Delivering EDU digital content to the Unconnected

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1 INTRODUCTION

Popular online platforms such as Zoom, Google Meet, and Google Classroom enable distance learning but require continuous Internet access. Self-hosted solutions, such as BigBlueButton[1], can operate on a local network but still require strong connectivity to the server, making them unsuitable for intermittent Internet connections. With the increasing disparity between connected and unconnected, which is happening at alarming rates, especially after the COVID-19 pandemic, we are prompted to urgently seek a remedy for the situation.

In this poster, we describe a design of a content delivery network (CDN) for educational (EDU) content to bridge the digital gap and provide unconnected communities with the ability to access and exchange learning materials in a remote classroom-like environment. The system integrates available technologies such as Unmanned Aerial Vehicles (UAVs), Wi-Fi mesh routers, mobile devices, and distributed micro data centers. A small server (e.g. Raspberry Pi) attached to a UAV can carry lesson materials from EDU providers to isolated villages and fetch completed homework or notes from remote sites and classes. Content is pushed to edge data centers in remote villages and vice versa using the Bundle Protocol (BP) [2], forming a Delay-tolerant network (DTN) [3]. The local community wireless mesh network (CWMN) in each village can further extend content access to local members. The local DNS is configured to direct all web access to the web server in the local micro data center as if they were using the Internet. Device-to-Device (D2D) communication also enables peer-to-peer sharing between mobile devices and extends coverage beyond the mesh.

2 SYSTEM ARCHITECTURE

Since 2013, we have adapted our earlier work on emergency disaster mitigation network DUMBO[6], based on the OLSR protocol, to a community network setting called TakNet[5]; these networks are still in operation today. More recently, we proposed leveraging mobile devices D2D communication [7] for content delivery among members of a community to enable communities without stable Internet connections to share content or to offload the need to consume the Internet or expensive mobile bandwidth. In these remote areas, even today, the concept of preloading EDU content remains of utmost importance, as when network conditions are unreliable, interrupted transmission can be disruptive for learning experiences; preloading can vastly make a difference.

As early as 2014, our project proposed pushing EDU content on a 10M link and dispersing it to thumb drives attached to our DUMBO mobile routers in the network [11] Afterward, learners can view the video content from their nearest DUMBO routers. Technically, the proposed scheme worked perfectly well; however, with limited non-copyright content available online at that time, the idea was somewhat left without further development.

As shown in Fig.1, we propose an EDU content delivery network (CDN) with UAVs carrying content to unconnected communities that are difficult to reach by foot. UAVs provide the last meter connectivity for content from content creators on the Internet to be pushed to the network edge. The micro data centers host web servers at the network edge, allowing the local community to access the content seamlessly while keeping submitted homework/notes from the students uploaded to the mules during the UAV's next visit. Once the UAV is back on the Internet, these responses can be forwarded to the content providers.

The proposed architecture can be divided into three main groups: content creators, EDU delivery on DTN, and content access and distribution.

2.1 Content Creator

Content creators upload their materials to an educational cloud platform called VClass+, which serves as a central repository accessible to learners across the Internet. Within this platform, teachers can create lessons, prepare and upload course materials, multimedia resources, and homework assignments, as well as collect homework submissions. These EDU contents can also be pre-downloaded from the Internet and fed into the EDU bundle, ready to be pushed to the edge server. Content creators can be anywhere on the Internet, and the uploaded content can be fetched and forwarded by the DTN to a server on the UAV.

2.2 EDU Delivery on DTN

To reach remote villages in difficult terrain, the UAV provides a very attractive solution. An aerial node, which is a lightweight embedded system (e.g., Raspberry Pi with large storage) attached to a UAV, functions as a UAV-based DTN data mule. Operating on a fixed or programmable flight path, the UAV routinely travels between a headquarter, i.e. Internet-connected locations and multiple remote villages.

The UAV and micro data centers form a DTN[3], designed for environments with intermittent connectivity, high latency and limited bandwidth. Using protocols such as the Bundle Protocol (BP) and Epidemic Routing, DTNs have supported communications in space missions, disaster recovery, and rural networks. Data mule or data ferry systems rely on mobile agents (humans, vehicles, or UAVs) to physically transport data between disconnected locations. UAV as data mules offer high mobility and flexibility for covering large areas with minimal infrastructure. UAV equipped with storage devices have been deployed in lightweight DTN applications [8][9][10].

