entered to the system as a diagnosis, (3) the length of stay was 1 - 14 days, (4) laboratory tests were performed during the encounter, and (5) medications were administered during the encounter. The data contains such information as patient number, race, gender, age, admission type, time in hospital, medical specialty of admitting physician, number of lab test performed, HbA1c test result, diagnosis, number of medication, diabetic medications, number of outpatient, inpatient, and emergency visits in the year before the hospitalization.

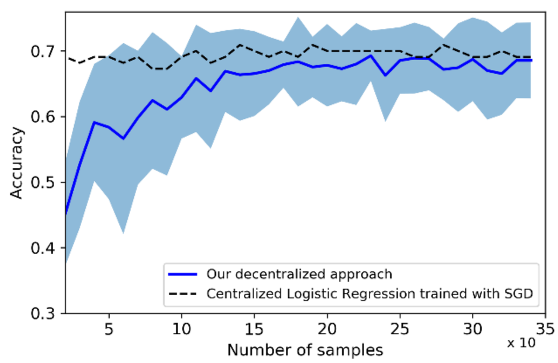

Figure 4: Accuracy on the test set extracted from Pima Indians DiabetesDatabase [7].

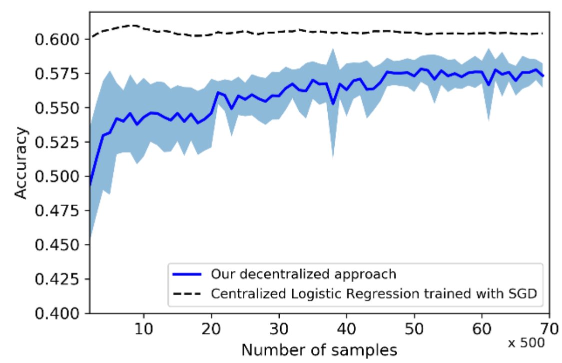

Figure 5: Accuracy on the test set extracted from Diabetes 130-US dataset [8].

In our experiment, we randomly split 75% for training and 25% for testing. We report the accuracy on test sets only since it reflects the model performance on unseen samples. Since updating parameters with calculation from each sample has a large variance [9], we adapt the mini-batch technique, in which the parameters are updated based on computation of multiple samples [3]. We configured the mini-batch size of our algorithm to 500 for the Diabetes 130-US dataset and 10 for the Pima Indians Diabetes one. In both experiments, we set the learning rate $\lambda = 0:001$. On the other hand, for comparison, we used the scikit-learn 0.20.1 library to implement the classifier trained with stochastic gradient descent on data stored in one location, which we called the centralized algorithm. The mini-batch size and the learning rate were the same for the centralized algorithm. We carried out the experiments on a desktop computer (Intel Core i5 1.8GHz, 8GB RAM). Since our technique relies on a random number generator to compute the parameter update, we repeated the experiments ten times and visualized mean results as well as confidence interval. In some rounds on the first dataset, our algorithm achieved a higher accuracy (up to 74%) than that of the centralized algorithm (see Figure 4). Our technique clearly benefits from random parameter updates, which can help the optimization algorithm to escape saddle points [9]. With a more challenging dataset, Figure 5 shows that our method can achieve competitive test accuracy compared to the centralized algorithm. In both comparison cases, the centralized logistic regression model requires all data to be transmitted and stored at one central site, which may raise privacy concerns.

Next, we compare the amount of data exchanged in our method and that in a related technique to tackle vertically-partitioned training data: *Pipelined variance-reduced dynamic diffusion* (PVRD) [2]. Ying *et al* [2] proposed PVRD to train classifiers over a vertically-partitioned dataset in which networked data collectors hold their own feature sets. The algorithm employed a consensus strategy to agree on the update. During one iteration, each data collector communicates a vector of $J \times C \times B$ values, where J is the number of iterations in each consensus step, C is the number of classes, and B is the mini-batch size [2]. In our algorithm, during one iteration, each collector transmits B scalar values and the coordinator broadcasts 1 binary feedback. In our comparison on the Diabetes 130-US dataset [8], J = 1, C = 2, and we varied B. Note that we aim to classify readmission and no readmission cases, hence C = 2. There are

49 data collectors, corresponding to the number of features in the dataset. Figure 6 displays the length of exchanged data of our algorithm and PVRD2 [2], which shows that ours is more communication-efficient because it requires significantly less values to be transmitted in one iteration.

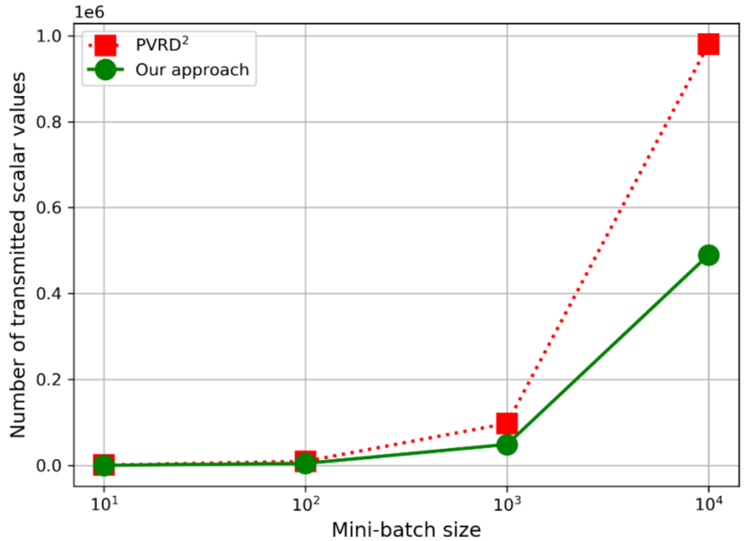

Figure 6: Comparison of communication load between our approach and PVRD [2] on the diabetes dataset [8].

4. Related Work

To handle vertically-partitioned data, optimization techniques applied on centralized training datasets can be modified through facilitating the coordinator to broadcast more data (e.g. [1]) or communication between data collectors (called agents) [2]. Stolpe et al [1] tackled the anomaly detection problem using a 1-class support vector machine with low communication cost. Their technique, namely *Vertically Distributed Core Vector Machine*, requires each data node to transmit a single numerical value instead of all attributes to the coordinator. The coordinator is able to send sample indices and parameter updates to the collectors, which is more complex than our approach that requires only binary feedback. Ying *et al* [2] investigate the problem of learning a model from both large datasets and large-dimensional feature space scenarios. In their setting, each networked collector holds its own set of features. They perform a consensus iteration with their neighbours to agree on model updates. Hence, it demands more communication between neighbouring nodes.

