Deploying Edge Computing to Augment Endpoint Functionality

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Abstract: The seamless integration of additional endpoint processing and storage as a separate component to an endpoint appliance can provide a platform for additional capabilities and services to existing products and services. A multidisciplinary project is presented where students were given high level objectives to add additional compute and networking functionality to field deployed mobile Cisco WebEx Boards. These additional resources support service monitoring and troubleshooting tools by providing a separate user agent to continually test the end-to-end network and control plane network performance. Students from BS in Industrial Engineering Technology, BS in Design, BS in Information and Computer Technology, and BS in Computer Science worked together to complete the project and deploy integrated Raspberry PI systems to Cisco WebEx boards funded by USDA for community college and high school collaboration and distance education. Tasks accomplished by the student team include physical design, fabrication, installation, configuration, instrumentation development, provisioning and deployment. An assessment of student learning outcomes unique to the interdisciplinary project will be presented.

Key words: IP, performance, Cisco WebEx Board, Raspberry PI, Industrial Design, SaaS, Monitoring, Student Learning.

Neither the entire paper nor any part of its content has been published or has been accepted for publication elsewhere. It has not been submitted to any other journal.

1. Introduction

Modern IT environments are driven by two major dynamics: the migration of services to cloud based delivery [1] and an exponential growth of end-point devices [2] enabling or supporting services. These two trends have a major impact on the architecture, structure, and operation of current and future cyberinfrastructures. Specifically, the most significant impact relates to great portions of the network becoming, in the view of the services being delivered, simply transport commodity. The “intelligence” of the infrastructure is migrating towards the cloud where services are controlled or towards the edge where data can be processed in a more local, less expensive way [3]. These changes require new technologies being deployed, new skills for the staff, and new operating processes. This paradigm change applies to all cyberinfrastructures including those of high education institutions.

The march to the Cloud is well accepted and well on its way for many organizations. The rise of edge computing (EC), on the other hand, is a more recent trend, naturally lagging the centralization of service delivery control. This means that for the next couple of years, cyberinfrastructures will be in a state of transition, a hybrid of traditional and new architectures [4]. Services will migrate to cloud lacking the operational tools for optimal delivery and management while edge computing requirements will be met by compute resources being bolted onto exiting infrastructures based on operational or service needs. This period of transition is a great opportunity for innovation in many areas of IT management and IT service delivery.

In this paper we capture the process of addressing these two trends in the context of deploying a new regional cloud-based video conferencing service. The deployment of this service offered an opportunity for a multi-disciplinary project for a diverse team of students from Industrial Engineering Technology and Design [5], Information and Computer Technology [6], and Computer Science [7]. The task assigned to the teams was to complement the cloud-based video conferencing service with the edge computing resources needed to manage the service.

2. Problem Definition

Department of Technology Systems at East Carolina University (ECU) received a grant from US Department of Agriculture (USDA) [8] to purchase Cisco WebEx boards [9] and deploy them to 12 colleges and high schools across Eastern North Carolina to facilitate distance education (Figure 1).

Figure 1. Footprint of the Planned Distance Education Service

This new service enables a more engaging, collaborative instructional experience involving students in multiple classrooms across Eastern North Carolina and ECU instructors. The potential positive impact of this service is significant. The USDA grant covers the cost of the hardware and the WebEx cloud-based service provided by Cisco [10].

Cloud-based services have been heavily marketed to give the impression that with the purchase of the endpoints and the service, the only thing needed to turn this offering into production is to assemble and deploy the WebEx boards. This is one of the reasons why organizations often time decide to skip working with their internal IT team to plan the rollout of cloud-based services. The practical aspects of operating IT services do however require answers to key operational questions:

- **How will these assets be tracked once they are deployed?** At a minimum, the service owner (ECU) should know if the endpoint is connected and what is the local network information.
- **What is the quality of the control-plane path?** ECU and the partner organizations need to know if the WebEx service is available to set up the sessions.
- **What is the quality of the data-plane path?** ECU and the partner organizations need to know if sessions established between various locations will deliver a good user experience
- **When there is an issue, who is responsible for it?** ECU and the partner organizations need to have the data that helps isolate fault domains and support any trouble-tickets opened with service providers.

