

High Performance Wireless Research and Education Network



The High Performance Wireless Research and Education Network (HPWREN) is a National Science Foundation funded network research program, which also functions as a collaborative cyberinfrastructure for research, education, and first responder activities. The program includes the creation, demonstration, and evaluation of a non-commercial, prototype, high-performance, wide-area, wireless network in San Diego, Riverside, and Imperial counties.

The network includes backbone nodes are located at the University of California–San Diego and San Diego State University campuses as well as a number of "hard-to-reach" areas in remote environments.

The HPWREN backbone itself operates primarily in the licensed spectrum and project researchers use off-the-shelf technology to create a redundant topology. Access links often utilize license-exempt radios.

The network spans from the southern California coast to the inland valleys, on to the high mountains (reaching more than 8700 feet), and out to the remote desert. The network's longest link is 72 miles in distance – reaching from the San Diego Supercomputer Center to San Clemente Island.

"For the past six years, we have been working on developing solutions for the technological needs of hard-to-reach communities ranging from educators at rural Native American reservations to astronomers at remote observatories and field scientists at ecological reserves," explains Hans-Werner Braun, HPWREN principal investigator. "The HPWREN program also collaborates with rural firefighters-providing them with opportunities to experiment and utilize the latest technology available for remote data transmission in areas that are often difficult to reach with standard communication tools."

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**Cover photographs.** From San Diego's Coastline to Remote Desert: The HPWREN project spans from the San Diego coast (Point Loma) to the county's inland valley (Santa Margarita Ecological Reserve), onto the rugged mountains (Palomar Mountain) and isolated desert (Anza Borrego Dessert).



Led by Principal Investigator Hans-Werner Braun at the San Diego Supercomputer Center, University of California at San Diego and Co-Principal Investigator Frank Vernon at the Scripps Institution of Oceanography, HPWREN is based on work funded by the National Science Foundation under Grant Numbers 0087344 and 0426879.

Please refer to http://hpwren.ucsd.edu/news/ for summaries regarding the research, education, and public safety activities discussed in this booklet.



- Backbone/relay node
- Astronomy site
- Biology science site
- Earth science site
- University site
- Researcher location
- Native American site
- Public Safety site





#### Broader Impacts of HPWREN

HPWREN influences many scientific disciplines that monitor and sense the environment. A fundamental impact is the field deployment of wireless networks for sharing real-time data across multiple disciplines ranging from environmental sciences, oceanography, and astronomy to rural education.

HPWREN plays an important role for large-scale sensor network applications in several NSF initiatives, such as:

- Earth sciences (EarthScope);
- Ocean sciences (OOI- Ocean Observatories Initiative);
- · Biological sciences (NEON National Ecological Observatory Network); and
- Civil engineering (NEES Network for Earthquake Engineering Simulation).

Each of these large scale initiatives aims to collect real-time data from many sensors, and each will require advanced technologies to process, manage, and communicate real-time multidisciplinary environmental data on regional, national, and global scales. The techniques influenced by HPWREN and the applications developed using the network will be used to create the next generation of scientific and environmental monitoring systems.



"The network environment which HPWREN provides is an excellent resource for my students. This especially helps with Quality of Service and Policy Based Routing research, which are useful to both HPWREN itself, as well as my work on networked embedded sensor systems." -Tajana Simunic Rosing, Professor in Computer Science and Engineering at UCSD





HPWREN Principal Investigator Hans-Werner Braun focuses his research on systems integration, workload profiling, performance analysis, and the utilization of quality of service (QoS) and policy based routing (PBR) methodologies to steer the performance of the network (Figure 3).

UC-San Diego Computer Science Professor Tajana Simunic Rosing (Figure 4) also conducts research on HPWREN– focusing her studies on managing access to the network so that QoS of sensing applications is maximized while energy consumption is minimized.

UCSD electrical and computer engineering professor Tara Javidi also participates in the QoS efforts.