Sigg [10] proposed a local random search technique based on binary feedback. The technique randomly alters phase-frequency combination to achieve synchronization of carriers. Since it was applied to distributed adaptive transmit beamforming, the search space of this problem is different with ours, where parameters of a machine learning model can be updated with various step-size.

In addition, our work is related to the recent meta-learning paradigm that casts optimization itself as a learning problem. Instead of using generic and hand-engineered optimizers (e.g. gradient descent), the update rule can be learned through exploiting problem structures. Andrychowicz et al [11] models the update rule with a recurrent neural network (RNN). The approach outperformed generic optimizers on the problems that it had been trained on. Beyond the update rule, Chen *et al* [12] goal is to generate algorithms for global blackbox optimization. They leveraged a train RNN to explore and exploit the domain of objective functions. Even though these techniques [11] [12] are superior to standard optimizers, they themselves require a training process. In addition, their applicability on vertically-partitioned datasets has not been investigated so far.

5. Conclusion

In this paper, we study the problem of learning a classification model over a distributed healthcare dataset. The data is collected at multiple locations each of which hold a non-overlapping set of features. The communication between these collectors is prohibited due to privacy issues. There exists a coordinator that can access the ground-truth data (i.e. labels) and guide the model training. We propose an approach that leverage randomly-generated values and local information to collaboratively optimize the parameters of a logistic regression model. Our method does not require the communication between data collectors. Furthermore, the coordinator needs to provide only binary feedback to control the optimization process.

We performed experiments on two diabetes datasets: Pima Indians Diabetes collected from 768 women and Diabetes 130-US containing 10 years (1999-2008) of clinical care information recorded at 130 US hospitals. Our method required significantly less communication load while achieving a higher accuracy (up to 74%) on the first dataset and a competitive result on the second one, in comparison to the centralized algorithm.

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SPECIAL ISSUE ON MOBILE AR/VR/MR AND HAPTICS OVER 5G AND BEYOND

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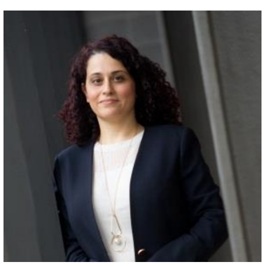
There is a growing demand for mobile Augmented Reality, Virtual Reality and Mixed Reality (AR/VR/MR) applications from the user end. Providing ubiquitous access to these new applications calls for a wireless mobile network that is capable of supporting high-capacity and low-latency requirements mandated by AR/VR/MR. Enhanced Mobile Broadband (eMBB) and ultra-Reliable and Low-Latency (uRLL) dimensions of the emerging 5G networks are ideal approaches to facilitate mobile AR/VR/MR. However, as articulated on our recent article, Edge Caching and Computing in 5G for Mobile AR/VR and Tactile Internet, published in IEEE Multimedia in the January March issue, there are many challenges for mobile AR/VR/MR over 5G and beyond networks.

In the article “Mobile XR over 5G: A way forward with mmWaves and Edge” by Cristina Perfecto, Mohammed S. Elbamby, Jihong Park, Javier Del Ser, Mehdi Bennis, the authors give an outstanding summary of their latest research efforts towards providing an immersive wireless XR experience which can be considered as a first step towards wirelessly delivering multi-sensory XR experiences over 5G networks.

Ozgur Oyman, in his contribution entitled “Recent 3GPP Standardization Activities on Immersive Media over 5G” introduces the most recent 3GPP efforts on the topic. Being an active researcher in the standardization bodies, the author provides the first-hand information on these latest topics.

Abdulmotaleb El Saddik et. al, provides a unique point of view in their article entitled “DTwins: A Digital Twins Ecosystem for Health and Well-being,” on a very important societal topic. They introduce the digital twin concept which has the potential to help improve the health and well-being of the citizens.

In summary, this special issue introduced several state-of-the-art research efforts in mobile AR/VR/MR rather than giving a complete coverage of the area. The contributions of the widely recognized researchers make the special issue a valuable source for the readers. The guest editor is thankful for all the authors for their valuable contributions and the help from the MMTC Communications – Frontiers Board.



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Mobile XR Over 5G: A Way Forward With Mmwaves And Edge

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1. Introduction

After having been labeled as a gamers' and geeks' technology and set aside from the mainstream consumer market, extended reality (XR) has re-emerged fueled by the promise of a mobile interconnected VR [1] and of a future Tactile Internet (TI) [2], that is called to allow remote interaction with real and virtual elements (objects or systems) in perceived real-time[1].

Accordingly, the anticipated application portfolio for XR –a term that encompasses all virtual or combined real-virtual environment compounds including virtual reality (VR), augmented reality (AR) and mixed reality (MR)– spans beyond immersive live-sport retransmissions, gaming or 360º video and finds its natural soil in areas of robotics for health care and smart factor environments with remote surgery their best representative. All these applications will require different levels of immersion built on extremely high-quality multi-sensory XR experiences; even more notably so those servicing critical areas for society [3].

However, immersion is fragile and sustaining it along time is computationally intensive which, paired to its acute sensitiveness to delay, makes it easy to break. Focusing on the visual response, there is a broad consensus that an end-to-end (E2E) delay, also known as motion-to-photon (MTP) delay, of 10-20 milliseconds is the maximum allowable in XR. Exceeding these values causes a visual-motor sensory conflict that might eventually trigger an episode of motion sickness. Likewise, to provide human tactile to visual feedback control, round-trip latencies below 1 ms together with robustness and availability will be needed.

Breakthroughs in computing and communication need to be harnessed to reduce latency, enhance reliability, and improve scalability, such that perceived real-time operation in multi-sensory XR, as the forerunner for TI and haptic communications [4][5], becomes feasible under resource constraints and the uncertainty arriving from wireless channel dynamics. In this regard, this e-letter summarizes our recent work and proposed approaches in [6]–[9] that weave together several technologies from emerging 5G communications systems towards enabling a fully immersive experience.

2. XR Requirement Triangle: Capacity, Latency, and Reliability in Scale

From the original three service categories in the fifth generation (5G), enhanced mobile broadband (eMBB) has been so far the one where most progress has been made towards boosting the capacity and enhancing connectivity to attain the anticipated 10/20 Gbps of peak data rate in UL/DL [10]. As opposed to these advancements, the utterly different statistical treatment required by principled ultra-reliable and low-latency communication (URLLC) [11] has hampered its progression that is still at its infancy. Mobile multi-sensory XR sits somewhere in between eMBB and URLLC requiring data rates covering from 100 Mbps (1K entry-level VR resolution) to up 1 Gbps (compressed human eye resolution) delivered uniformly [6] to end-users. Moreover, this delivery is further subject to latency constraints that significantly differ based on whether an exclusively visual or a visual plus haptic response is sought. As these values are clearly currently unrealizable, we postulate that smart network designs combining the use of higher frequency bands, multi-access edge computing (MEC) [12], edge machine learning (edgeML) [13], and decision making frameworks that incorporate the notions of risk and tail distributions of extreme events will need to be recruited.