Many of these questions might be answerable should ECU or the partner organizations have full management visibility in the WebEx service; however, that is rarely the case. Ultimately, cloud-based services insert multiple management domains in the service delivery path: Local IT, Internet Service Provider (ISP), Internet Backbone and Cloud Service Provider (WebEx) as shown in Figure 3. This leads to significant uncertainty on which one of these domains is responsible for the cause of an issue experienced by the service.

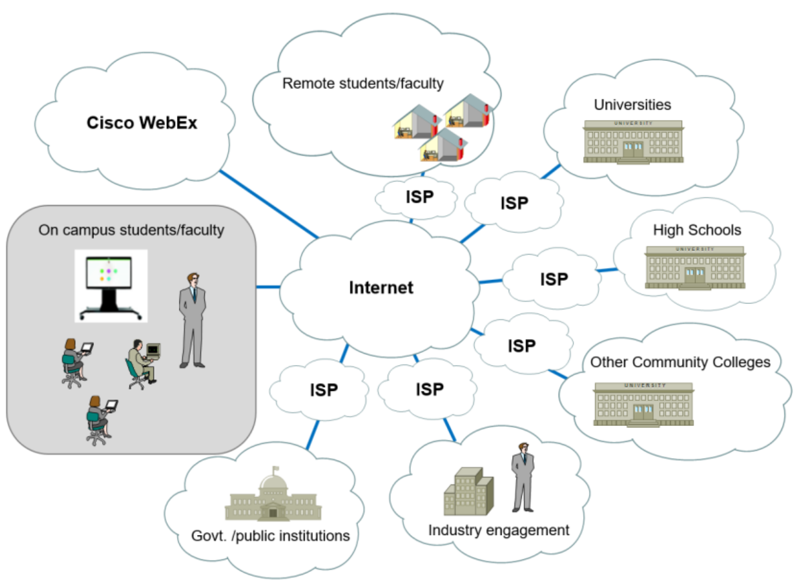

Figure 3. Management Domains for the WebEx Service.

This uncertainty becomes very problematic when issues crop up in service operations leading to significant downtime while finger-pointing delays resolution. Even if ECU explicitly states that it will not be responsible for the operational details of the service, it will inevitably find itself spending resources on issues that have nothing to do with its own IT environment. Moreover, ECU will have no access to the IT infrastructure hosting these endpoints thus limiting effective support.

The ECU team leading the service enablement project needed a solution that would enable it and the project stakeholders to have the visibility needed to manage the assets, the infrastructure and the services involved in this offering. The goal is to gain this visibility and enable self-governance without needing significant commitments from the IT teams at each of the locations.

This problem statement spurred two cross-departmental projects:

- The development of an Edge Computing platform that can support services and tools in support of the main service without requiring local IT departments to modify their own environment
- The development of a monitoring framework that enables effective yet simple management across multiple admin domains without requiring significant local IT resources [11]

The second project is providing the monitoring tools deployed on the platform developed by this project.

3. Project Setup

During their degree seeking studies students are mostly exposed to individual projects or projects involving classmates studying the same subject matter. Capstone projects, when offered, are the most common opportunities for more diverse and more creative learning opportunities. The challenge faced by the video-conferencing service provided an opportunity to explore models for formalizing models of engaging students from different departments to advance their own domain knowledge and to work across domains by addressing real-life problems. In this section we describe the project setup, the team composition and its structure.

3.1. Project Goals

The project was developed independent of exiting courses and degree requirements within the College of Engineering and was focused on two primary goals:

1. Facilitate independent student research in the context of customer defined solution requirements
2. Facilitate collaboration between students with different specialties on developing solution components

This project was meant to develop the following set of skills useful to future graduates in their industry, research or entrepreneurial careers:

1. Collecting, understanding and analyzing customer requirements
2. Project planning within and across teams
3. Effectively employ iterative development
4. Understanding complete solutions and develop the ability to effectively disseminate the entire value not just the value developed within individual domains of expertise

The project was also meant to measure interdisciplinary learning and student collaboration, to develop a template for formalizing such learning opportunities centered around research led by multiple professors.