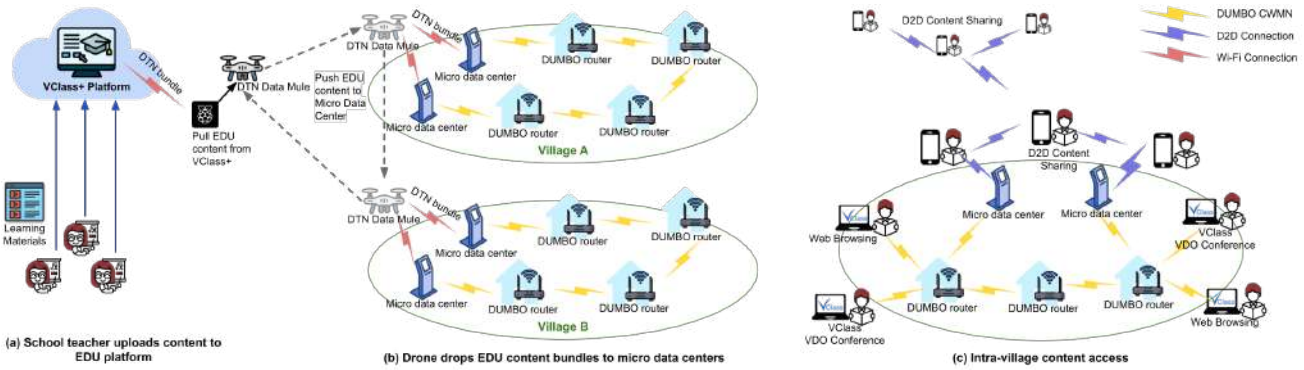


Figure 1: System Overview

In our proposed system, the UAV can deliver bundles of EDU content to multiple micro data centers in the village and fetch the returning bundles from them. As shown in Figure 1(a), when connected to the Internet, the UAV can synchronize with the VClass+ platform and pull bundles of EDU resources prepared by the teachers. It can then fly along its designated route and visit each village in sequence to deliver these materials.

At each village stop, as shown in Figure 1(b), the UAV hovers or lands near a micro data center and by using Wi-Fi communication, it pushes bundles of new content to nearby micro data centers and collects homework submissions, messages, and other locally generated data from the ground servers in the micro data centers. Our preliminary tests with Wi-Fi 802.11n showed that the UAV maintained a transfer rate of 11 Mbps to a ground node while hovering at 30 m, equivalent to about 80 MB per minute. This throughput falls within the range reported in other studies, from 2.8 Mbps [9] to 68 Mbps [8]. These results demonstrate the feasibility of using UAV to deliver EDU content in disconnected environments.

After completing its route, the UAV returns to the headquarters, where it uploads the collected data for the teachers to review and grade. This cycle enables daily educational interactions despite the lack of continuous Internet connectivity.

2.3 Content Access and Distribution

In each village, the ground infrastructure consists of micro data centers, CWMNs, and user devices. Micro data centers are edge CDN nodes that provide local access to EDU content. These are one or more small servers with large storage capacity, Wi-Fi, D2D communication, and a relatively stable electricity supply, deployed in village central or high-accessibility locations. These fixed stations host web servers that act as local content libraries, where users can upload and download educational videos, homework assignments, and messages. The servers in the same network can check among themselves for missing data and exchange bundles as needed to ensure that their content is complete and ready to provide services. Wi-Fi mesh routers running DUMBO with OLSR form a CWMN backbone that connects micro data centers, homes, and user devices for village-wide access via multi-hop routing. The network is self-configuring and self-healing, maintaining service continuity even if individual routers fail. User devices (smartphones and tablets) can connect to micro data centers via D2D or CWMN. They also function as mobile caches, sharing content through D2D communication and extending access beyond mesh coverage [7].

By combining CWMN and D2D capabilities, our proposed system enables digital EDU (web, streaming, VDO conferencing) in communities without Internet or cellular coverage. As shown in Figure 1(c), the system provides three modes of EDU service.

First, learners can access cached websites on local web servers hosted at micro data centers instead of the Internet. With local DNS setup in the CWMN, users are transparently connected to the web servers, allowing them to access the site, fill in forms, or create notes as if they were on the Internet. Their feedback is stored on the server, picked up and carried by the UAV, and automatically uploaded to the Internet once the UAV regains connectivity, allowing the responses to be forwarded to the content creators.

Second, learners can access and share educational video content through D2D connections with nearby devices. User devices are assumed to have D2D capabilities such as Wi-Fi Direct. When the CWMN is unavailable, devices can still connect directly to micro data centers via D2D links. Passive content, such as video clips, can be downloaded to personal devices for subsequent access. These contents can be fetched from the micro data center and shared among peer devices using opportunistic D2D connectivity.

Third, the system supports video conferencing through the VClass application [4], which is hosted at the micro data center, enabling group discussions and a classroom-style learning environment within a village. This provides learners with opportunities for collaborative learning without Internet connectivity.

3 CONCLUSION

This poster presents an architecture for delivering interactive e-learning to regions without reliable Internet connections by combining UAV-based DTN data transport, micro data centers, CWMN with OLSR routing, and D2D communication. It supports two-way interaction between teachers and learners despite long disconnections, ensuring that learners in remote villages can actively participate in education. Future work will integrate NDN to improve content access, include IoT sensors with machine learning for environment monitoring, expand to other services such as healthcare or disaster relief operations, and integrate renewable energy for micro data centers and UAV charging to improve sustainability.

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