Rosing and her team of three graduate students (Gaurav Dhiman, Jaewook Shim, and Daeseob Lim) are implementing a scheduling algorithm for data delivery and combining it with PBR within HPWREN. Preliminary results show a significant improvement in average throughput available when the scheduling algorithm is enabled.

Furthermore, the team developed and implemented an initial PBR algrithm, which will be critical to optimize multi-path routing issues as HPWREN evolves.

The work of Rosing, Dhiman, Shim, and Lim has received a great deal of attention from industry and they have recently received additional funding by several private corporations.

### Network Research

San Diego State University Computer Science Professor Marie Roch examines the use of HPWREN with acoustics sensors at the California Wolf Center. Roch and her students are examining techniques to automatically filter useful audio data so that biologists aren't required to listen to an endless amount of recordings when looking for something specific – like wolf howls (Figure 5) versus barks (Figure 6).

Roch, Deborah Curless, and Melissa Soldevilla from John Hildebrand's lab at Scripps Institution of Oceanography (SIO) recently wrote a software package that performs the signal detection task and determines when wolf calls (or other interesting sounds) occur at the Wolf Center. Not only does this assist biologists at the Center, but it also uses the HPWREN bandwidth more efficiently.

In addition, HPWREN researchers have conducted many ad-hoc wireless network experiments over the past years. For instance, the team worked with field scientists on evaluating the use of wireless technology in conjunction with a research airplane and ground station. Specifically, the study examined the use of radios the communicate using the unlicensed spectrum with a nearby airplane (Figures 1 and 2).

The HPWREN team also led several ad-hoc demonstrations that linked the remote Anza-Borrego Desert State Park with several sites, including a conferencing setup in the city of San Diego; these activities allowed remote participants to virtually tour the desert park via real-time interactive presentations (Figures 7 and 8).

Similarly, demonstrations with the US Navy and SIO allowed HPWREN researchers to better understand issues with 802.11b traffic over water as well as the technical challenges with connecting off-shore sensors and boats (Figures 9 and 10).





"The rapid responses by Palomar's telescopes are possible only because of HPWREN. With it, we have observed and categorized some of the most distant and energetic explosions in the universe." -Shri Kulkarni, MacArthur Professor of Astronomy and Planetary Science and director of the Caltech Optical Observatories.





For the past several years HPWREN has been providing data connectivity cyberinfrastructure for both California Institute of Technology's Palomar Observatory and San Diego State University's Mount Laguna Observatory (Figures 1 and 2).

Recent Palomar Observatory applications include the study of some of the most cataclysmic explosions in the universe, the hunt for extrasolar planets, and the discovery of objects on the edge of our solar system that resulted in a long-overdue definition of what constitutes a planet. The data for this research is transferred via HPWREN from the remote mountain observatory to college campuses throughout the country.

The Palomar Observatory is by far HPWREN's most bandwidth-demanding partner. Their networked applications are able to run the 45 megabits-per-second HPWREN backbone to capacity and will be able to utilize substantially more bandwidth in the future. The current plan is to upgrade critical links that support the observatory to 155 Mbps and create a redundant 45 Mbps path for a combined 200 megabits-per-second access speed at the observatory.

In 2005, Near Earth Asteroid Tracking Program (NEAT) astronomers making use of the Palomar 48-inch Samuel Oschin Telescope announced the discovery of an object larger than Pluto, and at a further distance from the sun. This discovery utilized a 161-million-pixel camera—one of the largest and most capable in the world. In support of this, modern digital technology with pipeline processing of the data produced enables astronomers to detect very faint moving and transient objects (Figures 3 through 6).

# Disciplinary Research: Astronomy

The Nearby Supernova Factory piggybacks this hunt for a certain type of exploding star, known as Type Ia supernovae, with the data collected by the NEAT program, and they then use the observations of these supernovae as "standard candles" for measuring the accelerating expansion of the universe. By mid-2006, the survey discovered about 350 supernovae, including 90 Type Ia supernovae such as the Supernova 2001dd (Figure 6).

