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Internet on the Edge

Abstract

We take broadband Internet access for granted sometimes, because it's all around us-- at our work, in our homes, at restaurants and coffee shops. But what if you need to provide broadband access out to the middle of a field through a tree line and hundreds of meters away from any buildings or utilities? What if you only have a few weeks to develop a solution and put it into production? How can we create a solution that will support a moving target? This paper describes how we provided Internet and Voice over Internet Protocol (VoIP) service to a group of researchers who were testing autonomous robotic vehicles on the grounds of the National Institute of Standards and Technology (NIST) by using commercially available wireless products and a few scraps of wood.

The Challenge

The Defense Advanced Research Projects Agency (DARPA) was testing autonomous wheeled robots used for search and rescue as part of the Learning Applied to Ground Robots (LAGR) project. We were asked to provide Internet access and VoIP communication to their contractors working on the NIST Gaithersburg campus at several remote outdoor areas, located hundreds of meters away from any building or utility. The DARPA team needed broadband Internet access for their small internal network of computers located in their mobile communications trailer. These computers were used to collect data and stream real-time video of the robotic trials conducted on the NIST grounds. The team also needed to communicate by telephone with the contributing researchers at several universities during the trials.

We only had a few weeks to figure out and implement a solution. We started by asking our centralized network team how close we could get to the testing sites with wired network access. We thought that if we could get fairly close to the testing area, we could use a wireless access point to shoot the signal the remaining distance.

The nearest wired access available to the first designated testing site was in an underground utility tunnel at the intersection of two streets, accessible via a manhole cover approximately 500 meters from the testing site. The network team estimated it would take one day of labor from a contract cable installer to complete the network run and provide us a physical network jack. The contractor who could do the work was only available one day during the week, and was about to leave on vacation for two weeks.

After some more investigation and physically walking the area above the network drop, we found that even if we established this wired connection from the underground utility tunnel, the surrounding terrain would not give us enough elevation to have wireless line of sight to the testing area. We needed to come up with another solution in a different location. Since running a wired connection to the various testing areas was not feasible due to time constraints and cost, a wireless solution seemed to be the only realistic option. But none of the access points in our inventory were capable of such range.

At the time, our wireless infrastructure only supported a couple of conference rooms and our system administration office. Our wireless equipment consisted of one Cisco 4402 Wireless LAN Controller, six Cisco 1131AG Lightweight Access Point Protocol (LWAPP) access points, and one Cisco 1240AG autonomous access point. All of these access points were designed for indoor operation. The theoretical maximum outdoor range of the 1131AG access points, while still providing an acceptable signal strength level, was approximately 250 meters. In real life, when traveling over rolling terrain, with a dense tree line in the way, the actual distance is much less. Clearly our existing indoor access points with internal antennas were not sufficient to provide an acceptable solution. There was no other centralized wireless presence on the campus at that time, so after consulting with and receiving permission from the central networking team, we created our own solution.

Can We Make It Happen?

At this stage, we knew we would have to purchase equipment designed to withstand outdoor use. NIST maintains a relationship with our network vendor so we started by contacting them to arrange a site survey with one of their engineers. We began testing with equipment we already owned, and we borrowed an external 13 dBi Yagi antenna from our vendor contact. We wanted to compare the coverage pattern of the Yagi antenna to the default internal access point antenna. From scraps of wood found in my garage, we built a wooden platform to mount the access point, the Yagi antenna, and a tripod mount, to which we attached a video tripod.

In order to get the signal to the external edges of our 234 hectare (578 acre) campus, we had to locate the originating access point as high as possible. The rooftop of our laboratory headquarters building seemed to be the ideal location, so after securing the appropriate permission from Facilities and Security, we accessed the roof of our building and set up the tripod with the wireless access point and the Yagi antenna. For signal and power, we temporarily ran 30 meters of Cat5 cable and an extension cord out the roof top door to the access point. While we were up there, we discovered a wonderful steel pipe support structure with mounting points for some construction webcams. The construction had been completed long ago, and the cameras were no longer needed, so we requested and received permission to use the structure. It would be perfect for mounting our wireless access point and external antenna when we were ready to deploy the system.

Our first test using the external Yagi was a line of site shot to the first designated testing location 650 meters away on the other side of the pond (Figure 1). At that location, we could make a weak 802.11g wireless connection with a disappointing throughput of only 80 Kbps. To improve our wireless performance, especially to reach testing sites that were farther away, without line of site, over uneven terrain, and choked with trees and vegetation (Figure 2), we would have to acquire the right equipment.

