Critical Links

Reference Architecture:
Micro-Cloud for Education

Conquering the Digital Divide

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The Digital Divide in Education

The potential to create a better world through global learning initiatives has never been greater. All of the wisdom and knowledge ever created has been captured, digitized, and catalogued to allow young people to learn and grow faster than ever before. World leaders from both the government and technology sectors have rallied over the last decade to increase learning absorption through e-Learning initiatives that put this knowledge at the fingertips of youth everywhere in the world.

However, it's been proven that these efforts can only be optimized in countries with solid infrastructure and ubiquitous high-speed internet connectivity. Nowhere is the 'digital divide' more evident than in K-12 education, particularly in the emerging countries where infrastructure and connectivity are still precious resources. In many cases, the government entities have tried to enable the education, possibly with 3G or 4G – but even that connectivity struggles to provide a solid foundation for learning, as usage and demand has grown faster than connection speeds. Consider the case of 4G wireless in a country such as India. According to research published by Quartz, average 4G LTE speed is 5 – 6Mbps. While that might sound strong, consider that a single YouTube video in 720P can take almost 1.5Mbps; this means that three students attempting to better their learning with a video lesson can bring the entire school to its knees. In regions like this, even if tech giants donate equipment or ministries of education allocate significant funding, students are too often cut off from the cloud-based learning resources enjoyed in the more developed world due to lack of regular or robust connectivity, or other infrastructure limitations such as power outages and fluctuations. The result is frustration from the students, through the teachers, through the administration.

The ITU estimates that entering 2016, 3.2B people globally had internet access…yet 4B people in the developing world remained offline, representing 2/3 of the developing world. Specific to the education sector, the United Nations (a number of years ago) endorsed the holding of a World Summit on the Information Society ("WSIS") to explore what was required for countries and their citizens to participate in and benefit from, the 'digital revolution'. Global meetings were held and a process was put in place to monitor a set of ten related general 'targets', the second of which was defined as "Connect all secondary and primary schools with ICTs (Information and Communication Technologies)", measured relating to the "proportion of schools with Internet access, by type of access (broad vs. narrowband)". This is a key reference point to the question of internet technology penetration in schools worldwide.

The assessment, according to the report from the Partnership on Measuring ICT for Development and the International Telecommunication Union (ITU), is that, when it comes to schools, "while Internet access has been universally achieved in the majority of European and other OCED countries, Internet connectivity is lagging behind in most developing countries. It remains under 10 per cent in some countries from all developing regions, including Latin America and the Caribbean, Asia and Africa.... Analysis has shown that while countries may have some success in building a computer infrastructure, connecting these devices to the Internet may lag behind."

Further insight from the World Bank's "Final WSIS Targets Review" stated, "The indicator measures the extent of Internet access among schools, but does not measure the degree to which it is used for educational purposes, as many schools in developing countries reserve

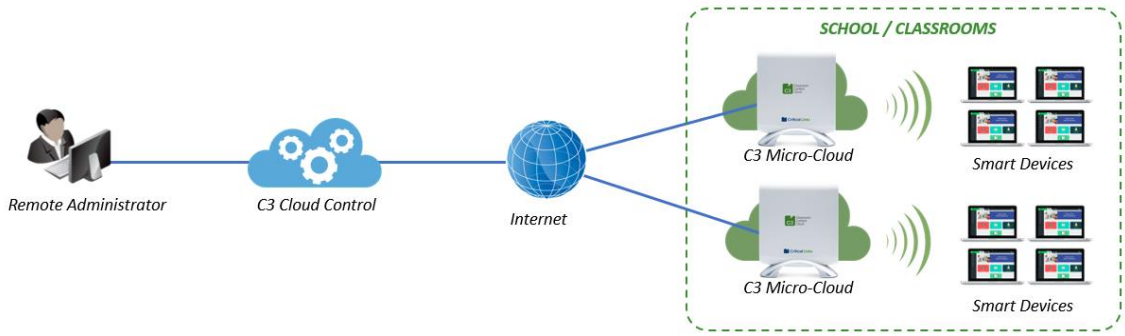
Internet for administration. Moreover, the indicators do not measure the quality or speed of Internet connectivity, which is known to vary significantly between countries."

Leveraging Technology to Address the Issue

To combat this global problem, industry leaders are driving an innovative new technology architecture that allows globalize learning on a local level, even in these infrastructure-challenged environments. Based on years of investment in cloud and distributed architecture development in the commercial world, a new topology known as the micro-cloud has emerged. This is seen in offerings such as Netflix's Open Connect appliances, Accelerator for YouTube, Content Repository Managers for the enterprise, and the emergence of hybrid IT in large enterprises. In this sector, the development is known as the micro-cloud learning environment, a completely self-contained but cloud-enabled e-Learning environment that allows students and teachers access to cloud-based learning management systems, curriculum, content, and resources – even when the school has no connectivity or power. With this innovative approach, the learning infrastructure, as well as the curriculum, content, and resources are staged on the micro-cloud platform in the school.