Next, we summarize some of the approaches contributed in our latest works and outlined in Figure 5, to increase the capacity, cut down on the latency and provide higher reliability in several VR scenarios.

[1] Perceived real-time implies that the latency incurred by computing and communication is negligible for the considered sensory context (muscular, audio, visual, and haptic or tactile) whereby human reaction and interaction times range from 1 s to 1 ms.

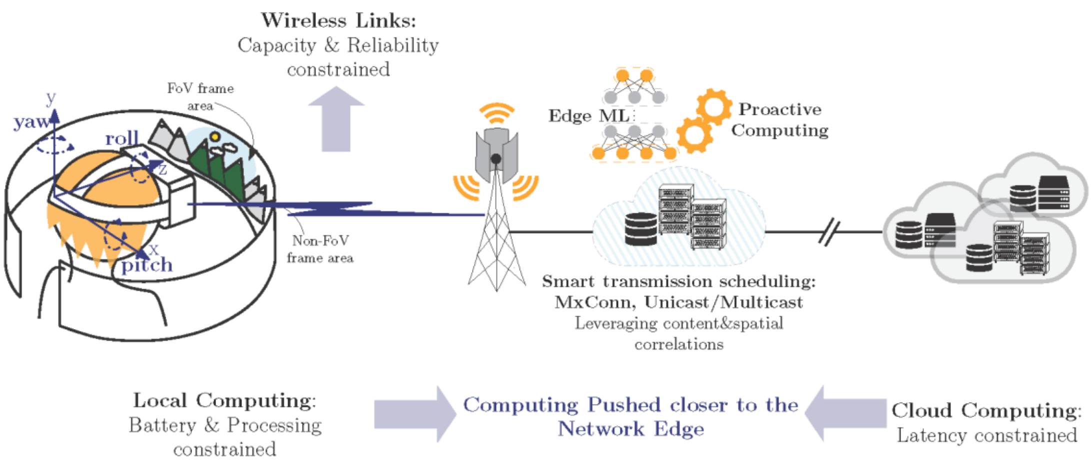

Figure 5: Illustration of some of the communication and computing related bottlenecks and possible enablers to provide a high-quality mobile XR experience.

2.1. Confronting the capacity crunch

Given the current spectrum shortage in the sub 6GHz cellular bands, the use of the millimeter wave (mmWave) frequency bands [14] seems the natural remedy to solve the clash between the available vs. demanded bandwidth for a UHD quality wireless VR [6]. In this regard, if the transmitter and receiver are in line-of-sight (LOS) and the mainlobes of their respective antenna radiation patterns pointing towards each other, i.e. aligned, the use of mmWave communications grants an immediate channel capacity increase. Nevertheless, mmWave links are vulnerable to blockage and beam misalignment. Hence, the resulting channel can be highly intermittent. For this reason, we strongly advocate for the use of mmWaves complemented with techniques to enhance the reliability of wireless links as exemplified in [7] and further discussed in Subsection 0.

An altogether different approach that has lately concentrated a significant amount of research efforts is aimed to reduce the bandwidth needs in mobile/wireless VR, thereby shrinking the amount of data processed and transmitted. In field-of-view adaptive streaming (FOVAS), raw 360º immersive VR video frames are spatially segmented[2], and only those portions that fall within the field of view (FoV) are transmitted in HD. For that purpose, the head movements need to be tracked and then, adopting a tiled[15] or viewport [16] based frame decomposition, decide on the parts of the video frame to be transmitted either real-time or based on estimations supplied by a companion machine learning (ML) backend. These latter predictions also allow carrying out proactive content transmissions.

2.2. Taming the latency

There are manifold aspects that contribute to E2E latency for XR. In this regard, enabling low latency requires intertwining several techniques to be implemented both at the computing/processing and communication levels.

Firstly, due to wireless VR headset limited computing resources, it is mandatory to offload computing-intensive tasks to servers and adopt the proximity computing commissioned by MEC whereby computing, content, and connectivity services are pushed closer to the data source and consumption points.

Secondly, considering the communication level, exploiting proximity computing and mmWave links play a significant role in reducing the latency as 1) the distance between the end devices and the edge servers is shrunken and 2) efficient wireless/wired backhauling with low latency access to MEC services is achieved.

At the computing processing level and related to proactive content caching, where knowledge of users' preferences and future interests allow for prefetching of their content, data availability and edgeML will help to speed up computing the tasks of network nodes. The latter idea is exemplified for XR in [8], [17] and [18] to predict users' future FoV and subsequently empowering data correlation to reduce latency and resource utilization.

[2] An alternative rendering method, foveated rendering, integrates eye gaze tracking in the VR headset and transmits high-resolution content only for the areas of the frame that correspond to the center of the human vision (fovea centralis) while greatly reducing resolution and color depth in the peripheral field of view.

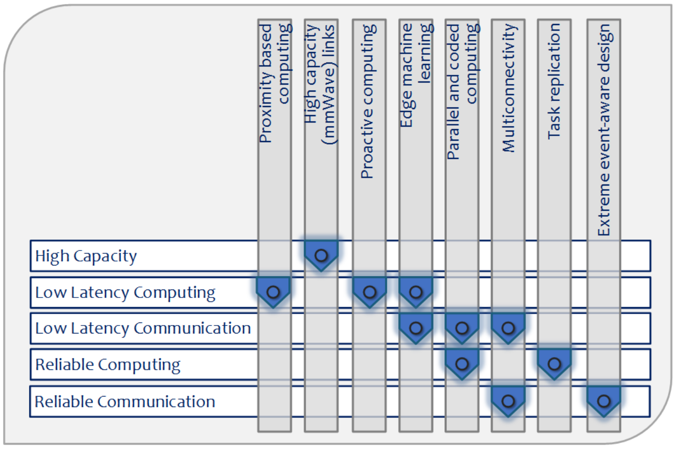

Figure 6: Mapping matrix of technological enablers to reduce latency and improve reliability in communication and computing related to mobile XR.

2.3. Enhancing Reliability

Reliability refers to the availability/provisioning of a certain level of communication or computing service with some assured guarantees, e.g., 99.99999 percent of the time. Nonetheless, a second interpretation that is widely adopted among wireless communications standardization bodies treats reliability as a probabilistic bound over the maximum allowable latency, i.e., it is interpreted as a delay-reliability.

