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SPECIAL SECTION

Leveraging cloud environment flexibility to smoothen the transition to remote teaching during COVID-19 pandemic – a case study

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Abstract. Cloud-based computational environments can offer elastic and flexible services to wide audiences. Małopolska Educational Cloud was originally developed to support the day-to-day collaboration of geographically scattered schools with universities which organized online classes, led by university teachers, as an amendment to face-to-face teaching. Due to the centralized management and ubiquitous access, both the set of services provided by MEC and their usage patterns can be adjusted rapidly. In this paper we show how – during the COVID-19 pandemic – the flexibility of Małopolska Educational Cloud was leveraged to speed up the transition from in-class to remote teaching, both in the classes and schools which were already involved in the MEC project, and newly added ones. We also discuss the actions that were required to support the smooth transition and draw conclusions for the future.

Key words: cloud; COVID-19 pandemic; collaboration; remote teaching; online classes.

1. INTRODUCTION

The COVID-19 pandemic found high schools unprepared – in general – to switch the education mode from in-class to remote teaching. In Poland, at the time of writing this article, schools suffered two closure periods, which started in March and October 2020, respectively. In this article we show how the Małopolska Educational Cloud (MEC) helped smoothen the transition to remote teaching in the Małopolska region high schools. We also discuss the problems faced by the project participants and the implemented solutions.

Małopolska Educational Cloud was originally developed by AGH University and its partners to foster collaboration between universities and high schools, in order for the high school students to learn more about particular universities and areas of study before they make decisions regarding their further education. MEC achieves that by organizing regular classes on specific topics led by university teachers, which both complement the schools' curricula, and make the high school students acquainted with the universities' ways of teaching. The rationale for implementing MEC and the ways the cloud is used in day-to-day teaching are discussed in [1]. More than 150 institutions (including 10 universities, 7 teacher excellence centers, over 120 schools, and 11 libraries), scattered over the Małopolska region (see Fig. 1), have been involved in the project.

MEC implemented a dedicated overlay network, connecting all project participants. They have been using the overlay to access MEC services hosted in a private cloud, operated by AGH University, the project leader. Additionally, the participants are leveraging public clouds of their choice.

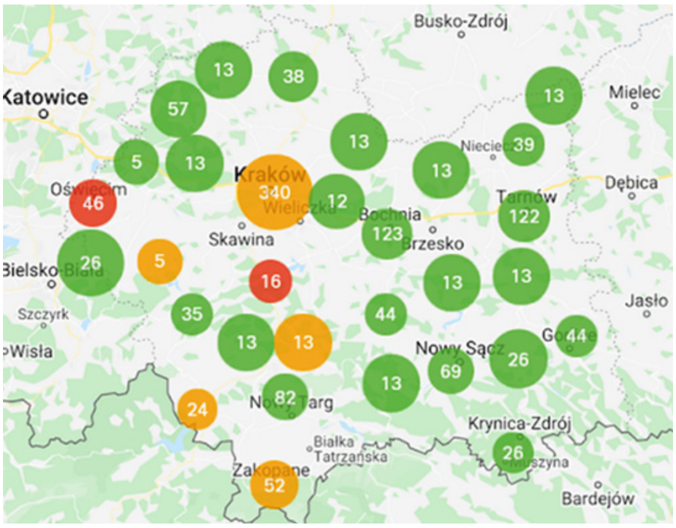

Fig. 1. MEC project coverage as of March 2020. The numbers denote the quantities of network devices installed in respective places

The main technical development of MEC is its educational integrated collaboration environment (E-ICE) [2]. MEC E-ICE was developed as a platform, which integrated MEC-only services offered by the MEC private cloud with external services, offered by respective providers' public clouds. The services used by collaborating parties include not only videoconferencing, but also virtual desktops and whiteboards, personal or shared learning spaces, cooperative document editing services, etc. – see Section 3 for more details. Because of the variety of educational areas and topics covered by cooperating parties,

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E-ICE was developed in a flexible manner, so that the parties can easily choose the services appropriate for their respective use cases. By implementing the services in accordance with cloud paradigms, we were also able to scale the most important services, which proved crucial when the sudden need for hosting many more remote online classes occurred.

In the article we contrast the pre-pandemic and in-pandemic usage patterns (Section 4), and describe the actions that were undertaken in response to the changes (Section 5). We also emphasize the role of training offered to MEC teachers during project development in the successful transition. Finally, we draw conclusions both for the MEC and other remote collaboration systems (Section 6).