The challenge for educational institutions is that this type of hybrid/distributed architecture tends to require specialized IT knowledge and complex infrastructure in order to create a workable topology; schools and universities don't tend to have such depth in IT staffing and budget. However, a new approach to micro-cloud now allows all the required services to be integrated into a single plug-and-play micro-cloud appliance, allowing any school to benefit from this architecture, allowing teachers and students greater access to digital knowledge.

Into this micro-cloud architecture, students connect on a local WiFi that appears to be an internet connection, hence the ability to use a cloud-based e-Learning paradigm even while sitting on a dirt floor in a school without power. Since not only are the learning management system, content, but valuable incremental resources (such as YouTube videos, simulators, interactive maps, Wikipedia content, etc.) are housed locally in the micro-cloud. In this scenario, students progress through the learning process without knowing (or needing to know) if there's actual internet connectivity to the school at any point in time.



Most importantly, with the micro-cloud architecture, hundreds or even thousands of micro-clouds throughout the region/country can be managed and administered from a single, centralized point. The administration or Ministry of Education can curate uniform curriculum

and content, which is then populated to the micro-clouds whenever a sporadic connection becomes available.

The impact is just as great – or greater – on teachers worldwide. A massive percentage of committed educators globally simply lack the resources to become educated on the latest teaching paradigms, methods, and curriculum. The micro-cloud delivers to a school administrator or teacher in an urban or remote area – who may have never left their village - the chance to leverage state-of-the-art LMS technology and student/class management tools, right at their desks.

Technology Components of a Micro-Cloud Architecture

A micro-cloud implementation spans three distinct levels of a distributed architecture. These are the centralized cloud console, the micro-cloud instance(s), and the intelligent devices.

Centralized Cloud Console

The core of a micro-cloud deployment is the centralized cloud console. This is a control point resident in either a public or private cloud which serves as a single, consolidated place for both content (curation, management, distribution) and systems management (both user and device levels).

The Centralized Cloud Console should have a repository function to house the resources of the pedagogical process, such as educational texts and content, structured learning plans, and adjunct educational material such as articles, videos, etc. Once this content has been loaded into the cloud repository, policy can allow it to be automatically distributed to authorized micro-cloud instances. If a network connection to any given micro-cloud is not available, the update process will occur upon the next connection. Through this process, a standardized approach to education can be applied to ensure base-level compliance with the directives of the governing body for education.

In a similar manner to content, systems-level management such as Active Directory GPOs or device updates, can be applied and distributed from a single point. Through this concept, standardization and compliance be assured even across a vast geographical area. Further, this can bring a massive savings on network bandwidth resource. Consider a school with 400 students that need to update their devices; rather than 400 discrete downloads, the update package can go one time to the local micro-cloud instance, and from that point be applied to any student that connects to the micro-cloud in that environment.

A viable micro-cloud environment should have at its foundation this capability of a cloud-based portal to allow centralized administration to set curriculum, content, and policy, and have that automatically updated to every/any individual micro-cloud in a school whenever an intermittent network connection is available. In truly ‘offline’ environments, this may be achieved via a USB key approach, although the increasing prevalence of 4G cellular technology worldwide can also fill this role.

Micro-Cloud Instance

In order for the micro-cloud architectural concept to work in practice, there needs to be a point of presence in each classroom (or school, depending upon the architecture) that meets minimum requirements to enable this approach. Normally found in the form of a server or

appliance footprint, a micro-cloud instance has a number of required functional components/features, which are outlined below.

Localized Wi-Fi capability

The power of the micro-cloud lies in its ability to present the learning environment locally to the students. To accomplish this, the students must be able to simply and easily connect their devices to the micro-cloud resources wirelessly. Different micro-cloud platforms have varying scale in terms of number of active concurrent students supported; hence some are more appropriate at the classroom level, and others at an entire school level. All, however, require WiFi access point capability.

Localized LMS Hosting

Once students are connected to the micro-cloud, the learning process should be guided by a Learning Management System (LMS) that manages a defined curriculum, assessment, and progress to plan. This helps both the students and teachers in their respective roles in the learning process, and is driven by the cached content.