One of the universe's most mysterious and explosive events is the phenomenon known as a gamma-ray burst (GRB). They are briefly bright enough to be visible billions of light years away, but they are difficult to study because they are very short lived and take place at seemingly random locations and times. Astronomers rely on satellites like Swift, which detects a GRB and immediately relays the information to observers worldwide via the Gamma-Ray Burst Coordinates Network. If a gamma-ray burst occurs when it is dark and clear at Palomar, the observatory's robotic 60-inch telescope immediately slews to the coordinates provided and images the fading optical glow of the explosion (Figures 7 and 8).

The smallest telescope at the Palomar Observatory is performing a search for exoplanets. With this telescope it is possible to detect a giant Jupiter-sized world that lies close to its parent star. By looking at a great many stars each night, the HPWREN-connected Sleuth Telescope has already caught one such planet in the act of passing directly in front of its star. Such an eclipse, known as a transit, dims the light of the star by about one percent (Figure 9).

Astronomers at San Diego State University's Mount Laguna Observatory (MLO) were among the first to benefit from HPWREN. Current MLO astronomers are partnering with three other universities and private industry (Composite Mirror Applications) to build and test the ULTRA (UltraLightweight Technology for Research in Astronomy) telescope (Figure 10).





"HPWREN has made it much easier for researchers and educators to collect and monitor a vast array of sensor data remotely as well as connect people and agencies that normally might not work or collaborate together." -Pablo Bryant, Technology Manager at San Diego State University's Santa Margarita Ecological Reserve





Thanks to HPWREN connectivity, biologists remotely observe the southern California environment on a continuous basis– giving them more data to understand ecological and Earth science processes while also providing a new infrastructure to conduct multidisciplinary research.

One of the primary collaborators of the HPWREN team is San Diego State University (SDSU), which serves as a backbone node for the network. The SDSU Field Station Programs manages the HPWREN-connected Santa Margarita Ecological Reserve (Figure 1) and the Sky Oaks Biological Field Station (Figure 2).

The Sky Oaks Biological Field Station recently implemented its own intra-field network. The HPWREN link and the intra-field network provides critical connectivity for three real-time web cameras and multiple sensors – including soil moisture, light intensity, vegetation reflectance data, carbon and water flux, and micrometeorlogical data (Figure 3).

Likewise, HPWREN-connected water quality and hydrology sensors along the Santa Margarita Watershed allow hydrologists to remotely measure parameters such as water acidity and pressure. Additionally, network-connected acoustic sensors allow biologists to track animal calls and other wildlife activity such as bat sonar—limiting the need to set foot on the remote 4500-acre Santa Margarita Ecological Reserve (Figures 4, 5, 6, and 7).

HPWREN-connected high-resolution cameras are controlled via a remote server across the Internet and allow both the research community and the general public to catch a glimpse of a biologically diverse area where hummingbirds sip nectar, coyotes roam, and hawks nest. (Figures 8 and 9).

# **Disciplinary Research: Biology**

One user of the cameras is biologist Rolf Baumberger, a researcher at the University of Zurich in Switzerland, who has been studying the Santa Margarita Ecological Reserve's bush monkey flower (*Mimulus aurantiacus*) for more than ten years. Since 2002, Baumberger has been observing the flower's alteration in shape and color during various conditions via an HPWREN-connected web camera.

Meanwhile, HPWREN-connected real-time cameras and acoustics sensors at the California Wolf Center allow researchers from the University of San Diego and San Diego State University to study wolf behavior while providing another tool for the Center's staff to observe and better manage the animals in their care.

An on-going study involving spectral analysis of wolf vocalizations recorded via the acoustic sensors and visual monitoring of a litter of pups born at the Wolf Center are examples of how researchers utilize the network connectivity at the site.

Live feeds from the HPWREN-connected cameras have also been used in university animal behavior classes and to enhance public education outreach programs hosted by the Center.

Another site equipped with HPWREN-connected cameras is the Boyd Deep Canyon Desert Research Center, where biology researchers are creating a database to document seasonal and long-term habitat changes of wildlife such as raptors and bighorn sheep (Figure 10).

In addition, the HPWREN-connected Boyd Deep Canyon Research Center team is developing light-weight portable solar powered camera systems that will operate reliably in extreme temperatures.





