Abstract:
The LINKROAMER 493 is a solar, wind, or AC powered Wi-Fi relay station that provides internet access in remote areas where Wi-Fi signals are not available. The main component of the system is a MikrotikRouterBOARD supporting up to three high power FCC Part 15 compliant wireless cards including the latest 802.11n PCI cards, giving the LINKROAMER the flexibility to operate as a relay point, a wireless bridge, or a Wi-Fi repeater. Standard N-type connectors enable the station to use a wide range of directional and omni-directional antennas, depending on the application. The LINKROAMER 493 operates on two 12V 12Ah Sealed Lead Acid Batteries, ensuring continuous operation of the system for up to 24 hours when no external power sources are available. The batteries are charged through the industry grade Hybrid Charge Controller that was designed by the group, accepting a wide variety of input sources including solar panels, wind turbines, and even 120/240VAC sources through an optional Meanwell RS-25-15 Power Supply. A NEMA 4 all-weather enclosure protects personnel against incidental contact with the enclosed equipment and prevents damage to the LINKROAMER 493 from harsh weather conditions such as rain, snow, and even sandstorm, giving the LINKROAMER the capability of operating virtually anywhere in the world.

1. Problem statement
These days many people expect Wi-Fi service virtually everywhere. Internet usage has grown by 138.7% in the United States and by 362.3% around the world during the period that spans 2000-2009. In the United States and in much of the industrial countries, the trend has been towards increased implementation of wireless networks.
Among one of the drawbacks of wireless networks is the short range of the radio frequency signals. One solution is to deploy a wireless relay point that can extend wireless coverage range as shown on Figure 1.

![Topology](image)

**Figure 1: Extending wireless coverage using LINKOAMER 493**

### 2. Approach

The LINKROUTER 493 is a Wi-Fi relay station designed to provide internet access in remote locations where Wi-Fi signals are not available. The LINKROUTER 493 can receive radio signals (802.11 frames) from an Access Point (AP), end user device, or another relay station. The device can then relay messages between individual users and even sub-networks that use different protocol types including the latest 802.11n standard. As a result, the LINKROUTER 493 is an effective solution to overcome signal impairments such as RF attenuation or reduction of signal strength during transmission. The LINKROAMER fills holes in coverage, enabling seamless roaming. When configured as a Wi-Fi Repeater, the LINKROAMER 493 acts as an Access Point (AP) to clients and as a client to the AP. The wireless repeater beacons the AP using one channel and communicates with the clients using a second channel. Because the on-board Mikrotik board allows simultaneous operation of three Wi-Fi devices, a third wireless card can be easily set up to allow wireless bridging between the main and a secondary network.

Wireless Relay Points similar to the LINKROAMER 493 currently exist in the market, but most are designed for use with AC power lines. In remote locations, where AC power availability is non-existent, AC powered relay stations are not feasible, and energy must then be harvested from available resources. A relatively new source of electricity is solar panels, which convert energy harnessed from the sun into usable electricity. However, solar panels are only about 30% efficient, and solar energy may not be available for extended periods of time in some regions in the world. The LINKROUTER 493 has therefore been designed with a third power source in mind that relies on wind power.

The LINKROUTER 493 features a battery charge controller that can accept direct input from solar panels, a wind turbine, or a combination of both for maximum power input. The circuitry automatically disconnects a fully charged battery from the sources to prevent damaging the battery from overcharging. Similarly, if the battery voltage approaches the minimum threshold voltage at which it can safely operate, all loads will be disconnected from the unit preventing further charge loss. During high wind conditions, a dump load mechanism is activated when the voltage of a wind turbine exceeds 17VDC. This circuit redirects the excess energy to a load resistor path, thereby slowing down a turbine and protecting it from self-destruction in high wind speed conditions.

### 3. Hardware design

The LINKROUTER 493 runs on two 12V 12Ah batteries and a charging mechanism is necessary to prevent damage to the battery from overcharge conditions. The charge controller circuit shown in Figure 2 compares the battery voltage to a fixed reference voltage through IC3. When the battery voltage is above 15VDC, the comparator’s output goes low and Q9 stops conducting, ensuring that the gate voltage of Q4 goes high. Any current from the source to the battery is consequently effectively blocked. The Schottky diode D1 prevents current from flowing to
the sources from the battery while keeping the forward voltage drop as low as possible. When the battery is disconnected from the load, its voltage usually tends to rise. To prevent Q4 from switching very rapidly, a feedback resistor R16 was added to introduce hysteresis to the system. The D-type flip flop IC4 prevents unwanted noise and drives the status LEDs.

Similarly, the system ensures that the battery voltage does not fall below a certain threshold that could potentially damage the battery. A Maxim ICL7665 Voltage Monitor was selected for this purpose. The ICL7665 is equipped with an internal reference voltage making it fairly simple to calculate the trip voltages. When the battery voltage of the batteries fall below the threshold voltage, the output of the ICL7665 goes high, disconnecting the battery from any loads that are connected to it (Figure 3). An LED connected to a second output of the Maxim chip can be used to indicate that the battery voltage is low. In the LINKROUTER 493, the low voltage warning LED turns on and the loads are disconnected when the battery voltage is below 12V and 11VDC respectively.

The LINKROUTER 493 charge controller also features a switching mode power supply operating in parallel with the Charge Controller. The heart of this switching supply is a LM5118 Buck Boost Controller. On the LINKROUTER 493
the LM5118 circuitry is designed to accept any voltage between 10 and 75VDC to output a constant 14.3V. Note, however, that because the LM5118 is connected in parallel to the charge controller, the controller with the higher voltage will be the one charging the battery. This prevents unnecessary power waste from the switching mode power supply when the battery is high by routing power through the charge controller. It also ensures that when the supply voltage is low, the battery keeps charging by means of the LM5118, making it an ideal solution for solar/wind powered systems.