2. RELATED WORK

The COVID-19 pandemic has had a tremendous, global impact not only on health [3] and economy [4], but also on all aspects of our daily lives, including work, home life, social life, education, and mental health [5, 6]. Ensuring continuity on all levels of education has been one of the biggest challenges for all affected countries. By the end of April 2020, more than 1.6 billion learners worldwide (over 93%) had their schools fully or at least partially closed [7]. Teachers and students alike were forced to transition to online learning in just a few days, even though digital transformation typically requires a long time to develop necessary skills, and to get people used to new ways of conducting previous activities [8]. For this sudden transition, some basic requirements needed to be met, including gaining access to equipment (computer, tablet or at least a smartphone), and an Internet connection, choosing and learning how to use video conferencing environments and e-learning platforms (some of which require licenses), organizing online meetings, and transforming educational materials and exercises into online forms. Even when those basic requirements were met, the transition to online learning was difficult due to a number of problems, such as inflexibility of students and teachers to adapt to new educational processes, technical problems (such as setting microphones), reduced student engagement, limited monitoring, impact of domestic affairs, and mental health problems due to the stress related to the pandemic and lockdowns [9, 10].

Experiences from transitioning to online learning have been presented in multiple studies from different countries. A systematic approach to remote learning was introduced in Portugal [11], where country-wide, official guidelines for organizing remote classes were released two weeks after the start of the first lockdown (March 2020). The guidelines referred to, among others, defining teaching methods, selecting technological means, sharing educational materials online, communicating and collaborating. A study comparing the transition to remote teaching between two countries, Finland and India [12], was also conducted. It showed that in the former country the transition was relatively quick and smooth due to common access to technology and vast previous experience with online learning, but in the latter it was much more difficult and some pupils became estranged due to a lack of access to communication means.

Reports from underdeveloped countries show that the lack of skills and experience with online learning made the educational process significantly less effective and resulted in low student engagement [13–15]. In a survey conducted in Pakistan [16], only 61% of students were comfortable with electronic communication. In the Philippines, transition to online learning was suspended after only a few days, as it quickly turned out that the technology adoption level in educational institutions was not sufficient [17]. Effects of the pandemic were also observed in various aspects related to education, including reduced student mobility [18], difficulties when teaching students with learning disorders [19], or challenges with providing proper medical education, particularly for residents who were focused on gaining practical experience [20, 21].

The aforementioned studies illustrate how difficult it is to organize effective remote learning on many levels. Technological readiness is essential, but by no means sufficient [22]. Both teachers and students need to adapt to new, remote educational processes to ensure the continuity of learning, and previous experience with online learning plays a very significant role [23, 24]. In this paper we present how the cloud architecture of the MEC project enabled the smooth transition to full online learning for its participants.

3. ARCHITECTURE OF MEC E-ICE

Services provided by the MEC E-ICE to an end-user can be categorized either as virtual classroom services (used mainly for online interaction) or virtual educational space services (used mainly for self-paced education), as depicted in Fig. 2. Vir-

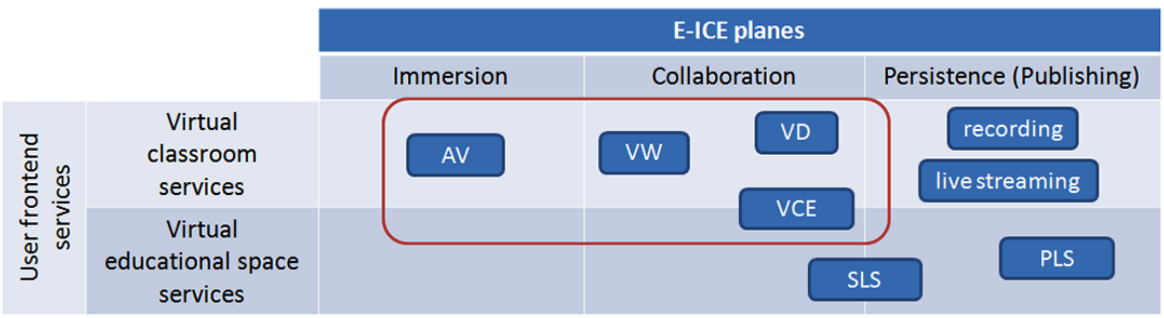

Fig. 2. Classes of front-end services provided by MEC E-ICE. The red frame marks the services which usage patterns changed significantly due to the COVID-19 pandemic

