

The Virtual Classroom: a Worldwide Wireless Internet Collaborative Experimental Environment

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This paper presents the design and current status of the interactive Virtual Classroom project. A prototype is currently in development at SJSU to implement and test equipment, software and processes for extending the classroom and experimental teams to remote sites via wireless internet. The intent of the center is to demonstrate and develop systems that can be implemented for outreach programs to provide the students immersed education by taking the classroom to the experimental site. The interactive IP network supports experiments such as, robot tele-presence, multi-sensor observatories, real time computational fluid dynamic, structural and thermal analyses for vehicles and payloads such as micro-satellites, high altitude balloons and rockets. The system deployed allows for worldwide collaboration and virtual access to remote experimental facilities and modeling laboratories. The collaborative services provided include

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video/audio, links between experiment areas and experimenters, archive capabilities and broadcast of two-way video and audio, instant messaging.

Nomenclature

- 3G = 3rd Generation cellular service
- 802.11g = IEEE wireless network standard at 2.4 GHz
- 802.11a = IEEE wireless network standard at 5 GHz
- APRS = *Automatic Position Reporting System* amateur radio standard for datagram telemetry
- IP = Internet Protocol
- GHz = Gigahertz
- LEO = Low Earth Orbit
- Mbps = Megabits per second

I. Introduction

THE Virtual Classroom is a network system to provide a distributed, near real-time electronic collaborative environment that allows video, audio, data and sensor participation by a worldwide set of participants in experiments undertaken in physically remote locations. These locations, due to cost, accessibility, safety or other concerns often do not permit communities to participate at the location. For example, all of the student members of a robotic satellite team may not be able to be at the launch and recovery site. The Virtual Classroom permits all members of these teams to view and participate in these experiments with many of the tools that on-site experimenters have and might well bring access to remote analysis tools that are impractical to bring

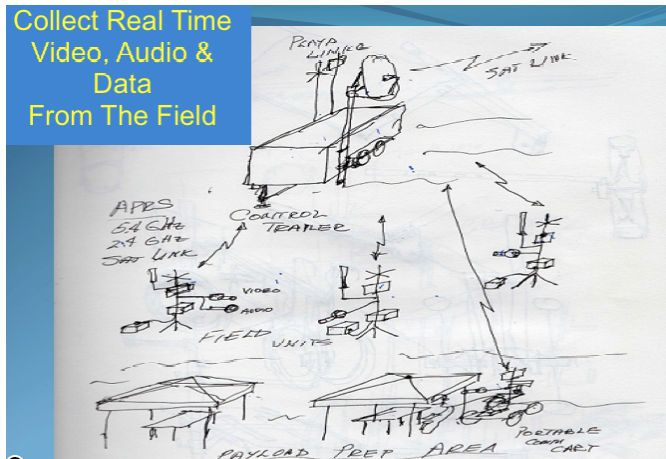


Figure 1. Real time network integrates video, audio and data to/from remote experiments.

to the remote site.

The Virtual Classroom is an integrated system of modern wireless networks that distribute video, audio, data and text within a remote experimental area and provides for the interconnection to remote participants in classrooms or indeed any worldwide location with a broadband Internet connection.

II. Design

The Virtual Classroom is a systems integration of a number of architectural

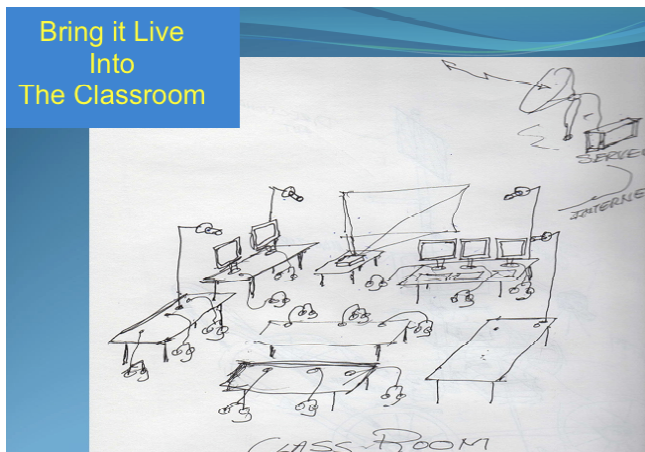


Figure 2. Internet permits near real-time collaboration with full video, audio, data and sensors information.