No matter in which of its connotations, reliability is a crucial element in future XR applications. In what relates to reliability in its original meaning, the adoption of mmWave links to deliver the visual traffic required high data rates comes at the cost of dealing with a more vulnerable channel, mainly due to signal blockage. A more robust mmWave communication is achievable by embracing multi-connectivity (MC). MC encompasses several techniques developed to increase effective data rates and mobility robustness of wireless links. For that purpose, diversity is applied to cut down on the number of failed handovers, dropped connections and radio-link failures (RLFs) originated service interruptions. MC allows users to establish simultaneous connections with multiple base stations (BSs) in the same frequency channel, i.e., intra-frequency MC, or through different channels/interfaces, i.e., inter-frequency MC.

As for delay/latency related reliability, which is more concerned with the reducing delay tail rather than with the average delay, low-latency enablers, such as proactive computing, can be useful. It should be noted here, that there is a clear tradeoff between minimizing the latency in general and providing guarantees on the delay exceedance. Therefore, it is essential to design XR systems with tools that look into characterizing the extremely rare conditions of delay, such as extreme-value theory (EVT) [19] [20].

3. Resource Provisioning for Multi-modal sensory information with EMBB/URLLC slicing

To realize a multi-sensory XR, flexible approaches to radio resource management, capable of providing on-demand functionality, would be essential in 5G networks. For instance, a key challenge for multi-sensory XR arises from having different sensory contexts with different requirements in terms of sampling, transmission rate, and latency which is usually referred to as *cross-modal asynchrony*. Accordingly, visuo-haptic XR traffic entails the use of two different network slices: eMBB for visual perception and URLLC for haptic perception. Therefore, a multiplexing scheme is required that is capable of exploiting priorities as well as temporal integration of these different modalities. Our work in [9] investigates how to share the DL resources orthogonally and non-orthogonally, respectively in terms of the impact in the just-noticeable difference (JND), a measure to describe the minimum detectable change amount of perceptual inputs, of the aggregate visuo-haptic perception.

As URLLC traffic cannot be queued due to its hard latency requirements, radio resources must be provided with priority for haptic communications. To that end, URLLC traffic is usually scheduled on top of the ongoing, i.e., puncturing, eMBB transmissions. Our work in [21] applies a risk-sensitive formulation to allocate resources to the incoming URLLC traffic while minimizing the risk of the eMBB transmission. Thereby low data rate eMBB users are protected while ensuring URLLC.

4. Conclusion

This letter has presented a summary of our latest research efforts towards providing an immersive wireless XR experience as a first stepping stone to wirelessly delivering multi-sensory XR experiences over 5G networks.

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Recent 3GPP Standardization Activities on Immersive Media over 5G

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1. Introduction

Higher bandwidths, lower latencies and support for edge computing enabled by 5G connectivity provide the desirable means to meet the high quality and interactivity needs of immersive media experiences that include Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR), referred collectively as Extended Reality (XR) [1]. The Third Generation Partnership Project (3GPP) has been conducting standardization work on immersive media since its launch of 5G-targeted standardization activities in 2015. In this brief contribution, we provide an overview of the recently completed and ongoing 3GPP standardization activities on immersive media over 5G, and describe the related normative specification work addressing the various interoperability enablers at the media handling level including codecs, protocols, formats, client and network interfaces and APIs.

2. 3GPP Standardization Activities on Immersive Media

2.1 Studies prior to Rel-15 leading to 5G Stage-1 Requirements on Immersive Media

Immersive media support over 5G was studied by 3GPP in the Rel-14 timeframe starting from 2015, with the completion of two study items, respectively by 3GPP SA1 (Requirements) and 3GPP SA4 (Codecs and Media) working groups.

In 3GPP SA1, Rel-14 Feasibility Study on New Services and Markets Technology Enablers developed a set of wide-ranging use cases of the identified market segments and verticals that the 3GPP ecosystem would need to support for 5G services of 2020 and beyond, which also included those use cases on immersive media as documented in TR 22.891 [2]. The findings of this study later led to the development of 5G Stage-1 requirements during Rel-15 in TS 22.261 [3], which described requirements toward supporting virtual reality (VR) and interactive conversation use cases, including relevant motion-to-photon and motion-to-sound latency requirements for video and audio, respectively.

In 3GPP SA4, a comprehensive study on Virtual Reality (VR) in 3GPP services was completed, resulting in TR 26.918 [4]. This technical report documented a broad range of on-demand and live streaming, broadcast and conversational VR use cases, relevant VR technologies for audio and video and various subjective quality evaluations, which then formed the basis of several normative work items in Rel-15 and beyond.

2.2 Virtual Reality Profiles for Streaming Applications

To help address the 5G Phase 1 service requirements for Virtual Reality (VR), 3GPP SA4 completed work on the support of 360° VR streaming services, within Release-15 of the specifications. To facilitate that presence a set of VR Video and Audio operating points and their mapping to Dynamic and Adaptive HTTP Streaming (DASH) are specified in 3GPP specification TS 26.118 [5], considering the related MPEG technologies such as Omnidirectional MediA Format (OMAF) specified in ISO/IEC 23090-2 [6] and HEVC Supplemental Enhancement Information (SEI) messages for omnidirectional video decoder rendering metadata as specified in ISO/IEC 23008-2 [7]. The current VR support in TS 26.118 is limited to the 3 degree of freedom (3DOF), which means that the viewing pose is only alterable through rotations on the x, y and z axes, represented as roll, pitch and yaw respectively, and purely translational movement does not result in different media being rendered.

In particular, TS 26.118 defines three Video operating points as follows:

- Basic H.264/AVC: using H.264/AVC High Profile Level 5.1 for mono only, single stream, and reuse of single stream DASH streaming. This profile addresses legacy services and devices. This profile allows reuse of existing file format and DASH implementations also for VR Streaming.
- Main H.265/HEVC: using H.265/HEVC Main-10 Profile Main Tier Profile Level 5.1 allowing mono and stereo, single stream, but either a single or multiple independent Adaptation Sets may be offered, such that a client can choose based on its current pose. This profile also allows reuse of existing file format and DASH implementations also for VR Streaming.
- Flexible H.265/HEVC using Main H.265/HEVC Main-10 Profile Main Tier Profile Level 5.1, but in addition to the Main H.265/HEVC features, it permits to stream and combine multiple tiles at the receiver for

improved quality.

One Audio operating point is also defined in TS 26.118 as follows:

- The OMAF 3D Audio Baseline Media Profile is based on MPEG-H 3D Audio Low Complexity profile enabling the distribution of channel, object and scene-based 3D audio.