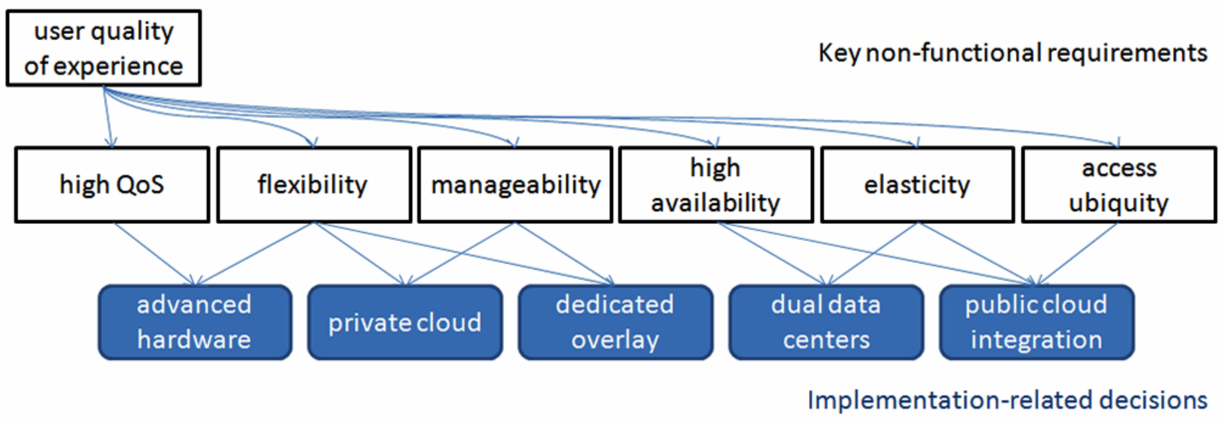

Fig. 3. Mapping of the main non-functional requirements into MEC E-ICE implementation concepts

tual classroom services, whose usage was much more changed by the pandemic, are typically accessed by software terminals running on user computers or dedicated hardware deployed at the users' locations. Such a terminal establishes a data channel (or channels) with a central service responsible for mediating collaboration and synchronizing its state. Virtual classroom services can offer extra functionality such as persisting or publishing of the collaboration state and results. The results can be published in various places, including virtual educational space services, which serve mainly as content stores (shared or private).

We identified three most important aspects of the E-ICE operation: immersion, collaboration, and publishing, each of which is represented by a respective plane. The immersion plane groups services which provide high-quality interactive communication between participants, and thus it contains implementations of the audiovisual (AV) service. The collaboration plane services facilitate content-oriented cooperation as well as cooperative experiments. These are implemented by virtual whiteboard (VW), virtual desktop (VD) and virtual collaboration environment (VCE) services. In short, VW service is designed so that the service endpoint is used by multiple users at the same location (an Internet-enabled interactive whiteboard could be a terminal used as such an endpoint), while VD endpoints are used by individuals who form teams collaborating remotely. VCE provides the capability of running SaaS applications of the teachers' choices and exposing them to the students. Additionally, portions of the collaboration plane functionality are implemented as shared and private learning spaces (SLS/PLS), which are used to store, annotate, and edit the educational materials. The publishing plane stores and exposes the state and outcomes of collaboration. That functionality is implemented by recording and live streaming services, as well as the learning spaces — shared, and private. Noteworthy, a learning space is not just a container for the educational materials, it should rather be thought of as a social media group (SLS) or a set of virtual notebooks (PLS). The virtual notebooks set could be implemented in various ways, provided that they allow for organizing, annotating, and persisting the materials both for current and future personal use (e.g., for reviews).

Figure 3 depicts the key non-functional requirements that were observed during the development of the E-ICE and the way they reflected onto key architectural decisions. The main non-functional requirement towards MEC E-ICE was to provide the participants with high-quality services. That refers not only to video stream metrics, but also to the students' in-school experience. Therefore, the participating schools were equipped with advanced hardware terminals that could be shared by multiple users. Because of the variety of educational areas to be addressed by the E-ICE, and in order to provide the collaborating parties with a flexible and manageable environment (that would host the services of teachers' choices), MEC implements its private cloud. The cloud is accessed by the participating institutions by using a dedicated overlay network, composed of schools' WLANs and a VPN. The private cloud is implemented in two data centers for redundancy. Although the dual-DC approach was dictated by the high availability requirement, it also allowed for elastic reaction to occasional greater load.

In most cases the MEC E-ICE provides multiple implementations of the services, to address the varying needs of its users. Such an approach was chosen to satisfy the flexibility and ubiquitous access requirements. From the MEC E-ICE frontend services, AV, VW, VD and VCE (marked with the red frame in Fig. 2) were the ones whose usage changed significantly during the pandemic. Moreover, the changes affected backend services mainly in terms of the numbers of users and endpoints.

