High Performance Wireless Networking and Weather

Jose Otero, Pavana Yalamanchili, Hans-Werner Braun

Abstract—**High performance wireless networking is effected by a number of internal and external variables. External weather phenomena, such as rain, fog, wind, and temperature can effect the performance of network equipment, as well as node to node communication efficiency. Through the collection of Management Information Base (MIB) data and meteorological data it is possible to begin an investigation on potential correlations.**

Keywords— **weather, wireless networks, measurement, HPWREN**

I. INTRODUCTION

The High Performance Wireless Research and Education Network (HPWREN) [1] team is creating, demonstrating, and evaluating, a non-commercial, prototype, high performance, wide area, wireless network in San Diego County. The NSF-funded network includes backbone nodes on the University of California, San Diego (UCSD) campus and a number of ‘hard to reach’ areas in San Diego County (an area located in Southern California). The HPWREN is intended to serve multiple purposes. In addition to providing high speed Internet access to field researchers from several disciplines and educational opportunities to rural Indian reservations and schools, it serves as a test-bed for network measurement and analysis.

We have begun investigating the effects of external variables, such as weather phenomena and atmospheric conditions on wireless network performance. A variety of measurement activities occur on a daily basis within the HPWREN, reflecting factors such as network throughput, error rates, wireless radio frequency interference, and general transceiver status information. Most of this data is recorded via Simple Network Management Protocol (SNMP) [2] operations.

Fig. 1. Weather station at Mt. Woodson

This paper will show the preliminary results of our study on the effects of weather on the HPWREN.

II. WIRELESS TOPOLOGY AND INSTRUMENTATION

The HPWREN provides an unique test-bed. Perhaps one of the most fascinating aspects of this network is that it spans a wide topography and traverses a number of biomes. The backbone link spans from the coast of San Diego, through the mountains of eastern San Diego County, and eventually to the deserts of Southern California (Figure 2). In itself, this provides a number of logistical challenges from a deployment stand point, as well as presenting an interesting milieu in terms of meteorological phenomena across the link path. For example, it can be snowing in the mountains, raining in San Diego, and quite warm in the desert. This sort of hypothetical situation leads to many inquiries about network adversities and benefits. With our research, we hope to be to able to answer such questions, as well as develop parameters for measurement and analysis.

The current HPWREN infrastructure utilizes two types of radios. The high speed backbone (45 Mbps) uses Western Multiplex Tsunami radios [3]; the backbone to user links (11 Mbps) use Lucent Technolo-

---

Jose Otero is with the NLANR Measurement and Network Analysis group and the HPWREN, University of California, San Diego, San Diego Supercomputer Center, 9500 Gilman Dr., La Jolla, CA 92093-0505. E-mail: jotero@nlanr.net

Pavana Yalamanchili is with the NLANR Measurement and Network Analysis group and the HPWREN, E-mail: pavana@hpwren.ucsd.edu

Hans-Werner Braun is the principal investigator of HPWREN and NLANR and Measurement and Network Analysis group.