elements. The two principal components are first, a real-time IP network backbone that provides a high capacity (multi Mbps), standard IP communications network interconnecting experiments and experimenters worldwide, and second, a set of network and processing elements for the dissemination, storage and analysis of video, audio, and data from the experiments.

With modern wireless IP network equipment, the Virtual Classroom can cover an

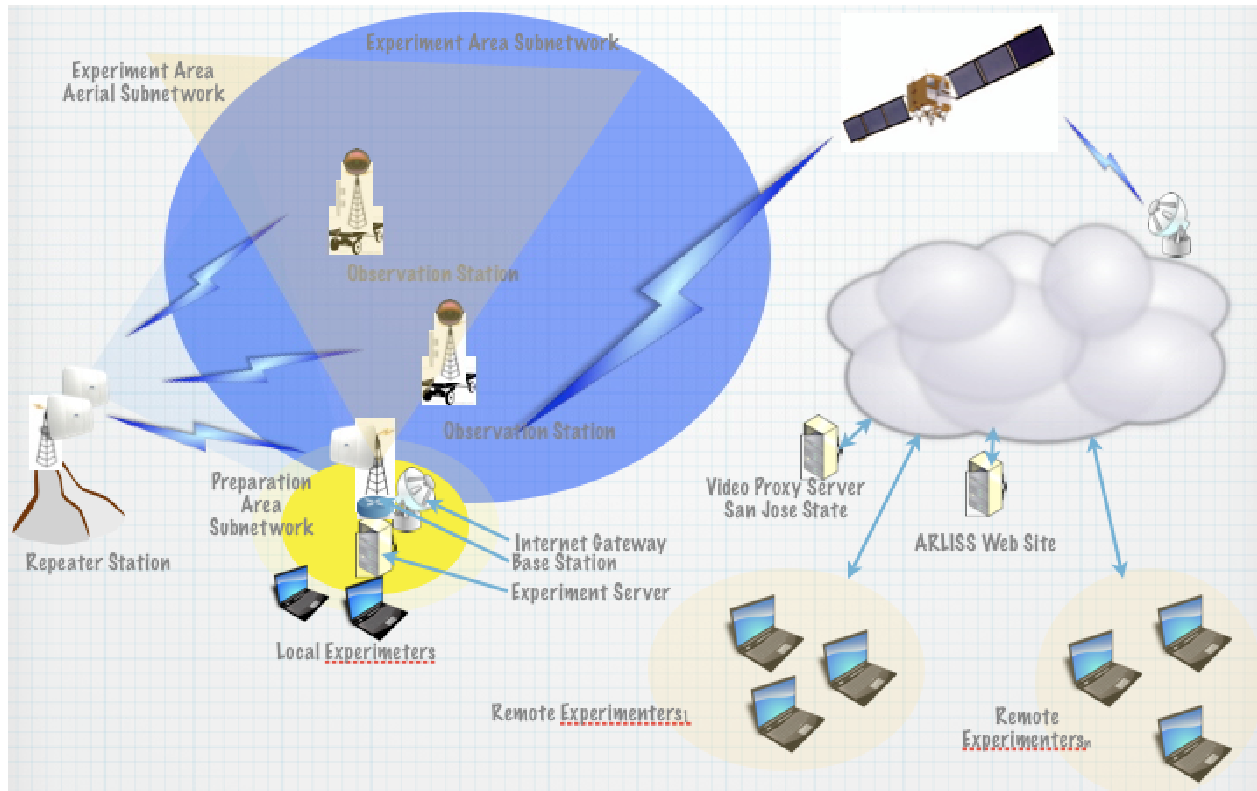


Figure 3. Virtual Classroom Architecture.

experimental area of up to two hundred and fifty square kilometers with multi Mbps service and then interconnect to the entire Internet.