3.2. Project Team

The envisioned outputs of the project and the corresponding resource requirements were:

1. A viable, production ready solution requiring the involvement of students interested in research and with prior experience in of three domains of expertise: Design/Manufacturing, Computer

Hardware and Computer Software. One faculty advisor was assigned to act as a customer ("Customer") for the solution, providing the solution requirements and evaluating project output
2. Assessment of the student learning experience led by an independent faculty advisor ("Assessor") focused on the education process

The project faculty advisor ("Advisor") formed three domain specific teams were created to address the key aspects of the solution:

1. **Case Team** – Focused on designing and building the device enclosure, this team included two undergraduate students form Industrial Engineering with experience in design and 3D printing
2. **Hardware Team** – Focused on selecting, validating and installing the hardware providing the compute and switching resources needed. This team was also involved in developing the lab environment for testing. The team included two undergraduate students from the Technology Systems department with experience in computing and networking
3. **Software Team** – Focused on developing the monitoring solution, standardizing the software components and building the automated test harness for product benchmarking. This team included an undergraduate student from Computer Science and one graduate student from Technology Systems both with experience in software development and systems software.

The teams were formed with students who were already involved in research or advanced projects within their specific domains of expertise. The team structure is shown in Figure 4.

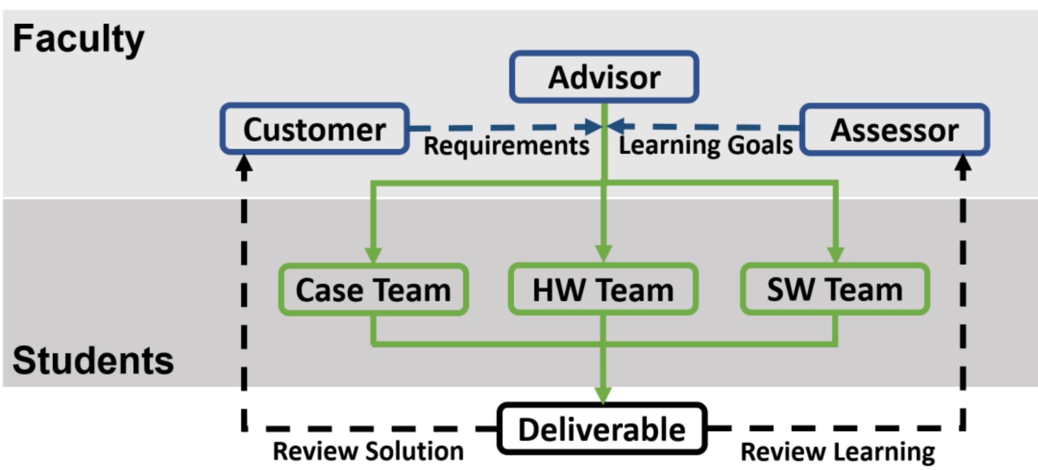

Figure 4. Project team structure, roles and responsibilities

As shown in Figure 4, two process loops were implemented to effectively meet the two project requirements: Solution development loop and the Learning loop.

3.3. Solution Requirements

To gain the information needed to enable self-management of the service without having to request local resources or support, it was decided to add inexpensive, managed compute resources to the WebEx boards. These compute resources can support the monitoring and troubleshooting capabilities needed to support the solution and to add additional capabilities in the future. These compute resources were added to the stands supporting the WebEx boards.

The edge computing platform needs to enable ECU to collect service operational information:

- **Network Attachment Information** – Collect information related to the access layer where the WebEx board is connected. IP address information, DNS information, WiFi metrics where applicable. This information can provide asset tracking information based on IP address assignment and/or geolocation services. This data can be collected assuming the EC platform is connected the same way as the WebEx board.
- **Location Availability Information** – Validate that the access layer at a given location is operational and available to the WebEx board
- **Network Path Quality** – Evaluate the quality of the network path between locations in terms of latency, drops and jitter
- **Service Availability Information** – Detect WebEx service availability at each location.

