BUILDING A "CYBER FOREST" IN COMPLEX TERRAIN AT THE ANDREWS EXPERIMENTAL FOREST

Donald L. Henshaw[1], Fred Bierlmaier[2], Barbara J. Bond[2], and Kari B. O'Connell[2]

[1] U.S. Forest Service, Pacific Northwest Research Station, Corvallis, OR 97331, USA
[2] Department of Forest Science, Oregon State University, Corvallis, OR 97331, USA

Abstract

Our vision for a future "cyber forest" at the Andrews Experimental Forest foresees high performance wireless communications enhancing connectivity among remote field research locations, station headquarters, and beyond to the university and outside world. New sensor technologies and collaboration tools foretell exponential increases in data and information flow to accommodate both research and education. We envision improving data transmission speed and bandwidth, enveloping the Andrews in a wireless cloud, installing new technologies for near real-time access to sensor networks, and assuring quality and management of streaming data The remote location of the Andrews Forest, far beyond the reach of conventional communication infrastructure, coupled with steep mountainous topography and very tall trees present significant challenges to the realization of this vision. This paper explores the innovative approaches being tested to provide real-time access to important data streams and unique educational opportunities.

Keywords: cyberinfrastructure, wireless networks, sensor arrays, complex terrain, Andrews Experimental Forest, Long-Term Ecological Research (LTER)

1. Introduction

New technological capabilities in environmental sensing and communications are revolutionizing the science questions asked and study experiments performed to reveal previously unobservable phenomena (Estrin et al. 2003). Sensor networks are enhancing the scales at which scientists perceive the natural world, increasing both spatial intensiveness and extensiveness and temporal frequency (Porter et al. 2005). Communication technologies are similarly expanding the education and outreach capacity of field stations allowing distance education and virtual field trips through real-time video and data connections with classrooms and meeting rooms around the world.

Recognizing the potential of these new technologies, field stations across the United States are beginning to "go cyber". However, strategies that work at one location may not be simply transferred to all others due to local constraints and circumstances. At the Andrews Forest, for example, we face extreme challenges due to the rugged terrain, massive trees, remote location, and large area of the experimental forest. We are developing a comprehensive plan to build a "cyber forest" at the Andrews that meets these challenges. Our plan includes increased bandwidth to the home institution, improved field-to-headquarters data transmission, complete wireless coverage of the Andrews Forest, and dynamic data management and quality control tools to accommodate streaming data from sensor arrays in near real-time *(Figure 1)*. This paper will primarily discuss improving bandwidth, development of the "wireless cloud" and field-to-headquarters communications, and our approach to examine the feasibility for establishment and implementation. This extended wireless local area network (WLAN) will provide a quantum leap in capability for both research and education at the Andrews Forest as well as provide a prototype that might be applied in other mountainous research areas. We anticipate researchers posing new science questions, such as understanding the influence of complex terrain on ecosystem structure and function, where topography creates enormous environmental variability that demands establishment and real-time access to sensor arrays.

Wireless communication systems (telemetry) were first installed in 1994 in a few of the high elevation meteorological and stream gaging stations at the Andrews Forest. Near real-time web displays of this data proved useful in assuring successful operation of remote sites and provided data access even when physical access was restricted due to heavy snow or debris avalanches. The telemetry network has since been expanded to include a more extensive hydrometeorological measurement system, and an automated system allows near real-time Internet access and graphical displays of data. This original Campbell Scientific radio telemetry system using VHF radios at a licensed frequency of 151.65 MHz is no longer supported by Campbell Scientific, requiring future replacement of the radio modems and associated repeaters and base station.