A. Real-time IP Network

1. Internet Backbone Network

The remote experimental site(s) each need to be connected back to the worldwide Internet with a broadband connection. The Virtual Classroom network has been designed to accommodate a variety of Internet connections based on availability, cost and location.

The prototype uses a new generation all IP small aperture (1.2m) portable VSAT that delivers an on-demand, low latency IP service of approximately .6 Mbps uplink and 2 Mbps downlink at an affordable cost. This capacity is sufficient for several simultaneous, high quality bidirectional MPEG4 video streams as well as real-time telemetry, teleconferencing, robot telepresence and general support for other IP based applications such as web access and email.

The VSAT, however, does not easily support mobile operations for such experiments as balloon payload communications that might cover a geographic area far in excess of a Virtual Classroom network footprint. For such an application, an IP gateway to the 3G cellular network will be more appropriate – permitting mobile communications wherever the cellular network extends though at the penalty of a 50% decrease in Internet capacity.

The Virtual Classroom can take advantage of higher capacity wired Internet backbone connections in experiment locations where such a connection is available.

2. Experimental Area Backbone Network

The core service of the Virtual Classroom network is a high performance IEEE 802.11 wireless network. The user network is an 802.11g network at 2.4 GHz defined by digital repeaters selectively mounted on nearby hills to illuminate the experimental area with 802.11g service. The repeaters are interconnected via a 5.8 GHz IEEE 802.11a backbone subnetwork to the VC Base Station.

The prototype uses a 10 kilometer long 5.8 GHz link from the Virtual Classroom Base Station to a single repeater and consistently delivers 18-20 Mbps of user throughput with an average of a 48 Mbps modulation rate. The repeater includes an IEEE 802.11g access point to illuminate the experimental area and delivers 18-20 Mbps of user throughput across 65 km² of experimental area. Slight improvements to the antenna of the prototype Mobile Cart would likely increase the area covered by almost 2x.

3. Experimental Area Network(s)

The Virtual Classroom offers two types of experimental area networks for use in experiments: a 2.4 GHz 802.11g network and an APRS telemetry network on both the 70 cm and 2 m amateur radio bands.

The 2.4 GHz IEEE 802.11g network is designed to support experiments and sensors both on the ground (over 65 km² of area) and overhead (up to 10 kilometers altitude) at throughput sufficient for real-time MPEG4 video. The 70 cm and 2m APRS telemetry network is designed to communicate location, weather and sensor telemetry embedded in aerial payloads (rockets, prototype satellites and balloons) to altitudes of over 20 miles. APRS standard protocols are used on dedicated frequencies to increase the telemetry capacity of the network.

Both networks are interconnected back via the Virtual Classroom Base Station to the Internet backbone. The modest traffic levels of the APRS telemetry subnetwork allows all traffic from these networks to be both stored at the Base Station's servers as well as forwarded to the APRS-IS Internet servers.

The Virtual Classroom experiment area IEEE 802.11 network has a much higher aggregate capacity than the backbone Internet link, so locally generated traffic, particularly video, is stored locally at the Virtual Classroom Base Station server and selectively streamed to the Internet. Traffic shaping capability of the base station permits selective transmission of real-time IP traffic as well as control of bandwidth intensive media traffic.

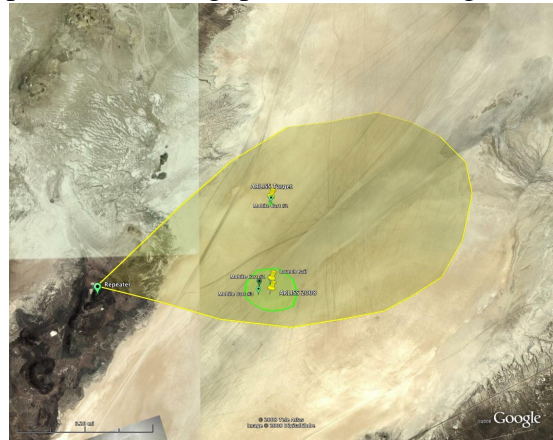


Figure 4. IEEE 802.11g wireless network covers over 65 km².