The solution needed to facilitate operations, not to make the entire system more complex, thus the following design criteria applied:

- **Fit to Existing Hardware** – Build an enclosure easily and securely attached to the existing stand.
- **Same Layer-Two Access Options** – Build the EC platform to use the same network access as used by the WebEx board (Gigabit Ethernet and WiFi).
- **Manageable** – Simple provisioning and management of the EC devices.
- **Secure** – The EC platform should have a level of physical and access security that meets the standard requirements of educational institutions.
- **Non-intrusive** – The tests executed by the platform should not negatively impact compliance or performance. For example, the platform should not listen to traffic unless explicitly requested and allowed by the local IT organization.

The solution requirements were defined by the faculty designated as the “Customer” who is the owner of the video-conferencing service. The project Advisor and the students had complete autonomy in developing the solution that supports the customer requirements.

4. Project Execution

4.1. Development Process

The three faculty advisors initiated the project by identifying the requirements, solution definition, learning goals and learning assessment methodology. This initial step was followed by the student team formation and technical project initialization. Figure 5 depicts the engagement process between the faculty and the student teams as well as the interaction between the teams.

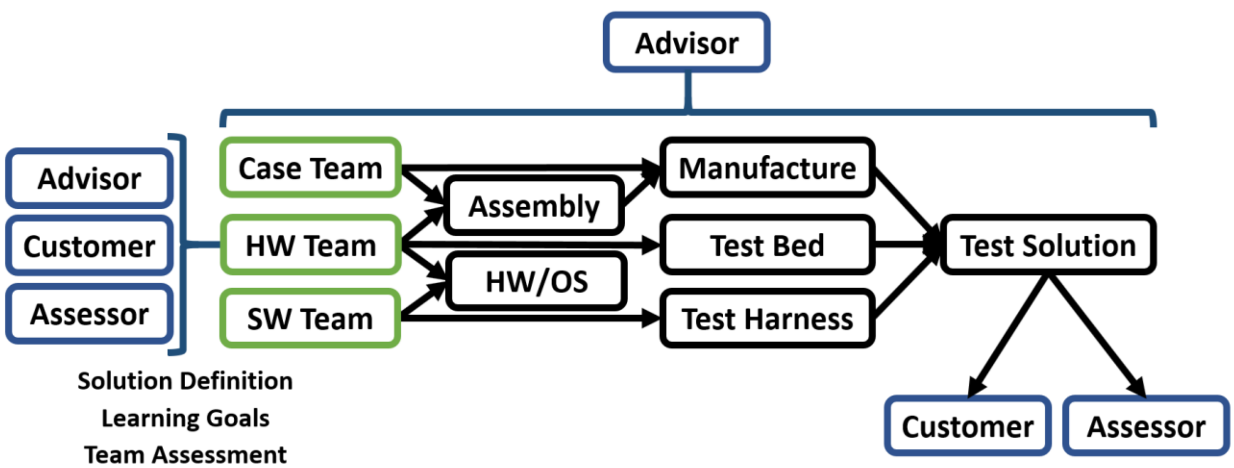

Figure 5. Project flow and the interaction between the student teams

Once the solution architecture was presented to the entire team, the project advisor suggested but did not enforce specific team interactions and team collaborations. Students had a large degree of independence in conducting research, design, implementation and testing within their domain and across domains. The evolution and interactions shown in Figure 5 represent a historical perspective on the project execution in that they developed organically and were not planned a priori. For example, the Case and Hardware teams worked together on the Assembly specific requirements while the Hardware and Software teams worked together on operating system selection and platform configuration.

At the end of the project the solution was internally tested and then delivered for evaluation to the “Customer”. The “Assessor” collected the learning metrics to evaluate the student experience through this learning experience.

4.2. Implementation

The solution developed by the project team was based on off the shelf computer hardware components, 3D printed enclosures and off the shelf software solutions.

4.2.1 Hardware – The hardware platforms considered were Beagle Bone Black [12] and Intel Nook [13] but it was decided to use the Raspberry PI as it is the fastest growing platform with the best community support. In particular, the recently released Raspberry PI 4 [14] was selected. To accommodate Gigabit Ethernet access for the WebEx board and for the EC device, a Gigabit Ethernet, PoE unmanaged switch was included as a requirement for the platform design [16]. The modular design of the enclosure enables the project team to fit alternative hardware as the various components evolve. Connectivity between the device components is accomplished with cabling selected for reduced bulk and high flexibility.