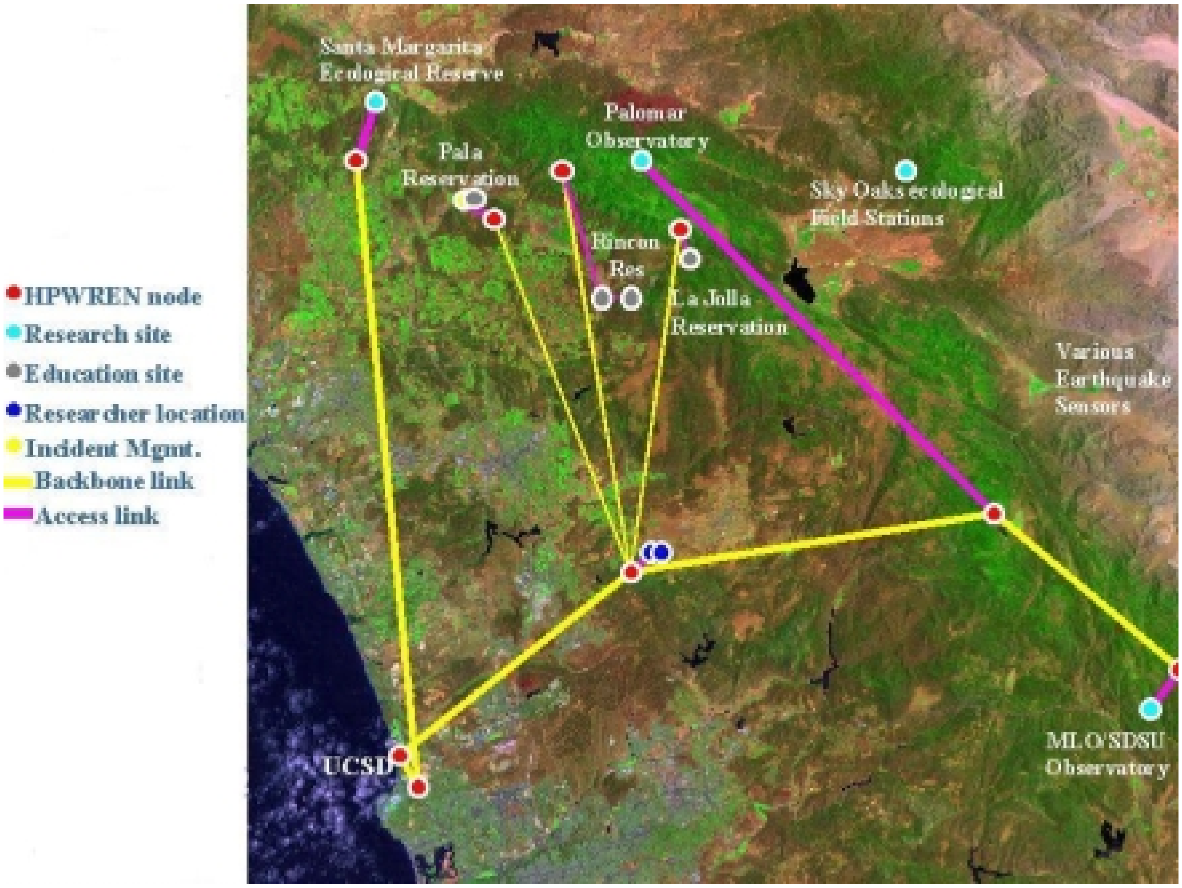

Fig. 2. Topology of the High Performance Wireless Research and Education Network (HPWREN)

gies [4] equipment. The Western Multiplex Tsunami radios utilize the unlicensed frequency spectrum of 5.75/5.8 GHz and proprietary protocols, while the Lucent radios utilize the unlicensed frequency spectrum of 2.4 GHz Direct Sequence Spread Spectrum (DSSS) and the IEEE 802.11b protocol.

At select sites, the HPWREN infrastructure also utilizes solar arrays to power the various network devices and radio equipment.

In order to fully understand the implications of weather conditions on network performance, it is necessary to have a standard procedure for weather collection across the HPWREN. Techniques for weather collection are as varied as the weather itself. For our network we have chosen the most effective and simple instrumentation for preliminary research purposes.

To measure and record weather conditions, we have chosen an inexpensive weather station with RS232 (serial) output. The Oregon Scientific WM-918 instrument [5] measures a variety of weather phenomena, including rainfall, humidity (indoor and outdoor), temperature (indoor and outdoor), wind speed, wind direction, and barometric pressure. Binary data is kept on a central server and fed from the HPWREN backbone sites for user retrieval [6]. This data is then plotted in reference to the wireless MIB data [7].

Construction design of the weather stations varies from location to location and is largely dependent on the surrounding environment and man-made structure(s). Preliminary weather station construction called for the weather collection apparatus to be mounted on large sections of plywood or plastic. This type of construction created a number of problems. The most crucial being the lack of shielding from radio frequency (RF) radiation and the relatively large foot print that the weather instrumentation requires. Current construction design has a more streamlined approach in which all of the collection apparatus are mounted in a linear fashion on top of each other through the use of a 2 inch rigid metal pipe (Figure 1). The modified pipe allows for easy mounting of the weather station, as well as supplying ample shielding from stray RF. For a list of parts and construction details, see the HPWREN weather station Web page