B. System Components

The Virtual Classroom system is composed of six key elements.

4. *Virtual Classroom Base Station*

The Virtual Classroom Base Station is the principal integration point for the system. It is implemented in a small, compact car pullable trailer both for simplicity of deployment and transport and for environmental robustness. It provides universal power (battery, solar panels, and generator) for all systems and is the platform for antennas used for the Virtual Classroom wireless network. It provides the following functions:

Internet connection. The Base Station includes backbone Internet connection(s), specifically including the VSAT, associated electronics and the traffic shaping router. Alternative Internet connections are provided for.

Video/audio server. An industry standard computer hosts a video and audio server capable of both recording and storing multiple MPEG4 video streams from multiple Mobile Carts, but also providing for restreaming of a selected video feed to the Internet.

Conferencing server. The Base Station server hosts a conferencing server for conferences among experimenters at the remote site as well as across the Internet.

Telemetry gateway/server. The Base Station contains the antennas and radios for multiple channels of 70 cm and 2 m APRS telemetry service. Telemetry and location data are both locally stored and forwarded to the global APRS-IS service for redistribution to the Internet. Global users can retrieve APRS-IS stored data for near real-time location plotting in Google Earth. Both systems use circularly polarized antennas specifically designed for overhead coverage of experiments and providing the basis for a LEOsatellite communications capability.

System management. The Base Station is designed for headless operation through remote network connected computers.

Repeater Connection. The Base Station includes one (or more) 5.8 GHz links to surrounding repeaters that define the experiment area network. This white panel can be seen mounted in Fig. 5.

Preparation Area Network. AIEEE 802.11g high power (26 dBm TX, 9 dBi antenna gain, -95 dBm RX sensitivity) access point is configured on the Base Station to extend the experiment wireless network providing laptop wireless access within 1 km of the Base Station. It is anticipated that this network will be used for experiment preparation and evaluation.



Figure 5. Base Station with APRS 70cm and 2m, 802.11a Backbone Panel and 802.11g Local Antennas.

Overhead Network. A high power 802.11g access point is configured on the Base Station with a circularly polarized panel antenna specifically designed for overhead coverage. We anticipate overhead multi Mbps 802.11g coverage up to 10 kilometers and likely higher with anticipated enhancements.

5. Network Repeaters

One important key to good wireless network coverage is taking appropriate advantage of geographic height. The Virtual Classroom uses local features (hills, buildings) as locations to mount a repeater station to link the Base Station to user stations in the experiment area. Our prototype uses a new generation of inexpensive, integrated, high performance IEEE 802.11a access points to connect the Base Station to the repeater over distances of tens of kilometers. The high transmit power (26 dBm), high antenna gain (22dBi), high receiver sensitivity (better than -95 dBm) and wide beamwidth (effectively 20 degrees) permits both high performance and simple field configuration.

These 802.11a backbone access points are then bridged to one or more IEEE 802.11g access points to provide experiment area network coverage. Multiple access points can be configured to either increase coverage area or increase capacity. The new generation of IEEE 802.11g access points permits high transmit power (26 dBm), high antenna gain (18 dBi), high receiver sensitivity (better than -95 dBm) and wide beamwidth (effectively 30 degrees) permits high performance, and a large coverage area (over 65 km² per 802.11g access point).

The repeater is independently powered (battery and solar panels) and environmentally robust.

6. Mobile Carts

The Virtual Classroom instruments the experiment area with Mobile Carts that provide an independent sensor platform to observe and document experiments. Each Mobile Cart provides for

- independent power (battery and solar panels),
- wireless IEEE 802.11g communications via the experiment area network to the Base Station, other stations in the experiment and the Internet, and
- remotely (from the Base Station) controlled (pan, tilt, zoom) MPEG4 video/audio cameras.