The AV backend is organized as depicted schematically in Fig. 4. Learning communities, formed by MEC project participants, are provided with dedicated, permanent virtual conference rooms hosted by the MEC cloud conference bridges cluster. The choice of a concrete conference bridge for a particular meeting is controlled by a load-balancing algorithm. All activities that occur in the learning communities' rooms are automatically recorded, in order to allow students and teachers to review the online classes again. The recording is automatically supplied with metadata for categorization purposes, uploaded onto a video portal and published after manual post-processing using an online video editor. The visibility of the recording is limited to the authorized members of the respective community, the list of whom is retrieved from an LDAP (Active Direc-

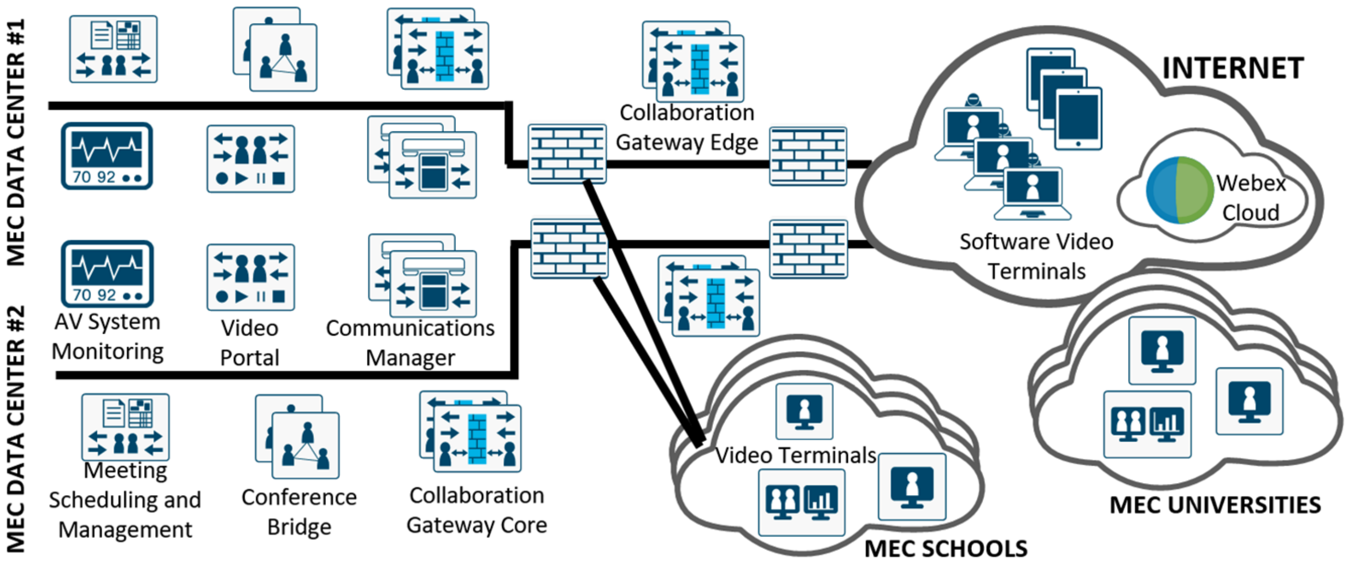

Fig. 4. MEC AV subsystem architecture (simplified)

tory) repository. The recording is also embedded in MEC social media portal. If the hosts want to allow non-interactive access to the event, they could also activate live streaming.

In addition to permanent classrooms, the conference bridges run also personal conference rooms created for each teacher participating in the project, affiliated with a university or a school, for the purpose of any non-scheduled activities (such as consultations, etc.). Teachers were also provided with personal conference rooms in the public cloud (Webex Meetings).

From the business point of view, the conference bridges, content recorder, and video portal are the most important elements of the AV infrastructure running in the MEC private cloud. The other elements are used to securely establish the communication, filter unauthorized calls, route call requests to appropriate destinations according to a numbering plan, schedule meetings, and efficiently monitor and manage the infrastructure located in remote locations (ca. 500 hardware terminals). The AV subsystem architecture is implemented with Cisco Unified Communication technologies, in accordance with the vendor best practices. Most AV components expose REST APIs, which were used for customization. The private cloud infrastructure is also integrated with the Cisco Webex Cloud so that users have a single account, managed by Active Directory, that allows them to transparently access all MEC services. It is worth emphasizing that AV infrastructure supports various conference terminals (hardware and software, including web-based), both MEC-internal and registered externally, as well as two contemporary signalling standards – SIP and WebRTC. That provides for interoperation with external systems.

School and university teachers, as well as technical staff, were provided with licenses for AV software terminals. The software could be run under various operating systems, including mobile devices. Licenses for most software terminals were offered also to students who could use them to remotely participate in online classes, e.g., in case of illness. They could use both the private cloud and public cloud AV service instances.

Just as in the case of other services, elements of the private-cloud AV service implementation were duplicated and deployed in two separated data centers. The system was scaled in such a way for high-availability reasons, i.e., to be capable of offering full service even if only a single data center was accessible to the participants.