4.2.2 Enclosure – The design of the hardware housing started with simple components with the Raspberry PI mounted on top of the network switch to save space and reduce housing size. To reduce bending stress on the wires connecting the boards, we added large radii to each end of the housing. These radii also increased the overall strength of the housing over a rectangular design (Figure 6).

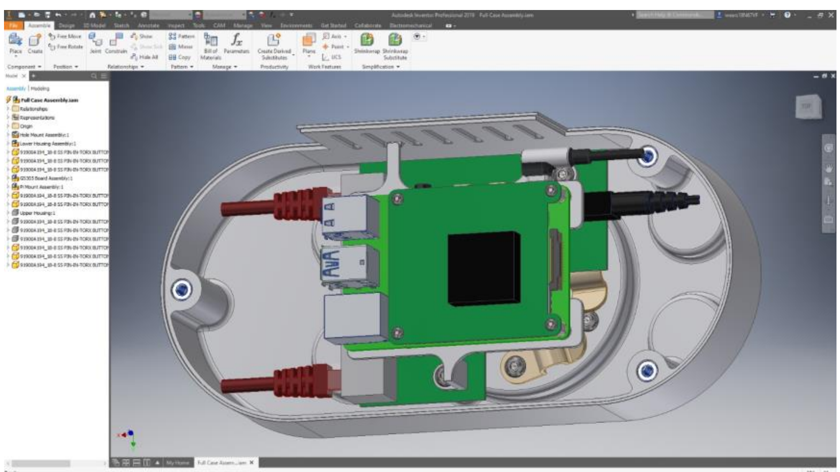

Figure 6. Enclosure Design with Modular Hardware Assembly.

All the design work was done in Autodesk Inventor 2019 with CAD files of the mounting and other hardware imported via McMaster-Carr. The printing of the prototype was done on a Stratasys Dimension SST 1200ES [17] using GrabCad Print [18] dedicated slicing software to get estimate print times and material usage to check against actual print time and material usage. The first version of the enclosure was printed with dissolvable support material to minimize post processing after the print finished. The assembly of the housing went smoothly with no major adjustments or design changes except for small artifacts from the printing process needed to be removed (Figure 7).

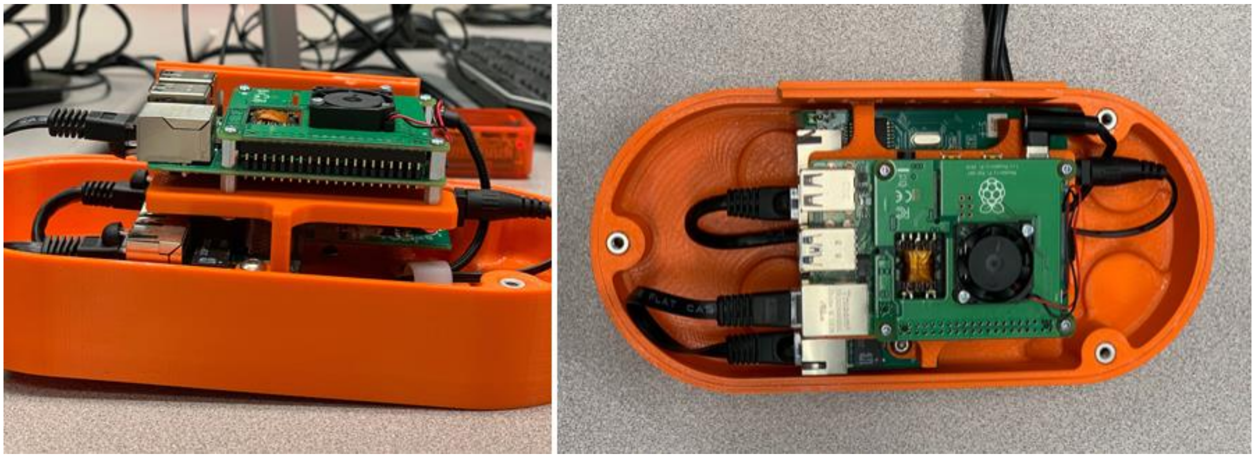

Figure 7. Enclosure Design with Modular Hardware Assembly.