The Mobile Cart video/audio is stored in real-time at the Base Station and selectively streamed to the Internet.

The prototype has four Mobile Carts.

The Mobile Carts are stored in the Base Station trailer for



Figure 6. Repeater Illuminating 65 km² of the Black Rock Desert.



Figure 7. Mobile Cart with Radio, PTZ Video Camera and Power.

transport.

7. Experiments

Experiments can take advantage of any or none of the network services of the Virtual Classroom.

The IEEE 802.11g network can be used by an experiment throughout the coverage volume of the network. A number of alternative high performance 802.11g network interfaces are available to be embedded within experiments and deliver multi Mbps network service with proven capability at speeds up to several hundred kilometers per hour. Balloons, rockets, prototype satellites, remote robots can all benefit from high bandwidth network communications.

Compact network interfaces for both the 70 cm and 2m APRS networks can be embedded inside experiments. The APRS protocol provides for standard location, sensor telemetry and low bandwidth messaging for these experiments. While narrowband, APRS has the proven advantage of demonstrated LEO communications capability.

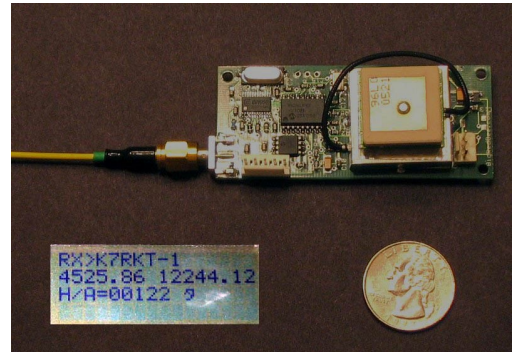


Figure 8. 70 cm APRS GPS location and telemetry transmitter.

8. Internet Hosts

The Virtual Classroom makes use of Internet hosted services to widely disseminate data from a remote experimental location. The use of these Internet services minimizes load on the limited bandwidth capacity of the Virtual Classroom Internet VSAT connection and maximizes use of wideband wired Internet services. The Virtual Classroom streams to the Internet services, which in turn stream to the much larger community of Internet experimenters.

Video/audio. Streaming video from the Mobile Carts, documenting experiments, is streamed to the Base Station for local storage. The Base Station selectively streams a subset of this video to an Internet based server at SJSU for distribution to Internet based experimenters.

Chat. The Virtual Classroom interfaces to open source chat services enabling bidirectional, multimedia chat conversations between experimenters at the remote location and distributed across the Internet.

APRS Telemetry. The Virtual Classroom forwards all APRS telemetry traffic to the amateur radio maintained APRS-IS. From several Internet based servers (findu.com, aprs.fi and others) Internet based experimenters have HTTP access to weather, telemetry and location information from the Virtual Classroom experiments.

Email. Access to standard email services are provided to remote experimenters.

Web access. Access to standard web sites are provided to remote experimenters.

Other TCP-IP. Pass through for extended IP communication services is provided in real-time for experiments to/from the Internet. It is anticipated that this will be a fertile experimental area for robotic telepresence experiments.

The Virtual Classroom Base station controls allocation of the limited Internet bandwidth among these applications and provides traffic shaping to prioritize traffic.

9. Experimenters

Remote and local experimenters have access to the complete video, audio, data and telemetry data streams via industry standard protocols on multivendor personal computer platforms.

III. Applications

The first application of the Virtual Classroom is in support of student satellite programs launched by amateur rockets at the Black Rock Desert in northwest Nevada.

C. ARLISS

The first operational deployment of the Virtual Classroom is for the ARLISS^{§§} 2008 event in September 2008 at Black Rock, Nevada. ARLISS has a ten year history of delivering over 200 student satellite payloads to 3 miles altitude for recovery in harsh desert conditions.