4. CHANGES IN USAGE PATTERNS CAUSED BY COVID-19 PANDEMIC

Before the pandemic, the typical MEC E-ICE usage pattern involved each of the high schools as a participant of two learning communities. The communities – typically consisting of one university and up to five schools – organized courses, designed and led cooperatively by university and high school teachers. The courses included many online classes, in which students of a particular high school participated as a group, supported and supervised by their school teacher. During the online class, the school's equipment was used for remote collaboration. That included shared (hardware) multimedia terminals, interactive whiteboards, dedicated WiFi, which was a part of MEC overlay, etc. Typically, a single learning community was formed for two semesters and involved about 20 people from each high school. The communities organized online classes on a regular – usually weekly – basis. During the online classes, several services were used to support the collaboration. The usage patterns were varying from one service to another – the students could have used them individually, or in groups of different sizes. Typically, the AV service was the most important service, while the others were used less intensively.
The services that supported online classes organized by MEC learning communities were orchestrated according to the generic use case, depicted in Fig. 5. In most cases, during pre-pandemic online classes multiple students shared a few dual-display hardware terminals equipped with cameras capable of tracking active speakers. Such functionality was economi-

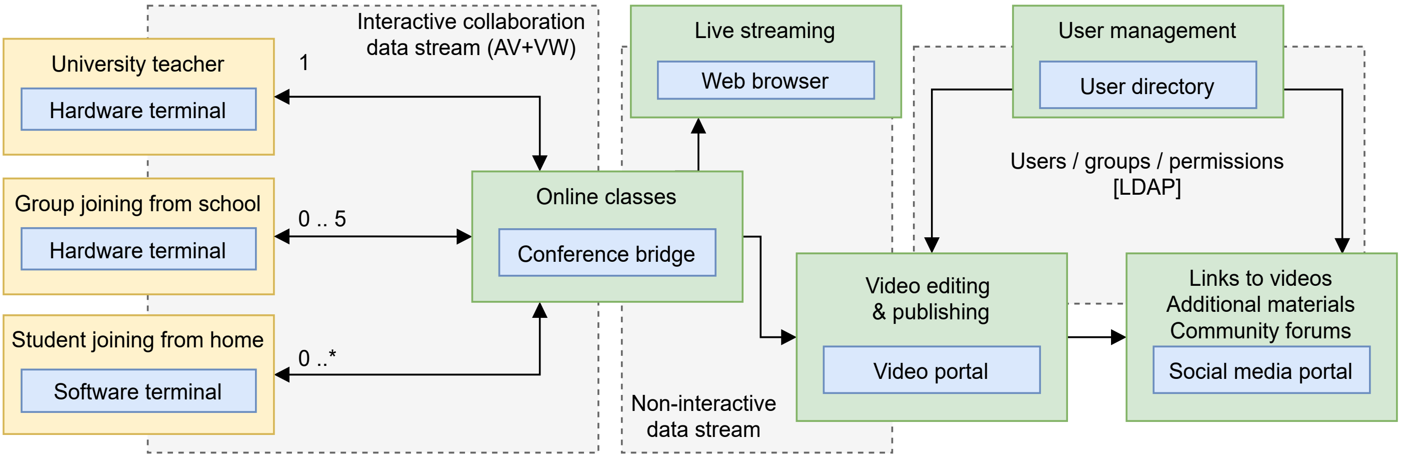

Fig. 5. Generic use case of MEC-supported audiovisual collaboration

cal from licensing, bandwidth, and computing power points of view. Moreover, the students were grouped in their schools, so no significant organizational effort was required. Because the use of software terminals by students joining from home was occasional, the conference bridges were typically serving only 5–7 endpoints connected to a single virtual room using high-bandwidth, low-latency links. Therefore, the quality of service was more than satisfactory to the users. The dual-display terminals installed in each of the participating schools were also used by virtual whiteboard service implementations. Virtual desktop and virtual collaboration environment services were used rather occasionally, mainly for homework and demonstrating the results of complex calculations (e.g., simulations in Matlab).

The schools also used single-display mobile terminals (that were shared by groups of 5–10 people), and a personal hardware terminal. The former was used when access to particular local equipment (e.g., of a chemical laboratory) was needed during the online class, and the latter was used to organize consultations in small groups. However, it was rather inconvenient to reuse such terminals as virtual whiteboards.

With the outbreak of the COVID pandemic, a sudden change in MEC usage patterns occurred. First of all, because of lockdowns, the participants of online classes could no longer share the schools' equipment. That resulted in a dramatic increase in the number of collaboration endpoints. That was especially important for the AV service (before the pandemic, ca. 20 students could be served by a single endpoint). In new circumstances, each of the students needed an individual AV service endpoint to join the online classes. Moreover, advanced features dedicated to shared environments such as speaker tracking cameras were used no longer. Instead, the feature was to some extent provided by active speaker detection by conference bridges. However, most students did not enable their cameras, which made the virtual collaboration space much less immersive.