"The HPWREN connectivity provides real-time data and video streams from the NSF-funded NEES@UCSB remote field sites– allowing researchers, students, and educators to remotely participate and even operate equipment at the field sites without physically having to be at the sites." -Jamison Steidl, Seismologist at the Institute for Crustal Studies, UC-Santa Barbara





The HPWREN team's work with the Earth, Ocean, and Engineering Sciences communities encompasses the fields of seismology, earthquake engineering, meteorology, and geodesy. The NSF George E. Brown Jr., Network for Earthquake Engineering Simulation (NEES) program has two facilities that both heavily utilize HPWREN, where scientists from around the world are able to monitor real-time seismic data collected in southern California and to remotely participate in experiments at the NEES@UCSB and NEES@UCSD facilities.

One NEES@UCSB facility consists of two permanently instrumented remote field sites that typically transmit over four gigabytes of data per day via HPWREN to recover continuous real-time data from the remote sites. The Garner Valley Downhole Array experimental site (Figure 4) monitors ground shaking via sensors located as deep as 500 meters below the Earth's surface in rock, at multiple shallower depths within the soil column above the rock, and at the surface. Improving the understanding of how the soils respond to earthquake shaking, and applying what is being learned to improve the earth-quake resiliency of the built environment is the primary goal of this NEES facility. In addition, an instrumented structure located at the site is monitored to improve the ability for engineers to simulate soil-foundation-structure interaction.

The second NEES@UCSB field site is the Wildlife Liquefaction Array (Figure 3). The primary focus of this site is simultaneous observations of pore water pressure and ground motion to improve understanding and predictability of the liquefaction phenomenon. A dense network of benchmarks and inclinometer casing wells close to the free face of the Alamo River also provides the ability to monitor lateral spreads during strong earthquake shaking. Lateral spreads, or permanent ground deformations, are often the cause of extensive damage to roads, pipelines, and structures during strong earthquakes.

# Disciplinary Research: Earth, Ocean, & Engineering Sciences<sup>09</sup>

In addition to the two NEES field sites, UCSB also operates an HPWREN-connected seismic array in the Anza Borrego Desert, just north of Borrego Springs, California (Figures 5 and 6). The large number of surface sensors (15 three-component accelerometers) distributed across the upper Borrego Valley measure the spatial variability of ground shaking during earthquakes, and is a unique feature that distinguishes this array from the NEES sites.

The Southern California Coastal Ocean Observing System (SCCOOS) also utilizes HPWREN for long haul data communication links. Current HPWREN-connected SCCOOS locations include Point Loma, the Coronado Islands, and San Clemente Island. The connectivity allows SCCOOS researchers to transmit surface current measurements for analysis and public display of regional surface current maps. SCCOOS aims to synthesize observations into products that will provide a scientific basis for improving evaluation, management and guardianship of the ocean environment and its resources (Figure 7).

Another Earth Science application, the Plate Boundary Observatory utilizes HPWREN at several sites for long-term crustal motion monitoring, helping scientists unravel the tectonic puzzle of the western United States (Figure 8). Two more southern California research sites equipped with HPWREN links and interfaces to real-time strainmeter data are the Pinyon Flat Observatory and Durmid Hill sites, which are both managed by Scripps Institution of Oceanography. The SIO Laboratory for Atmospheric Acoustics also utilizes HPWREN to monitor the continuous array state of health monitoring and data analysis.

Additionally, a NASA Satellite Laser Ranging Program Site uses HPWREN to transmit tracking data on a near real-time basis to a central data bank where it can be accessed by a global scientific community.

Supported by the USGS, the HPWREN-connected ANZA Seismic Network is managed by HPWREN's Co-PI and geophysicist Frank Vernon and consists of 21 stations that provide real-time and stored data and analysis of seismic activities (Figures 9, 10).