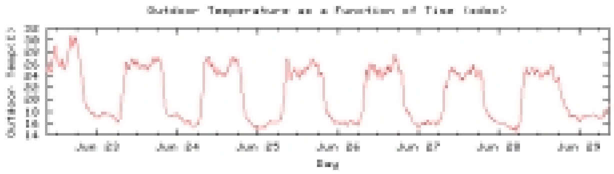

Fig. 3. Outdoor temperature at UCSD/SDSC

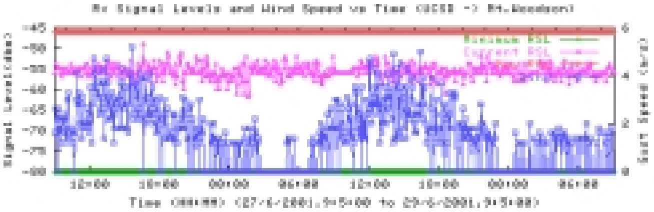

Fig. 4. RSL and wind speed at UCSD/SDSC

[8].

There are currently two such weather stations deployed, with a third planned for installation. The current locations are atop the roof of the San Diego Supercomputer Center (SDSC), a coastal site; the second is atop Mt. Woodson in Ramona, an inland mountain site. These stations are 17.75 miles apart. A third station is planned for the Mt. Laguna Observatory (MLO) site. It should be noted that weather conditions at any one site can vary drastically from the other sites.

With two weather stations deployed and data being collected, we have begun to look for correlations between network metrics and weather phenomena.

III. DATA COLLECTION

The HPWREN currently utilizes two types of data collection. Both radio data and weather data are collected at five minute intervals. Weather data is read off of the serial port in binary form and stored on a central collector located at SDSC. Several tools have been written to convert the binary data to graphical and ASCII forms.

A variety of graphs and tables can be found on the HPWREN performance analysis Web pages [7].

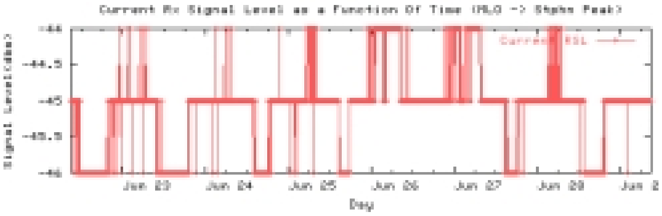

Fig. 5. RSL at Mt. Laguna Observatory (MLO)

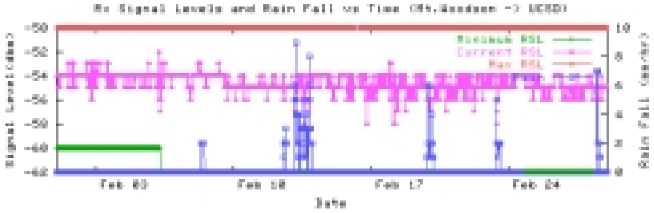

Fig. 6. RSL and rainfall at Mt. Woodson

Data tables include current weather conditions by site as well as weather almanac data. There are graphs for temperature, wind chill, humidity, rainfall, dew point, barometric pressure, wind speed, and wind direction. This data is available separately or in conjunction with the radio data. Figure 3 shows the outdoor temperature at UCSD/SDSC during a week in June 2001. Figure 4 shows the radio received signal level (RSL) data at UCSD/SDSC in conjunction with the wind speed data.

Unlike the weather stations which use RS232 and the existing Transmission Control Protocol/Internet Protocol (TCP/IP) [2] infrastructure, radio data is collected via SNMP calls and the User Datagram Protocol (UDP) [2]. The raw MIB data is then plotted with a number of *perl* scripts built into the HPWREN Web pages.

The MIB data reflects various parameters such as signal and noise values, signal to noise ratios, and transmission data for the Lucent radios, as well as radio status, RSLs, error intervals, and bit error rates for the Tsunami radios. Figure 5 illustrates RSL at MLO for the MLO to Stephenson Peak link.

IV. WEATHER CONDITIONS AND OBSERVATIONS

We have found that different weather phenomena effect the wireless links in a variety of ways. One of the strongest correlations that we have seen is that of precipitation and network performance degradation.