Individual participation also influenced the way the online classes were conducted. The students could no longer be directly supported by a school teacher. Therefore, most of the moderation-related tasks were suddenly shifted to the leading teacher or AGH university administrative staff. The creation of task-oriented subgroups became much more problematic. As a result, the classes were held mostly as lectures with an occasional conversation with individual participants. Virtual whiteboards were suddenly almost abandoned. Attempts to use Google Jamboard or similar services as a virtual whiteboard failed due to the number of independent endpoints (in the pre-pandemic cases, locally formed groups discussed what and when to put on the whiteboard, so the whiteboard content was much less messy). With regard to Virtual Desktop and Virtual Collaboration Environment services, no significant changes in usage patterns occurred.

Many schools decided to use MEC E-ICE not only for selected classes several times a week, but for a large part of their day-to-day activities. A number of schools which were not previously involved in MEC also expressed their interest in using the services. The increase of interest manifested in the number of newly created MEC accounts, depicted in Fig. 6. Usually, most of the new accounts are created in October, after the school and academic years start. Some leading (university) teachers decided not to require the students to have MEC accounts – when only the shared terminals are used for online classes, one can participate in them without having an account. The observed number of 790 new accounts (see Table 1) in the period of October – December 2019 is typical and can be interpreted as a baseline for analyzing the effects of the pandemic. During the first school closure in Poland (in the period of March-June 2020) 3361 new accounts were created, most of which in March. The accounts were requested by both new users and the students who previously did not have to have an indi-

Table 1
Newly created accounts in key periods

period	new accounts	reason
01.10.2019 – 31.12.2019	790	(new school year 2019)
12.03.2020 – 26.06.2020	3361	(pandemic)
01.10.2020 – 31.12.2020	3263	(new school year 2020)

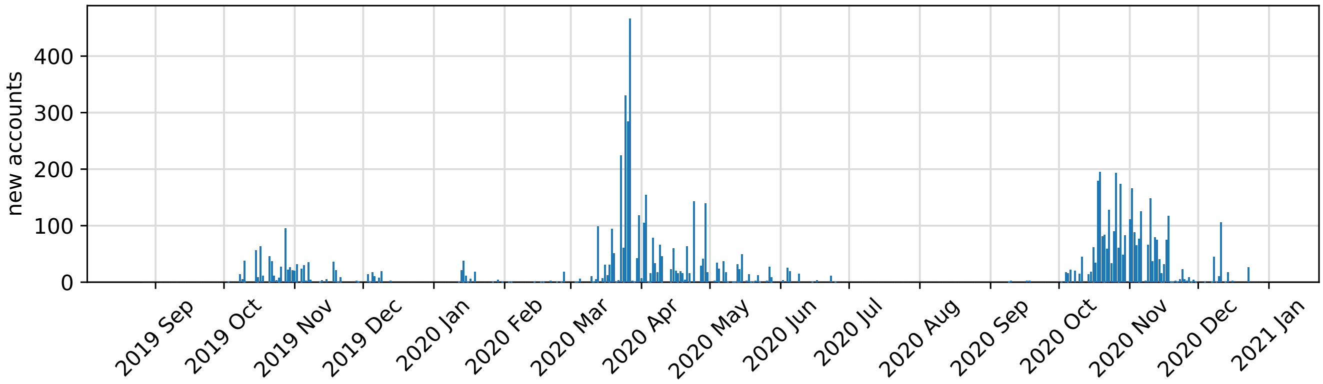

Fig. 6. Newly-created MEC accounts (between September 2019 and December 2020)

vidual MEC account. Having such an account suddenly became necessary in order to join online classes using an individual endpoint, and to use the shared learning spaces which became a much more important means of distributing didactic materials, etc. It is worth noting that most of the accounts were created in two weeks starting from March 12, which was the first day of the closure. This stands out from the situation observed in other countries [11, 13, 16], and was possible only because of the previously established collaboration between AGH and the schools, which involved providing technical training and assistance to the school teachers. The second closure, which started in October 2020 was rather expected, so the process of creating new accounts was much smoother. 3263 new accounts were created between October and December 2020 (see Table 1), about 2200 more than the expected number (between 2019 and 2020 the number of schools participating in the project grew by about 30%).

Regular MEC meetings (i.e., online classes in learning communities established before the pandemic) are provided mostly by the MEC private cloud, while for consultations and other meetings – including classes organized by the schools only for their students – Webex Meetings seem to be preferred. Its utilization increased dramatically reaching ca. 200 meetings daily with ca. 150,000 participant minutes (which gives about 750 participant minutes per meeting). No more than ca. 70% of meetings used video, and the very small participation of video minutes in participant minutes proves that most of the participants used only audio for communication.