Version 2.0 of the enclosure will be optimized toward 3D printing material and overall cost per assembly reduction. The color of the enclosure will be switched to one similar to the color of the rest of the stand.

4.2.3 Assembly Testing – Device benchmarking and testing (to avoid field issues [20]) was performed using an automated test harness built based on the Phoronix platform [21] with data stored using the OpenBenchmarking.org service [22]. The main tests enlisted in the benchmarking efforts related to utilization of hardware resources and are readily available in the Phoronix Test Suite [23] and IPerf test [24] used in network benchmarking.

Based on the project team assessment, the hardware choice (Raspberry PI 4) and the enclosure designed for the EC device meet or exceed the needs of this use case thus representing a long-term solution to the problem addressed.

4.2.4 Monitoring Tool – The EC devices represent local resources enabling the rollout of software tools supporting additional functionality or enhancing existing functionality. In the case of this project, the primary goal was to enable the management of the EC devices themselves, to enable active monitoring of the infrastructure and the WebEx service at each location and to provide support staff with the capability to perform basic level of troubleshooting without requiring special permissions [25].

The developed solution is using an agent based, SaaS (Software as a Service) tool eliminates the need to install and maintain dedicated infrastructure for the management tools. The agent is installed on the Raspberry PI during staging (before the WebEx board is deployed) with all the relevant layer 2 authentication information. When the EC device is powered up, the agent communicates with the cloud-based controller over port 443 and self-registers. The agent-controller communication is secure. Once registered, the agent is ready for scheduled or on demand tests configured via a centralized dashboard. The initial focus in data collection is path quality information (latency, jitter, drops) using PING tests. PING remains an easy, lightweight yet effective way to collect first order network information [26].

Data is centrally collected and made available to all stakeholders for pre-session preparation, post-session analysis, resource planning and troubleshooting. Examples of the data collected by the monitoring tool used for the proof of concept of the project are shown in Figure 8.

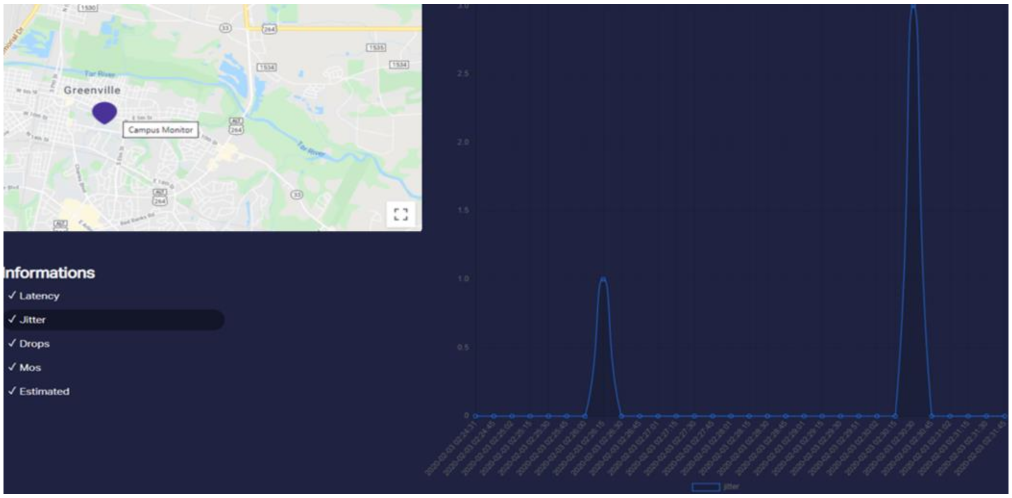

Figure 8. Example Jitter Measurements to WebEx

The evaluation of the SaaS control and monitoring tool used in this solution is detailed in [11].