A. Rain and Snowfall

Previous studies have shown that absorption, scattering, and refraction of microelectromagnetic waves by atmospheric gases and precipitation is an important limiting factor in transmission distances in wireless communications. In fact, rain, fog, and clouds become a significant source of attenuation when wireless networks operate using the microwave spectrum [9].

This limiting effect has been noticed on a number of occasions in the HPWREN. For example, we ob-

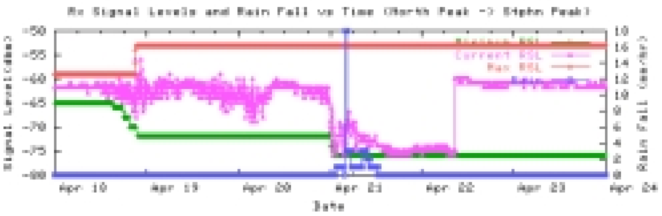

Fig. 7. RSL at North Peak and rainfall at Mt. Woodson

Fig. 8. Snow and ice on a grid antenna at the La Jolla relay

served a significant drop in the RSL on both sides of the UCSD to Mt. Woodson link during a particularly heavy rain storm in February 2001. In Figure 6, there is a drop in RSL of approximately 4 dBm between February 10th and February 17th.

A similar observation was made during a snow storm in April 2001, which resulted in an even larger RSL drop. The signal path between North Peak and Stephenson Peak (approximately 13 miles) experienced a RSL drop of about 14 dBm (Figure 7). It should be noted that Figure 7 does not exhibit a strong correlation between precipitation and network degradation. This is because weather conditions reflect only those of Mt. Woodson, which is located approximately 20 miles away from North Peak. Unfortunately there are no weather stations atop Stephenson Peak and North Peak. They are presented, however, to show that there was precipitation in the area.

The observation of signal degradation with the snow storm (signal fade) is particularly interesting because the RSL drop and eventual RSL increase occurred at very rapid rates. During this signal fade event, useful connectivity was lost for approximately the duration of the storm. Further details can be found in [10].

Many of the mountain sites within the HPWREN have snow on occasion; Figure 8 shows one of the grid antennae covered in snow and ice at the La Jolla relay site (backbone to user network node). As discussed in the preceding paragraph, it is quite evident that snow attenuates RSL. It would be reasonable to assume that this link path would be effected in a similarly negative manner. Unfortunately, radio data is unavailable for this time period (due to nonweather related conditions). In addition, even if radio data had been available, we lack weather instrumentation at this site. Clearly, additional work needs to be done in this area.

B. Wind

Wind appears to be another aspect of weather phenomena which may effect wireless network performance. To date, we have little direct evidence of this. However, the presumption of this effect is based on a number of factors. The pressure on an antenna during wind storms or strong wind gusts may shake or vibrate the radome thus causing it to gradually shift out of alignment. Even the slightest antenna misalignment can have noticeable effects on RSL.

For example, we had significant problems with antenna alignment atop the La Jolla relay. A particularly strong wind storm caused the antenna to move enough, such that the signal level dropped below acceptable limits. This forced us to revisit the site and realign the antenna to achieve a stronger signal level.

Special care must be taken to ensure precise and stable mounting, in order to avoid vibration and shifting. With our current deployment of cameras, it is possible to see antenna tower vibration in windy conditions. Knowing that our highly directional antennae (1.5 degree beamwidth for the 8 foot radome) are susceptible to misalignment, vibration of the tower and a shift in antenna alignment is a great concern.

C. Humidity and Temperature

Humidity and temperature are additional phenomena which may effect wireless networking equipment. Although the effects of temperature and humidity may be insignificant in terms of link path propagation, computer and radio equipment is highly susceptible to these factors. With this in mind, our measurements allow us to verify that the electronic equipment is maintained within the recommended environmental conditions. If these conditions are exceeded, negative results may arise. For example, if temperatures rise above recommended levels, the packet processors in the routers may cause errors and failures. Radio equipment is likewise effected, as high temperatures cause distortion in the output waveform during

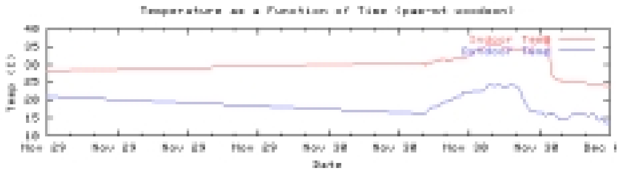

Fig. 9. Indoor and outdoor temperature at Mt. Woodson in November 2000

final stage amplification.