"It makes me really proud of all that has been accomplished, and that we have come full circle in that we can in return help the people who enabled us to help ourselves. We could not have accomplished what we have without Hans-Werner and the rest of the HPWREN staff." -Michael Peralta, TDVNet network administrator and chief architect, Rincon Reservation





One of HPWREN's first links was the Pala Learning Center, a resource for the rural Native American community of Pala, California (Figures 2 and 3). Once Pala educators and students embraced the networking technology, the word soon spread to neighboring tribes such as La Jolla (Figures 1, 4, 5, and 6), Rincon (Figure 7), and San Pasqual. Within a few years, the HPWREN team had armed the Native American community with the knowledge and expertise necessary to expand broad-band connectivity to all San Diego County reservations via their Tribal Digital Village Network (TDVNet).

Researchers with HPWREN continue to work with the TDVNet team on technology transfer–sharing wireless experiment data with the tribal network team to ensure that their own network continues to flourish. The collaboration has also proven critical for HPWREN's users at the San Diego State University Sky Oaks Biological Field Station.

Specifically, TDVNet leaders offered their solar-powered Mesa Grande 80-foot tower site (Figures 9 and 10) as a relay site for HPWREN's efforts to reach the remote 1600-acre Sky Oaks, which serves as a resource for carbon flux, meteorology, and many other environmental studies. The expansion to the Mesa Grande site provides a permanent connection capability to the California Department of Forestry and Fire Protection's (CDF) designated Incident Command Post (ICP) site at Puerta La Cruz. This would have been impossible without the TDVNet team's collaboration.

Over the years, the HPWREN staff has also teamed with Native American communities spanning from the nearby Santa Rosa tribe in Riverside County (Figure 8) to the Navajo Nation that spans Arizona, New Mexico, and Utah.

### **Native American Education**

HPWREN researchers most recently worked with the Navajo Nation on technology and expertise transfer to better enhance their efforts for tribal-sustained wireless network connectivity throughout the reservation, which covers approximately 27,000 square miles.

Collaborations between the HPWREN team and Native American communities in San Diego County include:

- HPWREN-led Internet classes at several San Diego County reservations,
- distance tutoring between UC San Diego mathematics students and Pala Learning Center students,
- tours of the San Diego Supercomputer Center,
- assistance with intra-network connectivity at tribal centers and schools,
- participation in the TDVNet's Native American Summer Youth Academy, and
- ongoing interactions for the insurance of continued connectivity.

Additional HPWREN-related educational activities involving the Native American tribes are sponsored by outreach programs on the campuses of institutions including the University of California at San Diego, San Diego State University, and Palomar College.





"Technology and collaborations with HPWREN allow us to broaden our footprint. When we can use bidirectional interactive video and audio technology for distance education, we increase the value and effectiveness of our education programs. Our ability to make a difference grows exponentially." -Patrick Valentino, Executive Director at the California Wolf Center

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The HPWREN team has been both directly and indirectly involved with distance learning activities via the network. Early in the project, the HPWREN team worked with Palomar College and the Southern California Tribal Chairmen's Association's Tribal Digital Village Network to offer a Computer Science and Information Systems course via the network for local Native American reservations (Figure 3). The course was taught in traditional classroom style and simultaneously via multicast technology at the Pala Learning Center for Pala, La Jolla, Rincon, and San Pasqual tribal members. UCSD mathematics students also used HPWREN to serve as online tutors for Pala Learning Center middle school students.

Building on experience gained during distance learning activities with rural Native American learning centers, HPWREN researchers work closely with the California Wolf Center to enhance their distance education programs. For instance, an HPWREN-connected web camera is installed in a high wolf traffic area of a wolf pack enclosure, which is home to twelve Alaskan wolves. Via HPWREN, the Center shows live images of these wolves during on-site educational programs and in scheduled off-site programs as well (Figures 1, 2, 4, 5, and 6).

Participants in the Center's on-site Wolves of North America Program observe the behavior of a wolf pack, undisturbed by the presence of humans, before they go outside to view the animals. The wolves are often more active when humans are not present, and program participants are likely to see natural interactions among the wolves. Thus, the HPWREN cameras provide visitors with a unique educational opportunity. In the same way, participants in off-site programs have the opportunity to view live action of the pack.