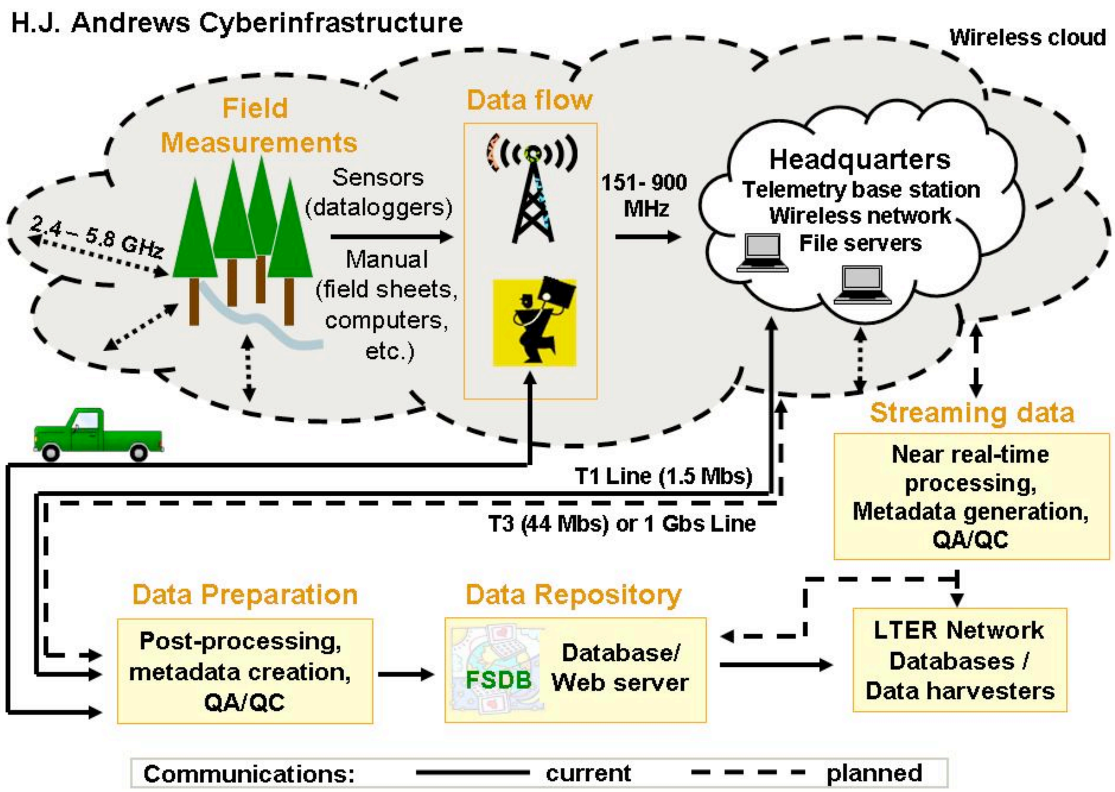

Figure 1. Current and planned infrastructure to support the Andrews "cyber forest". A wireless cloud (WLAN) blanketing the entire Andrews Forest is envisioned allowing transmission of sensor network data and Internet access throughout the mountainous topography. Improved bandwidth and communication rate are planned. Applications for near real-time data processing, data validation and metadata generation are anticipated.

Communication from the Andrews headquarters to Oregon State University (OSU), a distance of about 160 km, was limited to 56 Kbs until establishment of a T1 line (1.5Mbs) in 2001 using existing telephone cables. Currently, the headquarters site hosts a wireless local area network (802.11 standard) composed of a series of access points and wireless bridges that allow connection throughout the headquarters site including office and apartment buildings. However, voice communications throughout the forest are limited to handheld radios that do not work in many locations.

2. Methods

Our methods involve examining the science needs for these enhanced communications, explore the tremendous challenges to building the cyber forest including major issues of topography and bandwidth, and begin testing new technologies in forested conditions.

Science needs: Rapid increases in digital data collections and sensor array deployment demand improved data transmission and expose limitations in available bandwidth and performance, especially when considering the following current uses and future needs:

- Streaming sensor array data to the Internet at fine temporal resolution - atmospheric studies, hydrometeorological measurements, and snow and subsurface hydrology studies are underway with others planned.
- Planned deployment of acoustic sensors for biodiversity studies.
- Collaboration technologies including videoteleconferencing with multipoint software, voice over IP and video transmission from the field.
- Server backups and synchronization of mirrored servers at the university.
- Web cams and frequent transmittal of large-size digital images are in operation (i.e., university web cam sends images every 30 seconds), and web cams are planned for bird/animal tracking and phenology monitoring.
- Data intensive applications, e.g., GIS, visualization

Topography: The topography and vegetation of the Andrews Forest have created the need for more extensive sensor arrays while also presenting a significant obstacle in the transmission of collected data. The forest is broadly representative of the rugged mountainous landscape of the Pacific Northwest with elevation ranges from 410 m to 1630 m and old-growth forest stands among the tallest and most productive in the world. The richness ascribed to topographical-position has demanded that sensor arrays be established with high station density and wide variations in topography and canopy cover (Daly et al. 2007). The terrain and canopy cover seriously limit transmission range and bandwidth, but the Andrews Forest offers a unique research challenge in developing wireless connectivity in remote mountainous landscapes.