Structured Content Caching

When a curriculum is determined, it normally includes structured content such as texts, exercises, and other resources. The content should be stored locally (cached) in the micro-cloud, and accessed by the students as they progress through the learning process. In the event of a network outage or limited bandwidth resource, the localized caching function ensures the learning process continues without impact to the students.

Unstructured Resource Caching

While structured content to follow the curriculum is mandatory, educators embracing the experience are finding that adjunct unstructured resources can significantly enhance learning, knowledge uptake, and motivation during the learning process. In some cases, unstructured resources such as YouTube videos, Simulators, Interactive Maps, Wikipedia, etc. become as integral to the learning process as the basic curriculum texts themselves. Normally, these are selected either by the local teacher, or by the curriculum management administrators that are accessing the Centralized Cloud Console. As with the structured content, approved unstructured resources should be stored locally on the micro-cloud, as well, to facilitate full-spectrum learning regardless of infrastructure limitations.

Network Resource Management

Particularly in these regions, internet connectivity is a valuable resource, and great care must be taken to ensure maximum usage and minimal exploitation. To ensure maximum throughput per policies, the micro-cloud controls who can access internet resources, and what can be accessed based upon user profile. In addition, bandwidth is optimized by caching web pages as they are accessed, making the next 'visit' to the site free of upstream bandwidth usage. Inside a classroom, when all students go to the same website at internet (once it is cached) they have a feeling that Internet speed is faster, but this is because micro-cloud delivers the content from local cache without using network bandwidth, improving overall user experience. School administrators can easily define permissions and have tight control of what is allowed over Internet, ensuring network usage is focused on education usage while also protecting students from viewing inappropriate content.

Enterprise Infrastructure Integration

Security, compliance, and standardization are crucial in most country/region-wide rollouts of technology. The micro-cloud is a technology resource normally deployed by the schools/governments, so the platforms chosen should accommodate integration with existing management and control paradigms required to facilitate its use. Security, management, and networking foundations such as Active Directory and/or LDAP authentication capabilities, single-sign-on support, and policy-based management will be required for a wide rollout of the micro-cloud technology throughout a region or country.

Access by Smart Devices

The paradigm can be leveraged by a number of student device implementations, from smartphones to PCs to Chromebooks. The keys are that the student devices have WiFi capability (to attach to the local micro-cloud instance, normally via browser access), and that they fit into the centralized management schema (to meet audit, compliance, security objectives). It's not mandatory, but highly preferable, that they have local processing capability (i.e. the potential to run apps or applications).

With these devices, students will interact with the curriculum, the content – and their teachers. The intelligent device – once enabled by the rest of the functional micro-cloud architecture – becomes the student's point to access knowledge, interact with educators, and have his/her progress tracked real-time as a part of a broader view of how well the curriculum and pedagogical process is working across the region.

Reference Architecture Principles

When building a micro-cloud architecture for a country/region, it's important to remember to have key points of the architecture established properly. This section highlights a number of the key areas of consideration.

Operating environment summary

The topology referenced herein is a 'hub and spoke' model, whereby the network of geographically distributed micro-cloud instances is all accessing one common centralized cloud console. The key points of the reference architecture herein are:

1. Optional Centralized Cloud Console: Cloud console application running on a cloud-resident (i.e. Azure) virtual machine with attached disks
2. Extension of the central cloud console to the distributed locations
    a. Micro-cloud instance at the school level, or
    b. Micro-cloud instance at the classroom level
3. Network configuration
    a. Virtual Private Network connectivity
        i. Point-to-site, or
        ii. discreet Site-to-site
    b. (optional) SSL connectivity
4. Integration with organizational Active Directory domain structure

Configuring the Centralized Cloud Console

The ideal place to house the centralized cloud console is a secure, well-managed cloud environment that is always accessible by any micro-cloud instance, such as the Microsoft Azure cloud environment. The console could be hosted on a standard Azure VM such as the B2MS.

Storage resource (in this case, Azure Disks) would be attached to the virtual machine with sufficient capacity to house the required content, materials, and other management information.

When using the C3 Cloud Console as the centralized console for the micro-cloud implementation, it should be configured under Microsoft Azure dedicated VMs. Depending on the size of the project, different instances from the BxMS instance type can be selected (all of them run Ubuntu):

- Smaller deployments (up to 500 simultaneous C3 devices) (approx. $57.30/month)
  - B2MS: 2 Cores; 8GB of RAM; 16 GB temporary storage
  - 256GB Standard HDD + 200GB Snapshot
- Medium deployments (up to 1000 C3 devices) (approx. $113.68/mo)
  - B4MS: 4 cores; 16GB RAM; 32GB temporary storage
  - 512GB Standard HDD + 400GB Snapshot
- Large deployments (more than 1000 simultaneous devices) (approx. $224.82/mo)
  - B8MS: 8 cores; 32GB RAM; 64GB temporary storage
  - 1024GB Standard HDD + 800GB Snapshot

There are variables that optimal sizing depends upon, including:

- Number of simultaneous devices connected at the same time
- Size of uploaded content
- Update frequency

Based upon these variables, the VM characteristics can be optimized, namely, the amount of storage and snapshot, or the VM tier, which might help bring costs down.