# **Distance Learning**

Experiments in interactive audio/video demonstrate an ability to support an educator in real-time near an area where wolves are present. Both hand-held as well as backpack-based systems are being tested to evaluate the results and usability of such technologies. The goal is to determine whether bidirectional interactive multimedia will become one of the mainstream activities of an education/research facility such as the California Wolf Center.

Through a County of San Diego Community Grant, the wolf center has also increased the number of participants in K-12 Wolf Encounters education program, which utilizes the HPWREN connectivity for distance learning opportunities.

Similarly, thousands of students (K-12, undergraduate, and graduate) have remotely accessed data at the San Diego State University (SDSU) field stations via HPWREN connectivity. The remote real-time laboratories provide students with hands-on experiences of two southern California ecosystems without leaving their classrooms (Figures 7 and 8).

SDSU Field Station Programs and HPWREN teams are working together with the National Park Service and the California Mediterranean Research Learning Center to help design their own distance learning network plan.

The HPWREN team also participated with the California State Parks Distance Interpretation Program in their efforts to facilitate remote interactive presentations via a broadband connection. In Summer 2003, HPWREN researchers worked with California State Parks to allow park rangers, educators, and administrators from remote locations for a real-time visit to the Anza-Borrego State Park. That is, attendees of two different southern California conferences examined fossilized oyster beds in the remote Fish Creek, while sitting in urban conference rooms approximately 100 miles away (Figures 9 and 10).

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"HPWREN has been a good partner to public safety agencies and has been creatively supporting and enhancing our capabilities. I eagerly look forward to working together on technologies like airborne imaging systems and data links for air-toground applications." -Steve Shoemaker, CDF Fire Captain at Gillespie Helitack Base

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As a result of the successful collaboration between HPWREN and the public safety community, a consortium recently formed to capitalize on the research efforts of HPWREN. A formal Memorandum of Agreement between the San Diego City Police and Fire and Life Safety Departments, the San Diego County Sheriff and the California Department for Forestry and Fire Protection has been enacted and has sought and received funding to erect a large pipe data communications system expanding on the HPWREN research and development. Currently over eight million dollars is being invested in a multiple-agency HPWREN-like network to serve public safety in the southern California region.

Since 2001, the HPWREN team has been working with San Diego County first responders to better understand how highspeed wireless ad-hoc networking can assist with public safety in hard-to-reach areas.

The team deployed high-speed network communication capabilities at six major wildfire Incident Command Posts (ICPs): Coyote Fire in July 2003 (Figures 1 and 3), Mataguay Fire in July 2004 (Figure 4), Eagle Fire in May 2004 (Figure 5), Volcan Fire in September 2005 (Figure 6), the Border 50 Fire in October 2005 (Figure 7), and the Horse Fire in July 2006 (Figure 8).

HPWREN researchers also worked with the community to prepare connectivity for three California Department of Fire and Forestry (CDF) pre-designated ICPs: Dos Picos (Figure 9), Puerta La Cruz, and Potrero. The team also participated with CDF firefighters in two of their annual exercises: 2005 at Lake Hodges (Figures 2 and 10) and 2006 at Dos Picos. Permanent CDF sites connected to HPWREN include the following: Red Mountain Fire Station, La Cima Fire Camp, Ramona Air Attack Base, Gillespie Helitack Base, and Puerta La Cruz Conservation Camp.

# **Public Safety**

In addition to high-speed network access, ICP and permanent CDF sites connected to HPWREN also have access to realtime video and still cameras as well as meteorology sensors such as those atop Mount Laguna and Lyons Peak. Included with the suite of meteorology sensors is a real-time alert system that automatically pages first responders when concerning environmental conditions are present.

Working with first responders allows HPWREN researchers to experiment with and demonstrate rapid deployments of networking technologies, as well as how best to create and maintain high-speed data connectivity under difficult circumstances (e.g., wildfires). While the team continues to explore ways in which incident management applications can be added to the research portion of the network, the following lessons have already been learned:

Basic Needs. The need for digital data (Internet) communication is substantial for both ICPs and remote fire station/camp deployments. This need for digital communication access appears to have increased over the past few years. Further recognition and understanding of applicable requirements appear to be useful along the agency management chain.