The support for these VR operating points are enabled in 3GPP Packet Switched Streaming (PSS) Services and Multimedia Broadcast Multicast Service (MBMS) by updates of the specifications TS 26.234 [8] and TS 26.346 [9], respectively. The subjective and objective test methodologies for the evaluation of immersive audio systems have also been specified in TS 26.259 [10] and TS 26.260 [11], respectively, and characterization test results for VR streaming audio have been documented in TR 26.818 [12].

2.3 Virtual Reality Support for 5G Conversational Services

TR 26.918 contains use cases on conversational VR (i.e., spherical video calls, videoconferencing with 360 video), user-generated VR live streaming (i.e., "See what I see") and virtual world communication, respectively, involving interactive real-time encoding, delivery and consumption of VR content relevant for 3GPP conversational services including Multimedia Telephony Services over IMS (MTSI) in TS 26.114 [13] and IMS-based telepresence in TS 26.223 [14]. Furthermore, VR support over 5G conversational services was studied by 3GPP SA4 during the Rel-15 timeframe and relevant gaps and potential solutions were documented in TR 26.919 [15].

Figure 1 provides an overview of a possible receiver architecture documented in TR 26.919 that recovers the spherical video in an MTSI or IMS Telepresence client. Note that this figure does not represent an actual implementation, but a logical set of receiver functions. Based on a received RTP media stream, the UE parses, possibly decrypts and moves the elementary stream to the HEVC decoder. The HEVC decoder obtains the decoder output signal, referred to as the "texture", as well as the decoder metadata. The Decoder Metadata contains the Supplemental Information Enhancement (SEI) messages to be used in the rendering phase. In particular, the SEI messages may be used by the Texture-to-Sphere Mapping function to generate a spherical video based on the decoded output signal, i.e., the texture. The viewport is then generated from the spherical video signal by taking into account viewport position information from sensors, display characteristics as well as possibly other metadata such as initial viewport information.

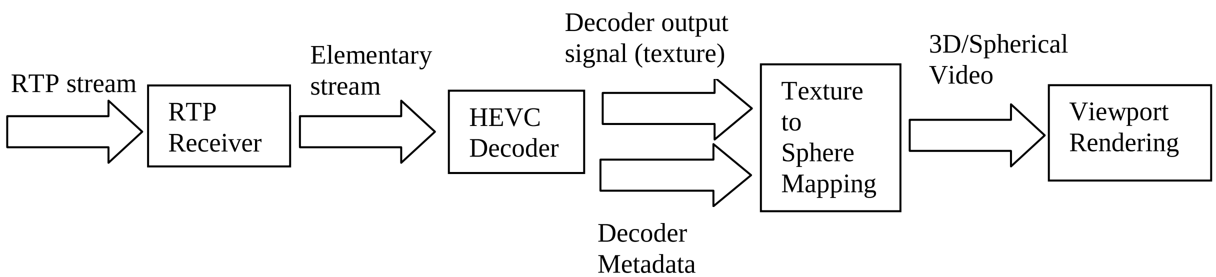

Figure 1: Potential receiver architecture for VR support over 3GPP conversational services

Based on the findings of TR 26.919, a new Rel-17 work item was launched and is being currently progressed to specify VR capabilities in MTSI in TS 26.114 and IMS-based Telepresence in TS 26.223 to enable support of an immersive experience for remote terminals joining teleconferencing and telepresence sessions. For MTSI, the work is expected to enable scenarios with two-way audio and one-way immersive video, e.g., a remote single user wearing an HMD participates to a conference will send audio and optionally 2D video (e.g., of a presentation, screen sharing and/or a capture of the user itself), but receives stereo or immersive voice/audio and immersive video captured by an omnidirectional camera in a conference room connected to a fixed network.

More specifically, the normative work aims on specifying the following aspects for immersive video and immersive voice/audio support:

- Recommendations of audio and video codec configurations (e.g., profile, level, and encoding constraints of IVAS, EVS, HEVC, AVC as applicable) to deliver high quality VR experiences

- Constraints on media elementary streams and Real-Time Transport Protocol (RTP) encapsulation formats

- Recommendations of Session Description Protocol (SDP) configurations for negotiating of immersive video and voice/audio capabilities.
- An appropriate signalling mechanism, e.g., RTP/RTCP-based, for indication of viewport information to enable viewport-dependent media processing and delivery

Support for the Immersive Voice and Audio Services (IVAS) codec will also be enabled in MTSI and IMS-based telepresence as part of this work item. IVAS is the Rel-17 codec developed by 3GPP SA4 in a separate work item as the EVS Codec extension toward a single general-purpose audio codec for immersive 4G and 5G services and applications including the VR use cases envisioned in 3GPP TR 26.918. The specifications of this codec are not yet available and development of the codec is expected to be finalized by the end of Rel-17 in Dec 2020. In order to further enable interoperability for immersive audio, a yet another Rel-17 work item on terminal audio quality performance and test methods for immersive audio services is also being progressed by 3GPP SA4 in order to develop objective quality characterization methodologies for 3GPP immersive services.

2.4 Architectural Enhancements for Immersive Media Support over 5G

During Rel-15, 3GPP SA4 completed a study on 5G media distribution, with the related findings documented in TR 26.891 [16]. Some part of this study investigated immersive media delivery over the 5G system. As described in TR 26.891, 5G can support a wider range of QoS requirements including high bandwidth low latency needs of interactive VR/AR/XR applications, through a New Radio (NR) air interface as well as flexible QoS enabled via 5G core network architecture and network slicing. Moreover, the ability of the 5G system to leverage edge computing is essential to meet the performance requirements of immersive media, not only for better delivery performance via edge caching but also to offload some of the complex VR/AR/XR processing to the edge to perform various operations such as decoding, rendering, graphics, stitching, encoding, transcoding, etc., toward lowering the computational burden on the client devices. A relevant potential solution for offloading compute-intensive media processing to the edge is based on MPEG's Network-Based Media Processing (NBMP) specification ISO/IEC 23090-8 [17], which aims to specify vides media / metadata formats and APIs for intelligent edge media processing. Benefits of other technologies for DASH streaming enhancements at the edge are also applicable for immersive media, such as those from Server and Network Assisted DASH (SAND), which is already specified as part of 3GPP DASH in TS 26.247 [18] with the supported modes of proxy caching, consistent QoE/QoS and network assistance.