5. COPING WITH CHALLENGES RELATED TO CHANGE OF USAGE PATTERNS

As previously mentioned, AV was the most frequently used MEC E-ICE service during the pandemic period. A number of problems were observed, most of them were successfully resolved. Three general categories of issues were identified: a) related to AV endpoints usage, b) related to AV endpoints operation, and c) related to AV backend operation. It occurred that the resolution of observed issues was streamlined thanks to proper organization of collaboration between project participants, which started before the pandemic.

To allow users to efficiently utilize the MEC infrastructure and services, AGH offered training for each partner institution participating in the project. Two representatives of each institution were trained at AGH and became so-called local MEC administrators in their schools or universities. The training was focused on technical and administrative tasks related to the overlay network, usage and management of hardware and software terminals, as well as management of MEC accounts. It also covered many topics related to the software tools used in the project. As a result, a distributed team of administrators was ready to assist users after the outbreak of the COVID pandemic.

The trainees were asked to transfer their knowledge and abilities to the end-users, mainly teachers. What is more, school teachers had the opportunity to participate in courses organized by other partners aimed at demonstrating the potential of MEC services in the didactics. As a result, MEC users had enough skills to efficiently participate in the online classes during the pre-pandemic era, and were acquainted with online education. Nevertheless, having no need to use the software offered by the MEC project in their everyday practice and having little deeper experience with any other collaboration tools, many of them experienced problems with switching to the new tools. Participation in the MEC online classes paradoxically did not help much, due to the simplicity of hardware terminals usage and their high level of automation. Many users lacked both technical skills related to, e.g., the establishment of audiovisual connection or sharing the PC camera, and the know-how about effective participation in multi-user events (related, among others, to how to share content, how to set up an environment to optimize the quality of audio-visual conversation, etc.). To successfully cope with that, local administrators and AGH technical staff involved in the MEC project supported users with much dedication via e-mails, telephone calls, and online consultations. Additionally, university and school teachers were given technical recommendations by the MEC administrators on how to lead online classes of specific types in new conditions – in terms of preferred tools and their usage pragmatics. These recommendations were changed several times in response to new conditions.

Problems related to AV endpoints operation depended on their type. The least troublesome were hardware terminals