Approach: The following approaches were used to explore potential improvements in data transmission speed and bandwidth, new technologies for near real-time access to sensor networks, and management and quality assurance of streaming data:

- Explore costs and feasibility of upgrading the T1 (phone line) transmission rate from the Andrews Forest to OSU including a) fiber-optic communications at 1Gbs and b) building wireless links over 160 km of mountainous terrain
- Explore costs and feasibility of blanketing the entire site with a wireless communications network by a) examining existing technologies, b) using line-of-site (GIS viewshed) software to determine an optimal wireless bridge configuration, and c) using point-to-point link estimator software to determine maximum rate of throughput given topography and vegetation obstruction

- Deploy an extensive sensor array in a small watershed near the headquarters designated as a "cyber watershed" to monitor ecohydrological processes while exploring new technologies and testing the efficiency of spread spectrum radios through dense vegetation
- Prototype a new data model to provide efficient throughput and near real-time quality assurance checking of data streams from multiple sensor networks

3. Results

Bandwidth: Dark (unused) optical fiber which could provide gigabit performance from the site to OSU is simply not available for the final 50 km to the site. Construction using existing aerial paths (power poles) for 40 km is estimated close to $1M, and construction over the final 10 km to the Andrews is more expensive with trenching required through rocky material and estimated cost is $2M. Given the high cost for an optical fiber cable connection, other options are considered. Options include building wireless links over 160 km of foothills using ridge-top towers to directly connect with OSU, or alternatively building a wireless connection to the end of the dark fiber. In both cases, solar-powered towers are necessary but problematic in winter because of low available light and difficult access due to snow.

The critical element for alternative wireless pathways to OSU as well as establishing site-wide wireless communications is the link from the valley-bottom headquarters to a ridge-top tower (Quarry), which is challenged by an intervening ridge and tall vegetation. A more expensive, non-line-of-site wireless bridge with maximum throughput of 300 Mbs is considered for this segment. Point-to-point link estimator software was used to conduct a preliminary path analysis and a theoretical mean throughput of only 92 Mbs is estimated due to free-space path loss and obstructions to line-of-site. Given these difficulties in providing a wireless link to the Quarry ridge site, trenching from the headquarters to the ridge to lay power and optical fiber cables becomes a viable option and costs are being estimated. Laser technology is also considered but power and direct line of sight requirements coupled with problems due to mist and fog conditions are serious impediments. For any option we will maintain the T1 connection as an alternate pathway to assure continual communication. In the interim it is likely that a strategy for sharing bandwidth (e.g., nighttime server backup or scheduled data downloads) between the headquarters and OSU will be needed to prevent transmission bottlenecks.

Wireless cloud: We envision blanketing as much of the Andrews Forest as possible with a wireless communications network, prioritizing roads and areas with intensive study sites. Intensive study sites targeted will include climate or stream gaging stations, a small "cyber watershed" in the SE corner (WS 1), and a transect along an elevation gradient designated for new biodiversity and climate change research.

To establish complete wireless coverage of the Andrews Forest, a series of wireless Ethernet bridges starting at the headquarters will be established on communication towers. Each of these bridges will be on high points or ridges with excellent visibility to a number of other ridge sites and a clear unobstructed view to a large forest area. At each of these bridge points, multiple wireless access points will be daisy-chained and established with directional antennas. Directional antennas (as opposed to omni-directional) will yield more power per area to target intensive study areas and provide optimal coverage within the forest boundary. Researchers will be able to connect to the network with WiFi-enabled laptop computers while in close proximity to an access point, but will likely require higher power client devices with integral directional antennas to connect throughout much of the Andrews Forest. While use of the 802.11 standard for the wireless access points is planned, the WiMax or 802.16 standard is being considered for its non-line-of-sight capability. Unlicensed frequencies of 5.8 GHz and 2.4 GHz for the wireless bridges and access points, respectively, are planned; however, 900 MHz radios might be necessary for access points with better penetration through tree canopies gained at the expense of bandwidth. New 900MHz wireless modems will take advantage of the Ethernet bridge infrastructure. A single wireless modem connected to the bridge at each tower site will be able to consecutively transmit data from several dataloggers at scheduled intervals. Faster transmission rates will allow for near real-time access.