After researching other potential antenna solutions and talking to several wireless engineers, we purchased two Cisco Aironet 1300 series outdoor access point/bridge devices, and two Cisco AIR-ANT 3338 parabolic dish antennas. The dish antennas had half as much azimuth 3dB beamwidth compared to the Yagi antenna and would provide an antenna gain of 21dBi (and they looked really cool, too!).

We configured the first outdoor access point as a regular LWAPP access point with the external dish antenna, connected to our existing wireless controller. This access point would send and receive the wireless signal to and from the remote site. However, we also realized that just getting a strong wireless signal to the designated testing site was not enough; the DARPA testers needed a wired network connection to connect their router and internal network. To accomplish this, we configured the second outdoor access point as an autonomous device (not dependent on the wireless controller) functioning as a workgroup bridge (WGB), connected to the second parabolic dish antenna. The WGB converts the wireless network signal from the access point into a wired Ethernet connection. Computers that cannot support a wireless client adapter can connect to the WGB through the wired Ethernet port.

Now that all the equipment was configured in our test lab, we setup a dedicated Service Set Identifier (SSID) for exclusive use by the WGB. All wireless network traffic between the access point and WGB was encrypted using Wi-Fi Protected Access 2, Pre-Shared Key (WPA-PSK) using Advanced Encryption Standard (AES).

We did some initial (and successful) connectivity testing in the lab, but we had no more time left in our schedule for field testing the access points with the new antennas. Since we knew our design was sound, we made the decision to go ahead and deploy the first wireless access point and dish antenna to the headquarters rooftop.

Let's Do It!

With less than a week to go until the autonomous vehicle testing began, we had finally received and configured all of our equipment and we were ready to physically mount the equipment to the existing steel pipe support structure sitting on the roof of our building. On the day we planned to install all the equipment, we loaded our access points, antennas, and cables onto a cart, and rolled it across campus to our headquarters building. As we approached the elevator to take us up to the roof, some maintenance men exited the elevator with steel pipes on their shoulders. The pipes seemed ordinary enough, but somehow looked strangely familiar. Oh, well, no big deal. We arrived at the top floor, and there were more men waiting for the elevator… holding more pipes. Suddenly we had a bad feeling. Surely it couldn't be. I mean, they wouldn't take down… gack! We walked out onto the rooftop to find our steel support structure was GONE! Vanished! Nothing left but a small pile of sand. Apparently, somebody had submitted a work request six months ago to remove the cameras and dismantle the unused support structure, and the workmen were just now getting around to removing it.

Now what? We had to be ready to go in a few days, and we needed some kind of structure to support our antenna and access point. We walked back to the office, completely shell-shocked. Our brains were spinning. Could we find some metal and a welder and someone who could weld? How fast could we recreate a structure on the roof and where would we get materials on such short notice? As we walked, we happened to pass a large wooden packing crate sitting on a pile of debris in front of someone's laboratory. Hmm, Plan B! We asked the owners if we could have the crate. Yes we could! With a few creative modifications, we could make this crate work!

First, we needed to cut the crate in half. Luckily, I always have a circular saw and other tools in the back of my car for such emergencies. My coworker and I, while following appropriate safety precautions, sawed the crate out in the hallway in front of the system administration office. While we were cutting, our supervisor walked by during this display and asked "Um, do I really want to know?" We said, "Don't ask."

After a quick trip to the local home improvement store to purchase some steel pipe, u-bolts, washers, nuts, and several hundred pounds of sand bags, we were all set. The newly modified crate became our support structure (Figure 3). We reinforced the base of the crate, mounted the steel pole to the side with the u-bolts, carried the monstrosity up to the roof, and weighted it down with sandbags. Voilà! Now we could mount our access point and antenna, hook up power and network and start broadcasting, right? Well, not quite.

Anytime you want to put an electrical device outside, you have to consider the safety requirements. You must properly electrically ground the device so it does not damage the rest of your system or any innocent bystanders if lightning should strike. Per the instructions provided by the manufacturer, we purchased a roll of #6 copper ground wire and ran a 75 foot section of wire from the coaxial cable grounding block to the building earth ground as identified by the Facilities electrician. The access point connected to the building network via dual, RG-6 coaxial cables, which provided both data and power. The grounding block was placed in-line with the dual coax cables, which connected the access point to a Cisco 1300 series LR2 Power Injector. The power injector was mounted indoors inside an electrical box (conveniently left behind from the previous camera project) and converted the dual F-Type connectors on the coax cables (suitable for harsh environments and outdoor use) into a standard Ethernet interface (suitable only for indoor use). The Ethernet port on the power injector connected into the building network, or in the case of the WGB, functioned as a local area network (LAN) port for other routers or switches.