5. Solution and Student Learning Evaluation

The project was not part of a capstone course or student credit hour requirement. Instead, the project was part of and funded by the applied research projects of the college faculty. Encouraging a collaborative environment among the undergraduate degree programs allows for opportunities for students to work together and get involved in both research and product development. A major difference between this type of project and a capstone project is that this project is not shelved after delivery, it represents a building block for future projects involving the same fields of research.

The project outcomes were evaluated by the faculty assigned to the roles of “Customer” (quality of solution delivered) and “Assessor” (student learning experience).

5.1. Solution Evaluation

The “Customer” evaluated the final solution based on several practical metrics on a scale of 1 (Does not meet the requirements) to 10 (Fully meets the requirements) as shown in Table 1.

Table 1. Customer evaluation of the delivered solution

Metric	Score	Observations
Met Solution Requirements	9	Despite some components requiring optimizations, the “Customer” estimated that the original requirements were mostly met
Cost	8	While the cost per case is competitive, it is expected that the design optimizations planned for version 2.0 will reduce the costs below the customer expectations
Appearance	9	The prototype color makes the device stand out even though it physically is hidden by the Webex board. Version 2.0 of the enclosure will be white to blend in with the frame.
Security	7	The device meets the customer physical security requirements. Additional access security was requested for the Raspberry PI which will be implemented using IP tables rules.

Ease of Use	10	The “Customer” was very happy with the ease of installation for the device and the ease of use of the monitoring platform.
Production Readiness	5	While version 2.0 of the case was not ready at the time of the evaluation and the monitoring platform required additional customization it was decided that additional work will be needed to make the solution production ready. This work will be completed by May 1, 2020.

The “Customer” intends to deploy the solution into production once the monitoring tools are further tested and prepared for deployment and version 2.0 of the case is manufactured.

5.2. Student Learning Evaluation

The student learning experience was evaluated based on student feedback around the learning goals, the student evolution and the student readiness to disseminate the project results. The evaluation was assessed on a scale of 1 (inadequate, limited, uncomfortable) to 10 (complete, very comfortable). The minimum, maximum and average scores are listed for each evaluation.

Table 2. Assessment of main learning goals

Metric	Min	Max	Average
Rate the level of independence in pursuing the solution implementation	5	9	8
Rate the level of collaboration with other domain teams in the project	4	10	8

The low scores are the result of reduced collaboration between the Case and Software teams. While this reduced collaboration can be justified, it has repercussions in terms of all students being able to disseminate all aspects of the solution. We believe this issue can be mitigated through regular organized meetings with all the project teams to deliver progress updates.

Student development throughout the project was captured by measuring several metrics at the start and at the end of the project. These metrics are visualized in Figure 9 where the lighter shade represents the value at the start of the project while the darker shade represents the value at the end of the projects.