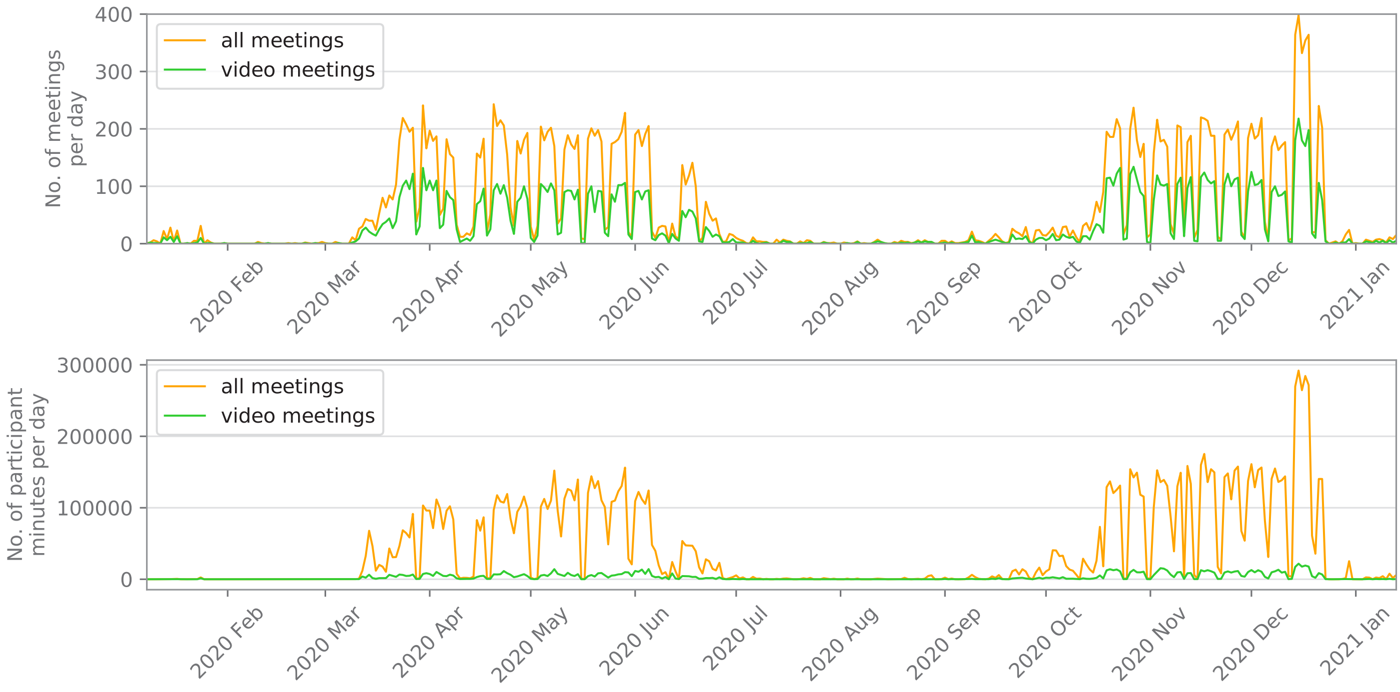

Fig. 7. Utilization of Webex Meetings (mche.edu.pl domain) before and during the pandemic: number of meetings per day (above) and number of participants minutes per day (below)

still used by some university teachers when the specifics of the classes required leading them from university laboratories, or when the teachers simply preferred to use the already known high-quality AV equipment. When it comes to software terminals enabling access to the MEC private cloud AV services, Webex Teams desktop application (or Web plugin), and WebRTC-based Web application were available to all MEC project participants. In both terminals, some deficiencies were identified. Issues with Webex Teams were generally related to insufficient quality of the audio-visual communication (i.e., low video resolution and considerable delay), and were observed mainly in the initial period of the pandemic. They were the consequence of the system architecture, i.e., routing traffic via the Cisco public cloud, and interim congestions of main Internet links. The most troublesome AV endpoint was the WebRTC endpoint. Issues with it were mainly caused by slight differences in the behaviour of WebRTC in various Web browsers, and by bugs appearing in specific hardware or software configuration of users' computers. Remote support in this case was complicated, so the problems remained unresolved for a longer period of time, sometimes resulting in users' dissatisfaction. Fortunately, users had an option to switch to a different terminal. Moreover, participants of MEC online classes could join a live stream of the event using the MEC video portal. The feature was simple to use (although with no interaction possible) and turned out to work very stably even under heavy load. The need to use this feature much more frequently made MEC administrators reconfigure most conference rooms to start the live streaming automatically (before the pandemic, as already mentioned, live streaming was activated manually on request).

The operation of infrastructural services also caused numerous problems. Their nature was twofold: configuration faults manifesting during peak service utilization, and bugs or deficiencies in functionality. The former were gradually eliminated and the latter were reported to the software vendors, so that new, patched versions of conference bridge software could be systematically installed. Growing utilization of the conference bridges required increasing their resources several times to satisfy the demand. Finally, during peak hours all four bridges were nearly fully utilized causing the high-availability of the AV service to traded off for scalability. What is important is that the flexibility of the MEC cloud facilitated transforming the utilization pattern of this service in a simple way.

Some of the problems that occurred stemmed from the differences in capabilities of various AV terminals. In general, the functionality provided by MEC software AV terminals reflects the functionality of hardware personal terminals. Because of that, they sometimes lack features which are typical for contemporary collaboration tools. Probably the most important inconvenience for the users was the lack of a chat widget which would be very useful, especially in meetings with numerous participants. Moreover, some MEC software terminals do not allow the host to mute other participants, which is a crucial feature to avoid interference and external noise. Although MEC also offers a conference tool (Cisco Webex Meetings), the recommendation to use it during the online classes was not made due to the lack of integration of its recording and live streaming features with the MEC E-ICE infrastructure. Nevertheless, it could be used to organize other meetings, and the numbers presented in Fig. 7 show that it became a very important tool for MEC users during the COVID pandemic.

6. CONCLUSIONS

The case study presented in the article shows that a community sharing a medium-size deployment of cloud-enabled educational integrated collaboration environment is able to respond rapidly to sudden changes in their daily teaching practice. It is a good example of how good design practices and usage of modern technologies can be leveraged to rearrange the collaboration. The design assumptions that in normal conditions resulted in increased user satisfaction due to high availability and freedom of choice from multiple implementations of the same service, allowed us to change the mode of operation in about 10 working days. Considering that there were more than 150 institutions served by MEC, and all were affected by the pandemic, the result is more than satisfactory.

The successful transition would not be so rapid without having a community of teachers built and communication channels for technical assistance established beforehand. The community was able to conduct all of the most important changes, including the creation of necessary accounts and instructing the students about the software functionality basics very rapidly. Moreover, the technical training conducted prior to the closures resulted in participants being acquainted with multiple tools. Therefore, the trained teachers could start using appropriate software instantly after the schools' closure was announced.

It may be safely assumed that after the pandemic, remote teaching will play a more important role in the daily operation of schools. Experiences drawn from use cases, such as the one described in the article, could be leveraged in order to organize future teaching in a more flexible way.

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