Based on the conclusions of the Rel-15 study, 3GPP SA4 has launched a normative Rel-16 work item to specify a 5G media streaming architecture in TS 26.501 [19], with the objective to develop architectures for mobile network operator and 3rd party Media Downlink and Uplink Streaming Services with relevant functions and interfaces to support different collaboration scenarios between third party-providers and mobile network operators for media distribution over 5G, including immersive media distribution, considering various aspects such as session management, QoS framework, network assistance, QoE reporting, accessibility, content replacement, notification, content rights management, etc. Relevant UE functions and APIs as well as usage of 5G specific features such as network slicing and edge computing are within scope of the anticipated normative specification work. For instance, extensions of SAND with new dedicated messages are relevant in this context to exclusively enhance immersive media delivery. Furthermore, use of MPEG NBMP APIs are relevant to offload complex media processing to the edge and may be considered as a potential solution in TS 26.501.

Finally, another Rel-16 work item is also in progress in 3GPP SA4 to define 3GPP media codec profile(s) and network-based media processing functions (e.g., video stitching, media transcoding and content reformatting) and enablers (e.g., network APIs) for immersive media support over 3GPP's Framework for Live Uplink Streaming (FLUS) service in TS 26.238 [20], and also recommend new QoS classes trading off video quality for immersive media delivery latency.

2.5 Ongoing Rel-16 Studies on Immersive Media

During Rel-16, 3GPP SA4 has been investigating the quality of experience (QoE) parameters and metrics which may need to be reported by the client to the network for evaluation of user experience in VR services, with the relevant findings documented in TR 26.929 [21]. The study of the user experience and QoE metrics in TR 26.929 considers end-to-end VR delivery chain including content creation, network transmission and device capabilities. A key consideration is placed on QoE metrics for viewport-dependent delivery, which uses HEVC tiling concept to deliver content in tiles allowing streams to have a different quality or resolution for different areas/regions of the omnidirectional video. While the viewport-dependent video delivery approach helps optimize the quality-bandwidth tradeoff, the interactivity performance in this case not only depends on motion-to-photon latency at the rendering level (which is always applicable even for viewport-independent delivery), but also on other metrics such as network-level latencies (since the high quality tiles corresponding to the new viewport need to be fetched continuously from the network) such as network request delay, origin-to-edge delay (in case of cache miss), transmission delay (accounting for access network delay) and delays incurred in the client device due to buffering, decoding and rendering.

Another newly launched Rel-16 study currently pursued by 3GPP SA4 investigates the relevance of Augmented and Extended Reality in the context of 3GPP services addressing aspects such as use cases, relevant technologies, media formats, metadata, interfaces and delivery procedures, client and network architectures and APIs, and QoS service parameters and other core network and radio functionalities. The findings of this study are being documented in TR 26.928 [1].

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Dtwins: A Digital Twins Ecosystem For Health And Well-Being

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1. Introduction

Seventy-one percent of deaths worldwide are due to chronic diseases caused by four lifestyle factors, namely smoking, alcohol consumption, imbalanced diets and excess of junk food, and long hours of sitting [1]. On a physical health and well-being level, overweight and obesity are globally the fifth leading death factor, and the number of death in adults caused by overweight or obesity reaches 2.8 million every year according to World Health Organization (WHO). One of the main causes of overweight and obesity is the sedentary lifestyle with non-existent or very little physical activity.

There are many technological solutions that are available today to help with behaviour change including incentives, gamification, social networks, health apps and wearables, most of which work in isolation and do not consider the combination of knowledge and technologies. Thus and in the context of smart cities, there is a need for converging multimedia technologies to help the subjects find an interoperable common platform to understand, monitor and achieve their lifestyle goals.

Digital twins is a multimedia convergence technology which represents a digital replica of any living or non-living physical entity [2]. By bridging the real and the virtual world, data is transmitted seamlessly allowing the virtual entity to exist simultaneously with the real one. Digital twins' applications are countless including, digital data ownership & security, immortality, dating, healthcare, space, sports, etc. They can, i.e., help athletes connect their different wearable devices or apps through a standardization software or platform and get a comprehensive personalized recommendation and feedback on their performance. The feedback can be given in different ways such holograms, AR/VR representation, haptics, or even through what-If simulation scenarios in order to help the athletes improving their form. Similarly based on physical and/or physiological stress, digital twins can help in distressing through preferred ways like mediation or music.

We believe that the proposed DTwins ecosystem will accelerate the convergence of and dynamic interplay between IoT, big data, communications mechanisms, security and multimodal interaction with the ultimate target of better eHealth care services to empower subjects' wellness and enhance their quality of life.

2. Proposed DTwins Ecosystem

The proposed DTwins ecosystem is designed based on the Digital Twins (DT) characteristics listed in [2], the personal health systems requirements listed in [3], the ubiquitous biofeedback described in [4] and the cyber physical reference model presented in [11]. The main goal of this ecosystem is to provide a foundation for a realizable DT system in preventive healthcare. This set of characteristics state that the preventive health DT must have a unique identifier, make use of sensors (hard and soft sensors) to capture the real twin health data as well as actuators to provide feedback, and an artificial intelligence (AI) core component to perform data analytics and make recommendation based on the fused multisensory data [2]. Furthermore, it must communicate in real time with the real twin, the environment and with other DTs, and provide trust in the relationship with the real twin [2]. We aim to fulfill this set of criteria to facilitate the incorporation of DT technology in the current personal health systems while utilizing other technologies such as Augmented Reality (AR), Virtual Reality (VR), Mixed Reality (MR) and Haptics over 5G for multimodal interaction.