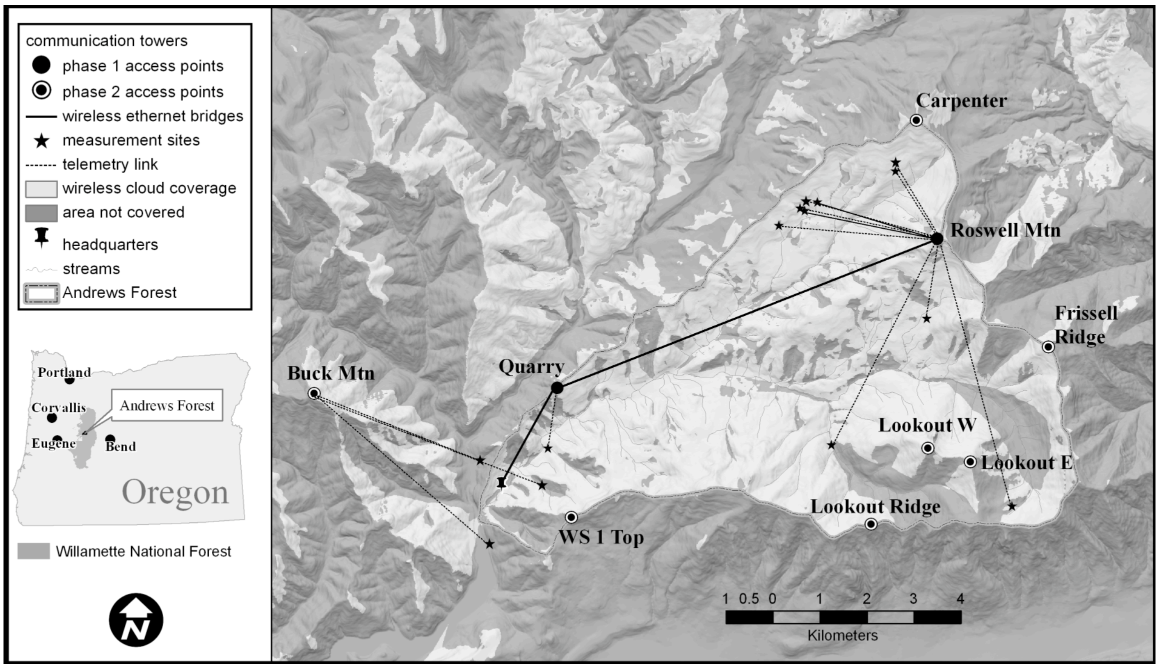

Figure 2. Phase 1 access points and two wireless bridge links should provide 80% WiFi coverage to the Andrews Forest as shown. Coverage is indicated by a light color; dark colored areas are predicted to be in a "wireless shadow." Phase 2 access points and point-to-multipoint wireless bridges will complete the "wireless cloud" with >95% coverage (estimated from line-of-sight analyses, ArcGIS Toolbox/surface raster/viewshed).

A line-of-sight analysis indicates that a total of 10 communication tower sites linked with wireless bridges will be necessary for complete (>95%) wireless coverage of the site *(Figure 2)*. Interestingly, only three tower sites are needed to provide 80% coverage, including the 11 current telemetry sites, and installation of these are planned as a first phase. Phase I installation will include two key point-to-point bridges between the headquarters and a high-elevation site (Quarry) and from this site to a distant ridge (Roswell Mountain). The Roswell site will provide line-of-sight coverage to the high-elevation watersheds and climate stations. Phase II will install more wireless bridges configured as point-to-multipoint to allow multiple pathways for communication.

Test deployment: An extensive sensor array is installed in a small watershed near the headquarters designated as a cyber watershed to monitor ecohydrological processes, and is accompanied by a telemetry system that uses modern 900 MHz spread spectrum wireless modems to transmit data from multiple dataloggers. The topography forces the use of a two-radio repeater on a nearby ridge top, but high-frequency data is reliably transmitted to headquarters even when radios are installed beneath heavy canopy cover. In conjunction with the cyber watershed concept, researchers have been developing new sensor technologies on the Andrews Forest including distributed temperature sensor (dts) data collection along 4 km of fiber optic cable in two watersheds (Selker et al. 2006) and low power sensor network development employing RF harvesting (Le et al. 2006) .