Service Integration. There is an increasing requirement for more service integration including Voice-over-IP, for both phone and FAX, across the data network. Additionally, video conferencing as well as real-time sensor telemetry and data integration is starting to provide significant value to the first responder community. The ability to create ad-hoc expansions of the network via a high-speed data connection can support ICP-local wired and wireless networks for activities such as video downlinks, IR mapping from aircraft of the incident, and remote Computer Assisted Dispatch.

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#### HPWREN Students: 2000-present

Jeff Baker, NSF Research Experience for Undergraduates (REU), White Paper, Summer 2002 to Spring 2003 (Figure 12, right) Deborah Curless, Computer Science Graduate Student, Acoustic Monitoring, Fall 2005 to present (Figure 9) Gaurav Dhiman, Computer Science Graduate Student, Quality of Service-Policy Based Routing, Winter 2006 to present William Gahr, NSF REU, Network Reports, Summer 2002 to Spring 2003 (Figure 12, middle) Ben Lee, Electrical & Computer Engineering Graduate Student, Quality of Service-Policy Based Routing, Fall 2006 to present Zhao Li, NSF REU, Tsunami RSL Statistics, Summer 2002 to Spring 2003 (Figure 12, left) Daeseob Lim, Computer Science Graduate Student, Quality of Service-Policy Based Routing, Winter 2006 to present (Fig. 10) Kuo-Wen Luo, NSF REU, Network Measurement and Analysis, Fall 2000 to Summer 2002 (Figure 16) Kimberly Mann Bruch, Communications Graduate Student, Masters Thesis, Fall 2001 to Summer 2002 (Figures 2 and 5) Angie Ng, NSF REU, Electrical Engineering Research - Radiofrequency effects, Summer 2001 to Winter 2002 (Figure 15) Viktor Passinsky, NSF REU, Network Measurement and Analysis, Summer 2003 to Fall 2003 Jeff Pinnow, Academic Enrichment Program, Distance Health Education-On-line Curricula and Paper, Summer 2001 (Fig. 13) Huggy Price, Pre-Law, Southern California Tribal Chairmen's Association, Spring to Fall 2001 & Summer 2002 (Figure 6) Jaewook Shim, Computer Science Graduate Student, Quality of Service-Policy Based Routing, Winter to Spring 2006 (Fig. 11) Robert Stacey, NSF REU, Network Measurement and Analysis, Summer 2003 to Fall 2004 Tony Tran, Computer Science Student, Quality of Service-Policy Based Routing, Fall 2006 to present Rock Yuen Wong, Computer Science Undergraduate Student, Fall 2001 to Summer 2003 Pavana Yalamanchili, Computer Science Graduate Student, Masters Thesis, Fall 2000 to Summer 2001 (Figures 1 and 4) Carmen Zavala, Academic Enrichment Program, Distance Learning - Conference Presentation, Summer 2001 (Figure 14)

"Without HPWREN, we would not have access to the real-time audio data from the California Wolf Center. Additionally, an important part of our project has been developing a solution to automatically transmit signal processing output across the network to our lab at SDSU." -Deborah Curless, San Diego State University graduate student researcher

#### **Affiliated Students**

Christian Braun, Palomar College Student, Network Installations, Spring 2001 to present Karin Braun, Palomar College Student, Black and White Photography Project, Spring 2001 Todd Hansen, Earth Sciences Graduate Student, Spring 2006 (Figures 3, 4, and 5) Jose Otero, Geophysics Graduate Student, Fall 2000 to present (Figure 4) Michael Peralta, Palomar College Student, Tribal Digital Village Network, Summer 2001 to present (Figure 7) Jared Ribble, NSF REU, Crownpoint Institute of Technology, Navajo Nation, Spring 2005 to present (Figure 8, left) Quincy Sultzbaugh, Ethnic Studies Student, Tribal Digital Village Research Paper, Summer 2001

More than 20 university students have teamed with HPWREN researchers to create the successful program that exists today. Since the program's beginnings in Fall 2000, students from multiple institutions have been involved in research ranging from network measurement and analysis to quality of service and policy-based routing. Additional students have examined HPWREN-related topics such as radiofrequency effects, impacts of distance health education, wireless network implementation, and the impact of HPWREN upon field science.