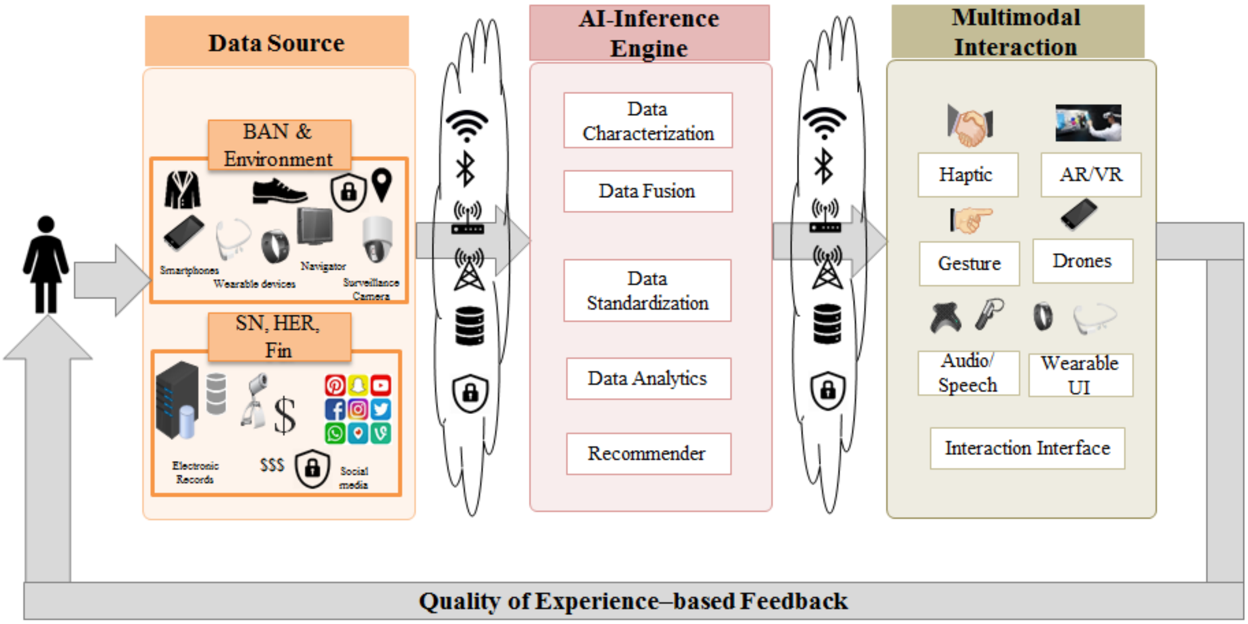

Figure 1: Ecosystem of the Digital Twin for health and well-being.

Figure 1 illustrates the proposed ecosystem of the Digital Twin for health and well-being while taking into consideration this set of criteria.

2.1 Data Source: To ensure a proper understanding of the wellbeing of subjects, data from different sources need to be captured without human intervention in order to perform intelligent processing.

The data sources can be of different types stemming from different sources including a) BAN known as body area network in order to capture physical activity and bio physiological signals (i.e., wearable sensors); b) contextual information from the environment such as GPS, weather, pollution, humidity, etc.; c) Social Networks (SN) in order to understand the social environment of the subject. This data might be from FaceBook, Instagram or WebMed; d) Health Electronic Records (HER) which contains several information about the subject wellness and historical well-being data; and e) Financial data to understand the economic situation of the real twin.

The sensors will measure several metrics such as body temperature, heart rate, body movement, and respiration, while the smart phone's built-in wireless services will measure the 3D acceleration and the geographical location (and therefore altitude) of the user. Altitude is important since it affects the energy that the patient has to spend to move a certain distance at a certain speed. Speed and distance can be derived from the 3D accelerometer and the smart phone's positioning system. Commercially available and custom made sensors fall in the category of IoT. This category includes data obtained from wearables such as a smartwatch or a Fitbit® (heart rate, galvanic response, and oxygen levels), a smartphone (location, acceleration, sound), surveillance cameras or even custom-made things such as an Arduino® powered shoe that captures the pressure areas in the insole [5]. Data available in social networks can be accessed in order to be mined and is available through this structure. It's the same for financial and health records.

2.2 AI-inference Engine: Data mining and analysis techniques to extract contextual and behavioral knowledge and analytics to provide real time monitoring, forecasting and collective decision making are taken into consideration. Machine and deep learning approaches to facilitate automated feature generation, reasoning, planning, and intelligent decision support mechanisms are considered. Some of the components are described in details in the following:

2.2.1 Data Characterization: Data collected from the DT data sources needs to be subjected to a process of summarization and extraction of parameters and properties pertaining to health and well-being, and without loss of data accuracy. This process is necessary especially that our data comes from a wide range of different personal health devices.

2.2.2 Data Fusion: This module considers the collecting and checking point for received data and their sources. It collects data and categorizes them into different data types such as text, numbers, discrete or continuous signals, audio and video. It also checks the status of the hard sensors that provide some or all of data at a given time to determine if the source device is standardized or not to decide on the next module.

2.2.3 Data Standardization: This module is responsible for standardizing the data, communication and operation in accordance to the predefined standard for a source device to guarantee the interoperability/ plug and play feature for the DT. Thus, the personal DT can integrate easily with other DTs and smart services. Furthermore, the use of wearable technology and personal health devices is on the rise and with this large amounts of data are uploaded to the cloud every day. This data, although valuable, remains of not much use. Indeed, this data comes in different proprietary formats and caregivers cannot integrated in their systems so many formats. However, it is important to benefit from this collected data as it contains vital information about individuals state of health. In the digital twin system, we adopt the ISO/IEEE 11073 standard also called X73. This standard has been developed to ensure interoperability in data transmission [6], in the goal of growing the personal health devices market and allowing individuals to be better informed and better equipped to participate in the improvement of their health and well-being.

2.2.4 Data Analytics: This is the module where AI processes initiate. As reflected from its name, this module is responsible for analyzing the received stream of data. It utilizes machine/deep learning techniques to recognize patterns, predict results and make intelligent decisions and actions. Medical data can be used to predict future health problems, financial data to recommend real twin better management of real twin's money, social network data to evaluate and suggest successful and stimulating interpersonal relationships and social contributions [7]. Based on some input data that can be measured directly (heart rate, oxygen in the blood, galvanic response of the skin, among others) predicted information can be extracted such as the psychological state of the real twin (excitement, depression or level of exhaustion). More complex physiological aspects such as current state of health in real time can also be inferred.

2.2.5 Recommender: This module utilizes the results from Data Analytics module to provide various recommendations to the real twin through the interaction interface. The DT monitors the current health state of the real twin at all times collecting data from the data source in real time. The use of appropriate AI methods trigger the DT to make recommendations that allow the real twin to "procure their well-being". An efficient mean to motivate the real twin to achieve his health and well-being goals is by introducing the right incentives. By “right” we mean personalized depending on the real twin preferences and on the context s/he is in. Indeed, an incentive-driven approach has the potential to change the real twin behavior and health habits for the better.

2.3. Multimodal Interaction (MMI): The real twin can easily interact with the world around her and her peers. The digital twin, even though it does not inherently have a physical body, can interact with other DTs and with the real twin using different interaction means. Indeed, MMI allows the DT to have representations by means of video, augmented and virtual reality, holograms and even haptics or (social) robotics. This type of representation enables the digital twin to interact with its peers (another digital twin) and at the same time with the physical world; including its physical counterpart. This structure performs its function based on the real twin’s preferences.

2.4. Cybersecurity: Cybersecurity is present in all aspects of the DTwins ecosystem. Among the most important aspects to ensure is the fact that the data is only accessible under the authorization of the real twin, that is why biometric is present and under no circumstances does a third party have access to data other than the authorized. This also ensures privacy of the data. Passwords methods are traditionally used in order to protect this physical interaction; however, this method does not guarantee that the user is genuine. Another disadvantage is password managing with many of the physical components involved in the digital twin. Multi-level biometrics (including iris, finger print and ECG) [8] handles those issues and is proposed to be used as a security measure in the DT ecosystem. In addition to biometric security, the DT uses communication security which refers to the measures that the network has to take in order to prevent attacks during the data transmission between the main components of the DT. Encryption is one of the measures that the communication security implements in order to preserve the confidentiality of digital twin data during its transmission.