In addition to allowing us to monitor whether equipment is within recommended operating environmental conditions, sudden temperature changes can alert us to potential problems or emergencies. For example, in November 2000 (Figure 9), we noticed that the temperature in the Mt. Woodson communications room rapidly approached 40 degrees centigrade. Our first thought was perhaps a small fire, but investigation showed that it was an air conditioning issue. While not as dangerous as a fire, if left unrepaired, this situation could have damaged the equipment at this site, thus corrupting the data.

V. FUTURE WORK AND CONCLUSION

We have yet to find conclusive evidence that associates network degradation or improvement to defined weather phenomena. There are a number of possible reasons for this. First, we have not deployed weather stations at all of the wireless network sites. Second, we have collected data for a relatively short period of time. Third, our weather instrumentation is rather rudimentary, and although accurate, does not give high precision. Furthermore, there may be an association between weather phenomena and network metrics that we cannot yet measure. For example, we cannot accurately measure cloud cover, ionospheric levels and inversion layers. This leaves open many questions regarding weather phenomena and their effects on the wireless network performance.

The effects of solar conditions on the HPWREN may also be an interesting area for future research. Solar flux, a measurement of the intensity of solar radio emissions with a wavelength of 10.7 cm (a frequency of about 2800 MHz), may have a significant role in the daily functioning of the HPWREN. During solar activity peaks, the noise floor may increase, thereby effecting RSL. Currently, work is being done to record daily solar flux values. When available, these values will be displayed with the Tsunami and Lucent MIB data sets.

Visibility and cloud cover may also have strong effects on network performance and our solar arrays. The exact effects caused by fog and the marine layer, in terms of radio wave propagation, within the HPWREN infrastructure are as yet unknown. It has been noted, however, that ‘rain fade’ (the degradation of RSL due to rain) is a large problem when going through cloud cover at microwave frequencies. With the marine layer being at a lower elevation than our mountain sites, significant effects may be felt between the coastal and mountain nodes. We hope to associate marine layer, inversion layer, and fog effects with RSL, through the use of high quality Web cameras atop Mt. Woodson and MLO.

With our current equipment and research, we have shown evidence of certain weather phenomena effecting network performance. Future work should provide the opportunity to give more insight into the association of network performance and external weather phenomena.

VI. ACKNOWLEDGMENTS

This work was sponsored by the National Science Foundation under Cooperative Agreement No. ANI-9807479 and Grant No. ANI-0087344 to the University of California, San Diego (UCSD). Frank L. Vernon of Scripps Institute of Oceanography (SIO), UCSD is the co-principal investigator of the HPWREN. This work was done in close collaboration with the National Laboratory for Applied Network Research (NLANR) Measurement and Network Analysis group [11]. We would like to thank Todd Hansen for his support and inspiration. We would like to acknowledge the editing help received from Maureen C. Curran and Kim Bruch.

REFERENCES

[1] High Performance Wireless Research and Education Network (HPWREN), http://hpwren.ucsd.edu/
[2] Request For Comments, http://www.freesoft.org/CIE/RFC/
[3] Broadband wireless WAN networking systems: Western Multiplex, http://www.wmux.com/
[4] Lucent, http://www.lucent.com/
[5] Oregon Scientific, http://www.oregonscientific.com/wm918.html
[6] HPWREN Weather Station Data, http://stat.hpwren.ucsd.edu/Weather
[7] HPWREN Measurement and Analysis Web Server, http://stat.hpwren.ucsd.edu/
[8] Weather Station Parts, http://stat.hpwren.ucsd.edu/Weather/html/construction.html
[9] VHF/UHF/Microwave Radio Propagation: A Primer for Digital Experimenters, http://www.tapr.org/tapr/html/ve3jf.dcc97/ve3jf.dcc97.html

[10] Todd Hansen, Pavana Yalamanchili, and Hans-Werner Braun. Wireless Measurement and Analysis on HPWREN, unpublished. E-mail: tshansen@nlanr.net

[11] National Laboratory for Applied Network Research (NLANR) Measurement and Network Analysis group, http://moat.nlanr.net/