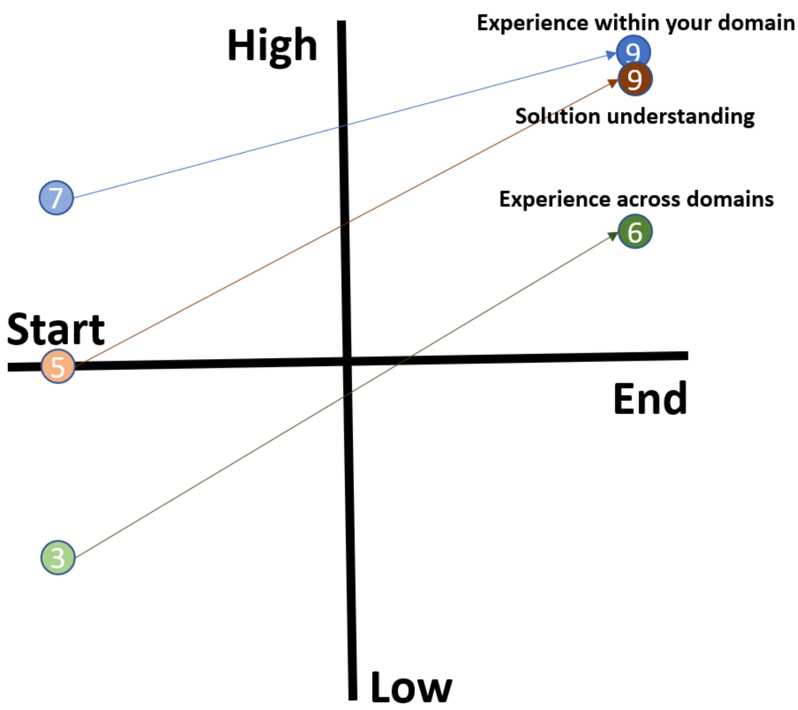

Figure 9. Student learning evolution through the project

The project succeeded in enabling students to grow within their respective concentrations as well as in their understanding of the other domains related to the solution. However, in alignment with the data shown in Table 2, more attention needs to be provided to driving collaboration across all teams, not just those naturally aligned for specific deliverables. The most dramatic improvement was observed in student understanding of the full solution.

Finally, we wanted to make sure at the end of the project all students were comfortable pitching, describing and supporting the solution beyond the project. Table 3 captures two specific metrics used in evaluating this aspect of student development.

Table 3. Dissemination readiness of the students.

Metric	Min	Max	Average
Rate understanding of the field applicability of the solution	2	9	7
Rate the readiness to present the solution to external audiences	7	10	9

Students presented the solution in the College of Engineering Research Day poster session where they had to explain the motivation for the solution, the design and implementation choices and finally the viability of the solution for commercialization. Students had to be able to present the full solution by themselves, regardless the domain they worked in. It was determined that an end of project review discussing commercialization in greater details would have helped the students better address questions.

An additional, positive outcome of the project is a student initiative to investigate the options for patenting the enclosure or components of it. This activity is supported by the faculty as a good learning experience in Intellectual Property management. The fact that this activity was initiated by the students reflects the sense of ownership developed by the students and their confidence in the long-term value of the design.

The overall student experience was very positive with all participants recommending the introduction of such projects in the regular instruction process. Students gained not only the skills, but the appreciation for the skills needed to work together in a group to succeed in a project that encompassed many disciplines. Student comment: "I believe projects such as this should be run regularly if not more frequently. Projects like this are the missing link between the classroom and the real-world, problem solving expertise students need. I believe that I am not the same student I was before joining in on this experience and that more students should have the opportunity to be involved in this type of work."

One issue with projects such as this is scalability. There are not enough research projects to allow for all undergraduate students to participate, and the student population that does participate is often taken from the best students. Lower performing students that may benefit from the experience may not be motivated to apply to research positions. Recruiting from different disciplines can also be a challenge unless you directly involve faculty from each area. In fact, one of the suggestions made by the participating students was to develop the means to facilitate inter-departmental collaboration amongst both faculty and students to facilitate project opportunities and the recruitment of students.

6. Conclusions and future work

Edge computing is becoming an important enabler of optimal service delivery and of scalable, distributed functionality. Most current infrastructures do not allocate resource that could support edge computing. Moreover, cloud-based services supported my multiple management domains makes it difficult to allocate edge computing resources in their support. In this paper we documented a multidisciplinary project focused on enabling a multi-domain monitoring service for cloud-based teleconferencing without the need of engaging individual IT organizations where the endpoints are hosted. The solution developed adds the necessary compute resources to mobile Webex boards thus providing an independent management overlay that enables collaborative monitoring and management of a cloud-based service. The project covered all key aspects of the solution, from compute platform selection to enclosure design and manufacturing to testing and running a proof of concept for the monitoring tools. This project provided an environment for multidisciplinary collaboration between students from various departments and various fields of study. It enabled them to apply their knowledge in the context of a real-world problem while understanding the impact their work has on the overall solution. The students improved not only within their specific concentrations and domains of expertise but also in the adjacent domains within the solution.

We believe this type of learning environment can be formalized and made available to a wider number of students. The participants in the project agree with this conclusion. The advising faculty received a request for the development of a similar solution enabling edge computing for IoT deployments monitoring environmental parameters. These new projects come with additional requirements on the enclosure (ruggedized versions) and the compute platform however, they build on top of the experience and data already developed during this project. The goal is to create a repository with the results of this and all subsequent projects and the ongoing test data to enable future teams of students to confidently develop solutions and to enable faculty to organize and manage such projects.

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