It is recommended to employ an automated backup process, such as Azure Backup, to ensure that the environment is protected on a regularly-scheduled basis.

Active Directory Integration

A micro-cloud instance is, by itself, a full-fledged Active Directory server. Being an Active Directory Server, the micro-cloud can provide, among others, authentication, authorization and policy enforcement to supported client devices. At the same time, it can be integrated in a distributed Active Directory Forest.

Stand-Alone Active Directory Server

In this mode, the micro-cloud works in the default mode, which means that it presents itself to client devices as an Active Directory Server.

Master-Slave mode

In this mode, it's assumed that there is a Master micro-cloud that assumes the role of a coordination server. What this implies is that it's expected that major operations are performed on the Master Server, like user creation and policy application, and those changes then get propagated to all the remote, or slave, micro-clouds. This implies a VPN connection between the slave micro-clouds and the Master. Due to the nature of a micro-cloud, it's expected that the

VPN connection be as simple and automatic as possible to remove any possible complications for the set-up.

If a slave micro-cloud fails to communicate with the Master server, it should not pose a problem and clients shall be able to access the slave micro-cloud without any problem. In this regard, when the slave micro-cloud re-establishes the connection, all pending changes shall automatically be applied.

Windows Server Active Directory Mode

A micro-cloud shall also be capable of integrating with a Windows Server acting as the Master for an Active Directory environment. The scenario is the same one as the Master-Slave mode, where the Master micro-cloud is replaced by a Windows Server. Particular attention must be taken to the Active Directory version that is running on the Windows Server. In order to ensure full combability with the micro-cloud, the Active Directory Functional Level shall be at least Windows 2008 R2.

At the same time, a VPN software must be installed in the Windows Server in order to fully emulate the Master-Slave mode scenario.

Azure Active Directory Mode

The final Active Directory integration mode for the micro-cloud is with Azure Active Directory (AAD). Due to the way AAD is implemented, the micro-cloud cannot integrate directly with it. In order to overcome this problem, a Windows Server must be used to work as a bridge between the several micro-clouds and the AAD. In this case, the integration mode is the same as the Windows Server Active Directory Mode. Then, to integrate with AAD, an application called Azure AD Connect must be installed on the Windows Server and integrated with the AAD Domain. In this integration, all the users must be created on the Windows Server. They will be automatically replicated to the micro-clouds and to the AAD. Depending on the license, user passwords can be changed directly on the AAD Administration interface, and they will be automatically synchronized to the micro-clouds.

Local Micro-Cloud Instance Considerations

In case of school deployment, the local micro-cloud should be located in a protected, low-traffic environment (not in the open and subject to student interaction), yet doesn't require special housing or cooling. It should have proximity to a power source and be located in a dry area.

If the micro-cloud instance is covering a single classroom (the most common configuration), it can be mounted in the wall or can sit in the teachers table. In the absence of a reliable power supply at the classroom, the micro-cloud should have a battery pack to hold the device on during school period. The WiFi range isn't likely an issue considering a single classroom. If, however, the micro-cloud instance will be responsible to service more than one classroom, careful consideration should be given to the coverage requirement of the access point in relation to where users will be located. Factors include distance, wall/structures, and other sources of metallic and electrical interference.

The Future

World leaders have aligned on the understanding that a powerful key to a building a better world is through the ability to drive globalized learning at a local level. The micro-cloud – proven for years in commercial and enterprise settings - is the result of the technology and education

sectors joining forces to determine how this global learning can happen in the face of a very real digital divide for the emerging/developing nations. The exploitation of this type of technical approach is projected to continue, as the requirements for global education escalate and require greater access to vast resources on a real-time basis.

Critical Links is a pioneer in delivering innovative e-learning infrastructure for the next generation of schools, especially in challenging environments. Nowhere is the 'digital divide' more evident than in education, particularly in emerging countries where infrastructure and connectivity are still precious resources. In these regions, even if students have access to PCs and tablets, they are too often cut off from the internet and cloud-based learning resources enjoyed by the more developed world due to lack of regular or robust connectivity, or other infrastructure limitations such as power outages and fluctuations.

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