2.5. Privacy: Depending on the interaction scenario the DT should be aware of what kind of information it chooses to disclose. Hence, the need of highly customizable and intelligent privacy profiles. The DT will determine what information will be shared with other DT’s and/or smart services. Different information will have various sensitivity levels. There may be a case were the real twin allows data sharing such as current job and years of employment to professional contacts turning a switch once. Other times, active consent of the real twin will be needed every time data is shared, e. g. sending physiological data to a hospital's smart service. Security measures are always followed when changes to privacy are trying to be applied.

2.6. Communication: Among the different structures and components in the DTwins ecosystem, there is a constant communication that must be governed by the principle of Quality of Experience QoE [9]. To achieve the best communication experience, the use of different communication technologies is established depending on the scenario. A holographic or virtual representation (high quality video) of the DT may need to consider Edge computing and 5G communication between the MMI and Data structures to ensure the best possible QoE since the expected data volume is high [10]. In contrast, if the interaction with the DT only considers audio, maybe 4G is enough. Another case are the things (IoT) that in many cases transmit data between them, communication by Bluetooth in most cases will suffice.

2.7. Feedback loop: The interaction with the real twin occurs basically as a QoE-based feedback aim to increase subject's awareness about their current physical and psychological status. In many cases, this communication needs to happen in real time to provide the real twin with instant feedback or a well-timed incentive. Consequently, the real twin can take the proper actions or follow the given recommendations to enhance their well-being. A ubiquitous, real-time biofeedback is an example of such feedback [4].

3. Conclusion

The digital twin has the potential to help improve the health and well-being of the real twin and to be her faithful companion in his future endeavours, or her substitute when he is away. We can see this when adopting digital twins for space travel. Astronauts are away from their families and workstations and with the advent of commercial space travel, many other people may benefit from digital twins as well. Space travellers can leave their digital twins on earth with their family members, workstations or for some legal representation. Healthcare professionals on earth can run "what-if" simulation on the health of the astronaut based on their body parameters which can be collected through smart clothing. If the astronauts miss their families, haptics memories through augmented reality can be played and they can feel as if they are touching their real families.

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EVENT REPORT

The 3rd International Workshop On Quality Of Experience Management: Qoe-Management 2019 (In Conjunction With Icin 2019)

The 3rd International Workshop on Quality of Experience Management (QoE-Management 2019, https://www.icin-conference.org/QOE.php) was a successful full day event held on February 18, 2019 in Paris, France, where it was co-located with the 22nd Conference on Innovation in Clouds, Internet and Networks (ICIN). After the success of the previous QoE-Management workshops, the third edition of the workshop was also endorsed by the QoE and Networking Initiative (http://qoe.community). It was organized by workshop co-chairs Michael Seufert (AIT, Austrian Institute of Technology, Austria), Lea Skorin-Kapov (University of Zagreb, Croatia) and Luigi Atzori (University of Cagliari, Italy). The workshop attracted 24 full paper and 3 short paper submissions. The Technical Program Committee consisted of 33 experts in the field of QoE Management, which provided at least three reviews per submitted paper. Eventually, 12 full papers and 1 short paper were accepted for publication, which gave an acceptance rate of 48%.

On the day of the workshop, the co-chairs welcomed 30 participants. The workshop started with a keynote given by Martín Varela (callstats.io, Finland) who elaborated on “Some things we might have missed along the way”. He presented open technical and business-related research challenges for the QoE Management community, which he supported with examples from his current research on the QoE monitoring of WebRTC video conferencing.

Afterwards, the first two technical sessions focused on video streaming. Susanna Schwarzmann (TU Berlin, Germany) presented a discrete time analysis approach to compute QoE-relevant metrics for adaptive video streaming. Michael Seufert (AIT Austrian Institute of Technology, Austria) reported the results of an empirical comparison, which did not find any differences in the QoE between QUIC- and TCP-based video streaming for naïve end users. Anika Schwind (University of Würzburg, Germany) discussed the impact of virtualization on video streaming behavior in measurement studies. Maria Torres Vega (Ghent University, Belgium) presented a probabilistic approach for QoE assessment based on user’s gaze in 360° video streams with head mounted displays. Finally, Tatsuya Otoshi (Osaka University, Japan) outlined how quantum decision making-based recommendation methods for adaptive video streaming could be implemented.

The next session was centered around machine learning-based quality prediction. Pedro Casas (AIT Austrian Institute of Technology) presented a stream-based machine learning approach for detecting stalling in real-time from encrypted video traffic. Simone Porcu (University of Cagliari, Italy) reported on the results of a study investigating the potential of predicting QoE from facial expressions and gaze direction for video streaming services. Belmoukadam Othmane (Cote D’Azur University & INRIA Sophia Antipolis, France) introduced ACQUA, which is a lightweight platform for network monitoring and QoE forecasting from mobile devices.

After the lunch break, Dario Rossi (Huawei, France) gave the second keynote, entitled “Human in the QoE loop (aka the Wolf in Sheep's clothing)”. He used the main leitmotiv of Web browsing and showed relevant practical examples to discuss the challenges towards QoE-driven network management and data-driven QoE models based on machine learning.

The following technical session was focused on resource allocation. Tobias Hoßfeld (University of Würzburg, Germany) elaborated on the interplay between QoE, user behavior and system blocking in QoE management. Lea Skorin-Kapov (University of Zagreb, Croatia) presented studies on QoE-aware resource allocation for multiple cloud gaming users sharing a bottleneck link.

Quality monitoring was the topic of the last technical session. Tomas Boros (Slovak University of Technology, Slovakia) reported how video streaming QoE could be improved by 5G network orchestration. Alessandro Floris (University of Cagliari, Italy) talked about the value of influence factors data for QoE-aware management. Finally, Antoine Saverimoutou (Orange, France) presented WebView, a measurement platform for web browsing QoE.

The workshop co-chairs closed the day with a short recap and thanked all speakers and participants, who joined in the fruitful discussions. To summarize, the third edition of the QoE Management workshop proved to be very successful, as it brought together researchers from both academia and industry to discuss emerging concepts and challenges related to managing QoE for network services. As the workshop has proven to foster active collaborations in the research community over the past years, a fourth edition is planned in 2020.

We would like to thank all the authors, reviewers, and attendants for their precious contributions towards the successful organization of the workshop!

The Workshops Co-Chairs:
Michael Seufert (Austrian Institute of Technology, Austria)
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