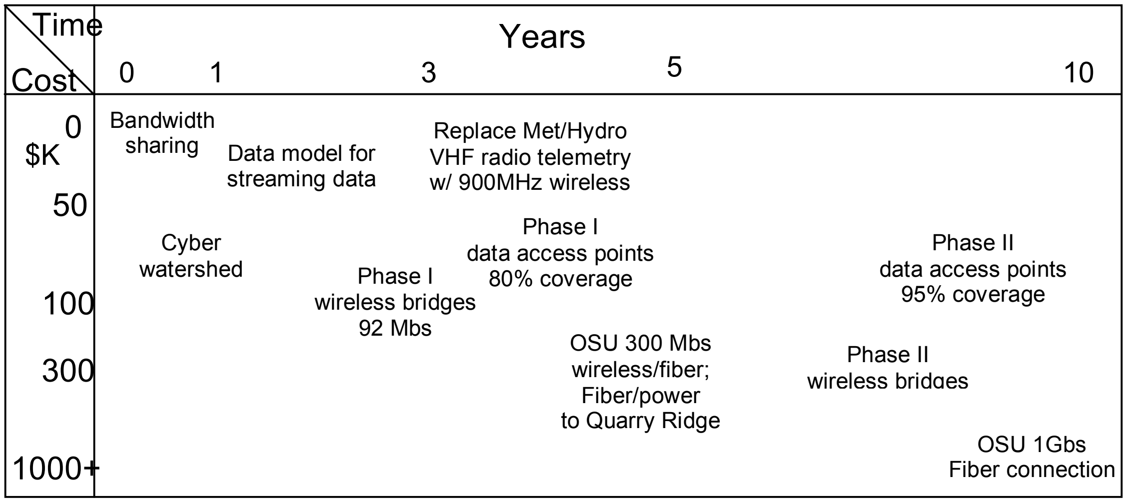

Figure 3. The general timeline for cyberinfrastructure establishment will proceed based on funding resources and success in establishing connections in complex terrain.

Data model: The arrival of new sensor arrays has resulted in an exponential increase in the quantity of data collected and places significant strain on existing resources used to quality assure and archive data. Current metadata-driven, post-collection processing and data validation methods struggle to keep pace with timely archiving of sensor data. Resolving many of these issues of data stream management is a community problem and the Andrews information managers will track progress and solutions emerging from other Long-Term Ecological Research sites and observatory networks, but at the same time we continue to push for local solutions. A short description of one current effort follows.

A new data model and processing system is being established to manage and provide for seamless acquisition of hydrometeorological data streams. Features include:

- Master catalog of all sensor arrays (or data loggers) with operational date ranges
- Detailed table of all sensor array (or data logger) configurations including measurement metadata and ordered lists of measured parameters
- Normalized data tables of all sensor data with qualifier codes to preserve all raw data streams with appropriate metadata for later resampling
- Automatic screening of data against prescribed data limits and assignment of qualifier codes for each measurement value
- Data acquisition and graphical interface to monitor data streams and provide comparative graphs of questionable data.

For other sensor networks, the headquarters base station will facilitate direct streaming of data to campus labs where processing protocols are established.

4. Conclusions

Multiple challenges face the scientists and educators at the Andrews Forest before the vision of a “cyber forest” is reached. New cyberinfrastructure capability is necessary to assure near real-time data access, storage and backup requirements, efficiency of processing, and data quality. The remoteness and distance from conventional communication pathways stand in the way of the desired high performance connectivity between the site and university. The forest topography and tree canopy height pose unique challenges compared with more typical telecommunication installations. An approach to the development of an all encompassing WLAN is established, and the planning and installation of new technologies and sensor arrays proceeds.

While relying on expert advice to guide our planning, it is clear that there are many uncertainties in developing this telecommunications network. Resources for reliable fiber optic solutions may not be available, and knowledge of whether planned wireless bridges will work effectively until tested in complex terrain is unknown. The general implementation timeline *(Figure 3)* will have to be modified if key wireless segments prove untenable. This is a new frontier in ecological studies to conduct such research in complex terrain, and it will require flexible timelines and significant resources to build necessary bandwidth for rapid communications. Once achieved, however, our vision for cyberinfrastructure will provide unique new opportunities for science and education.

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