We also had to consider the overall power level produced by the access point in combination with the parabolic dish antenna. Due to the 21dbi antenna gain, and minimal antenna line losses due to the very short cable we used, we could not run the access point at maximum power without exceeding the power limitations as determined by the Federal Communications Commission (FCC). We calculated the line loss, antenna gain, and power output from the access point to determine the total Effective Isotropic Radiated Power (EIRP), which could not exceed 30dBm per FCC regulation, and stepped down the access point power output accordingly.

We mounted the second outdoor access point (configured as a WGB) and its dish antenna to the vendor's roof mount kit, which was then mounted to a small wooden base created from a scrap sheet of plywood. This base could then be easily attached with clamps to the roof rack on top of the DARPA mobile communications trailer.

We had to manually align the rooftop dish antenna to direct the signal to the position of the WGB dish antenna for each testing site. We were able to determine the correct position for the rooftop antenna and the mobile antenna using Google Earth. The program allowed us to quickly locate and identify a specific testing site from a given latitude/longitude, measure distances between the roof-mounted access point and proposed testing site, and determine the proper azimuths and elevations for the external antennas.

Once the antennas were properly aligned, we were ready to begin transmitting our wireless signal to the WGB mounted at the remote site. We powered up the devices, and… they worked! Using the built-in tools on the wireless controller, we measured a connection data rate of 54Mb/s between the roof-mounted access point and the trailer mounted WGB. Live bandwidth speed tests varied from 6 Mb/s down, 4 Mb/s up (during early morning hours) to 2 Mb/s down, 700Kb/s up (during middle of the day peak load). These bandwidth variations were due to load on the network backbone and had nothing to do with wireless configuration.

Additionally, we provided VoIP so that the team could have a central number for conference calls and general communication, avoiding the use of personal cell phones. We purchased a Grandstream GXP 2000 VoIP phone for less than $100, which had more than enough capability for what we needed, and setup a VoIP service agreement, including a local Direct Inward Dial (DID) number, for less than $4 per month.

It's Showtime!

All of the computer and network equipment used by the DARPA team was housed in a mobile communications trailer. The team had a second trailer used for robotic support and storage. The trailers were delivered to the NIST campus the day before testing operations commenced and moved to the designated location for that week's testing schedule. Because there were no utilities available at the testing sites, the trailers were powered by a generator using inverter technology to provide clean power for the DARPA computers and other electronic devices, including our remote WGB.

DARPA returned to NIST four more times after the initial test. The testing location moved with each visit. DARPA would e-mail the location of the next test site, allowing us to pre-align the rooftop antenna in preparation for the test day. The locations were selected based upon the physical terrain features. Most of the locations were not visible from the access point mounted on the roof. DARPA also gave us less notice of the location with each subsequent visit. For one visit, I drove out to the proposed test site the day before the testing was to begin. There was nothing there! They had found "a better test location" and moved there without notifying us, so we had to go back to Google Earth and recompute the azimuth and elevation for the new test site, then reposition the antenna.

Overall, the DARPA contractors were very happy with the services we provided. Despite the challenges and hiccups along the way, we managed to put together a solution that had never been considered (really-- who puts Internet service and VoIP in the middle of a field) and we learned a lot in the process.

Lessons Learned

1. Be flexible (or as I like to say, "Semper Gumby"). When things don't go according to your plans, you've got to figure out Plan B. Or C.

2. You need a lot more sandbags than you think you do.

3. Sandbags will deteriorate and fall apart after exposure to the weather for a year.

4. If you build it, they will come… back (apologies to Kevin Costner). Don't plan on a solution only being used for a short time if it works well. What you think is a temporary solution might become permanent.

5. Use the tools you have available to you. Who would have thought a wooden crate and Google Earth would have such an impact on the success of this project?

6. You can glue a few pieces of technology together, and with a reasonable amount of effort, provide a business solution that has never been done before.

Figure 1 – Rooftop view of the first test location, just beyond the far side of the pond.

Figure 2 – Rooftop view of the second test location, somewhere between the pond (just below the tree line) and the water tower in the background.

Figure 3 – The modified packing crate turned into a support structure (minus the sandbags).