Two women completed their Masters degrees while working on the HPWREN project. Pavana Yalamanchili (Figure 1), a UCSD computer science major, conducted her research in conjunction with the Center for Wireless Communications Research. Kimberly Mann Bruch (Figures 2 and 5) completed her Masters degree at San Diego State University; her thesis examined the diffusion of HPWREN within the Santa Margarita Ecological Reserve and the network's impact upon ecological field work at the 4500-acre living laboratory.

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For the past year, San Diego State University (SDSU) graduate student Deborah Curless (Figure 9) worked with SDSU computer science professor Marie Roch - gathering and analyzing bioacoustic data in collaboration with the HPWREN-connected California Wolf Center. Funded by HPWREN, Deborah worked with several researchers to develop a software package that automatically filters useful audio data so that biologists aren't required to listen to an endless amount of recordings when looking for something specific - like wolf howls versus barks. This filtering software allows for a more efficient use of HPWREN bandwidth.

Meanwhile, student researcher Daeseob Lim (Figure 10) works with UC San Diego computer science and engineering professor Tajana Simunic Rosing on the development of a simulation environment which he is using to evaluate scheduling and routing algorithms developed by the HPWREN team. Gaurav Dhiman, also in Rosing's lab, wrote a paper for the 2006 International Conference on Computer-Aided Design; the paper discussed power management in mobile environments and was nominated for best conference paper. Another student in Rosing's lab, Jaewook Shim (Figure 11), doctorate student in electrical and computer engineering, focused on statistical analysis of data traffic on HPWREN and development of theoretical bounds on the bandwidth improvements possible when scheduling data delivery on wireless channel.

HPWREN student researchers Jeff Baker, William Gahr, and Zhao Li (Figure 12) also concentrated their efforts on network measurement and analysis as well as documentation. Specifically, the three students focused their work on active, passive, and management information base (MIB) network data as well as network status documentation such as outages and utilization.

### **HPWREN Student Researchers**

In addition to conducting research and documenting their work in written reports, HPWREN students also participate in conferences and poster sessions, such as those held at San Diego Supercomputer Center (SDSC). For instance, UCSD premedical student Jeff Pinnow (Figure 13) worked with Kim Bruch of HPWREN and Bob Pozos of SDSU to develop a telemedicine literature review and an on-line course in Summer 2001. Jeff's work was presented at the SDSC Student Poster Session, the UCSD Summer Research Program conference, and the Native American Physician's Conference in New Mexico.

Carmen Zavala (Figure 14), a UCSD math education (computer science concentration) student, also worked with Kim Bruch in Summer 2001. Carmen's project examined ways in which high-speed networks like HPWREN can better assist with distance learning in remote education communities

While Jeff and Carmen were funded by EOT-PACI, the HPWREN team also often hosts National Science Foundation Research Experience for Undergraduates (REUs). Specifically, Angie Ng (Figure 15), a UCSD electrical engineering student, focused on two projects: 1) literature review of RF effects on humans, and 2) field work regarding spectrum analysis, power measurements, etc. Meanwhile, UCSD computer science student Kuo-Wen Lo (Figure 16) worked closely with HPWREN computer scientist Todd Hansen on network analysis and measurement.

Jared Ribble (Figure 8, left) is a recent San Diego Supercomputer Center and NSF REU student working with the HPWREN team. With guidance from HPWREN PI Hans-Werner Braun and Tribal Digital Village Network computer technologist Michael Peralta, Jared focuses his work on building an HPWREN-like network for the Navajo Nation in conjunction with his studies at the Crownpoint Institute of Technology (New Mexico).

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# High Performance Wireless Research and Education Network

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