The Virtual Classroom will provide real-time video, audio, chat and telemetry support for both payloads and airframes. An example of a Google Earth plot of several airframe tracks using 70 cm APRS location tracking is shown in Fig. 9.

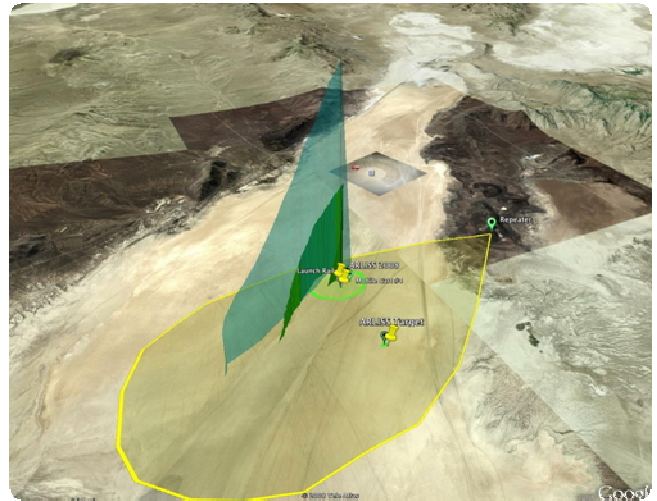


Figure 9. Near real-time APRS rocket tracking via APRS-IS and Google Earth.

D. Balloon Flights

2m APRS services have often been used to track and support high altitude near earth balloon experiments. The Virtual Classroom supports these services but adds high bandwidth IEEE 802.11g services that potentially can extend to the altitudes these balloons achieve.

The Virtual Classroom can provide real-time forwarding of these experiments to the Internet and real-time access from remote experimenters to these experiments.

E. Robot Tele-Presence

Robots increasingly benefit from high bandwidth communications. The ability to communicate permits experimentation with varying degrees of autonomy and with algorithms that can later be moved to the robotic platform while being developed in a more computationally friendly remote environment. The Virtual Classroom is expected to be a strong asset for such robotic experiments.

IV. Future Opportunities

The Virtual Classroom provides a powerful platform for the support of experiments and education that is not limited to the physical classroom.

A. Platform Improvements

The prototype Virtual Classroom has demonstrated the potential of the concept and exposes key opportunities for improvements in the basic platform.

^{§§} A Rocket Launch for International Student Satellites, www.arliss.org

- Increased performance.* The IEEE 802.11 family of standards on which the Virtual Classroom is based is an evolving standard. The latest standard IEEE 802.11n promises to increase throughput performance by a factor of 2.
- Increased coverage.* More repeaters and more access points can be used to increase the coverage area.
- Power independence.* Upgrade Mobile Carts with solar panels to be completely power self-sufficient.
- LEO communications.* 2m and 70cm APRS has the proven capability for the support of LEO satellite communications. The Virtual Classroom has the harder capability to support this service and further integration to explicitly support LEO communications is likely.
- User interface.* The current user interface to the Virtual Classroom is the aggregate of existing, individual service user interfaces. Providing an integrated web based user interface to the aggregate services will likely substantially increase the usability of the system to experimenters that are not computer experts.

B. New Applications

The Virtual Classroom provides a platform for the support of new applications.

While it was designed for support of student satellite experiments, the Virtual Classroom can be extended to provide remote access to any field based experiments.

One intriguing future new application is the exploration of extending IEEE 802.11 communications to domains currently unexplored. Overhead high bandwidth network coverage to high altitudes and speed - high altitude rockets, balloons and LEO satellites – is a potentially profitable area of examination.

C. Replication

The Virtual Classroom is an inexpensive, open system constructed with the intent of ease of replication for other experimenters and applications.

V. Conclusion

The Virtual Classroom demonstrates that modern wireless communications systems can be integrated to provide seamless, high performance communications even to remote locations. It provides a platform for extending to the entire Internet both education to experiments conventionally only performed in remote locations, but also for the conduct of experiments that can only occur with the aid of high performance digital communications.

Acknowledgments

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