A Dump Load Controller is necessary to prevent damage to Wind Turbines from over-spinning. Over-spinning of a wind turbine can be controlled by placing a very low resistance load between its two terminals, however this load resistance should only be connected when the turbine is over-spinning to avoid wasting power into that resistance. The Dump Load Controller works in a similar fashion as the Charge Controller, with the difference that when the turbine voltage is too high, meaning it’s probably over-spinning, the current is redirected through a low impedance path to ground. The comparator IC3B is used to monitor the turbine’s voltage, and when this voltage is above 18VDC, its output goes low. An inverter IC3C then flips the voltage to high so that Q5 starts conducting, making the gate voltage at Q6 go low thus allowing current to flow to the dump load. A status LED is used to indicate when current is flowing to the dump load.
The Charge Controller and the Dump Load Controller both require a 5V source to establish a reference voltage. This 5V source is not connected to the battery, but directly to the sources, and is activated only when the source voltage is above 12VDC. Additionally, the Charge Controller makes use of D-type flip flops, so a clock oscillator is necessary for proper operation. The Power Routing Section is designed so that the voltage that goes towards the battery is the sum of the voltages from two input sources. Input 1 can be any DC source including solar panels and 10-15V supplies like an RS-25-15, while input 2 is designed exclusively for wind turbines, though any other input source would be acceptable, so long as 18VDC is not exceeded. The circuit board has three outputs: Battery, which provides power to the batteries; 12Vload1, which provides power to the radio board; and Option, which the user can configure to output either 12V or 5VDC depending on the application.

All circuits have been implemented on a single PCB board. This target board is a fabricated 4-layer PCB, as shown in Figure 6. Figure 7 shows the final charge controller and professionally implemented system with respect to safety standards and regulations.

4. The digital board
The design of the networking component of the LINKROAMER 493 originally started out as just a wireless (Wi-Fi) signal repeater. Later on during development, the MikroTikRouterboard 493 (RB493) was chosen to replace the WRAP.2c board, which opened up the project to more options that weren’t available with the previous hardware. The RB493 has three mini-PCI slots that can accommodate wireless radio cards. With the RouterOS v4.0 release, the RB493 could also support 802.11n technology. Considering this, the board was equipped with three radio cards: 2 Atheros 5213 802.11a/b/g WLAN cards and 1 MikroTik R52n 802.11 a/b/g/n WLAN card.

The first card was configured to use 802.11g on the 2.4GHz band. This card was used as a link to a base wireless access point (AP). It was named WLAN 1 and was also configured as a DHCP client so this interface can acquire an IP address automatically from the AP. The second card, named WLAN 2, was also configured to use 802.11g on the 2.4GHz band. This interface, however, was configured to be used as a wireless distribution system (WDS), so that other devices similar to the LINKROAMER could have access to the base AP through the router board by daisy chaining WDS bridge connections. The third card, named WLAN 3, was configured to use 802.11n on the 2.4GHz band. This interface implements a DHCP server in order to distribute IP addresses to client/host computers that connect to it. WLAN 3 is essentially the RB493’s redistribution AP. This is where the “repeating” of the signal comes into play, although the device as a whole is no longer a Wi-Fi repeater. It is more of a “Wi-Fi Routing
Repeater,” because the wireless interface on WLAN 3 is on a different subnet than the subnet the other two wireless interfaces use.

![Image of charge controller circuit board and LINKROAMER 493 system](image1)

**Figure 7:** The charge controller circuit board and the LINKROAMER 493 system in its enclosure

In order to achieve connectivity from a client/host computer through the LINKROAMER to the base AP, a routing protocol and Network Address Translation (NAT) had to be implemented. To do this, Routing Information Protocol (RIP) v2 was chosen. Since the network area doesn’t consist of many different devices, a more complex routing protocol was not needed. The routing protocol was configured to use the 3 wireless interfaces and the IP address of the base AP was set as the neighbor to the router. Since the routing table populates itself, no other routing configuration was needed. For added security and functionality, a network address translation (NAT) was setup between WLAN 3 and WLAN 1, so that all IP addresses from WLAN 3 would be translated as the outgoing IP address of WLAN 1. NAT thus makes it very hard for someone to observe or scan IP addresses behind WLAN 1 because all they can see is the IP address of WLAN 1. However, outgoing traffic can still reach all network destinations outside of WLAN 1.

![Image of Test Area](image2)

**Figure 8:** Test Area. Building 1 hosted the Wi-Fi signal the LINKROAMER 493 provided coverage of up to 1400ft.
With this configuration, multiple clients/hosts can connect to WLAN 3 and acquire IP addresses from its DHCP server. These computers can then reach any network resources (including the Internet if connection is provided to the AP) connected to the base AP through the LINKROAMER. The throughput is governed by the data rate of the slowest performing wireless interface. WLAN 3, which uses 802.11n has a data rate that can reach up to 300Mbps. In this situation, WLAN 1, which uses 802.11g is a bottleneck because its maximum throughput is 54Mbps. So the overall maximum air data rate of the LINKROAMER is 54Mbps. The WDS bridges the connection to the base AP to other LINKROAMER nodes that may be daisy chained to WLAN 2 without loss in throughput.

5. Experimentation
During experimentation, the LINKROAMER 493 was capable of providing service to a Wi-Fi user up to 1400 ft away from the station. The George Mason University (GMU) campus area where the testing was performed is detailed in Figure 8. A pair of 10dBi directional antennas was used for this purpose. One pointed at the campus to get connection to an Access Point (AP) in a building. This radio in the device became a client to that AP. The other antenna pointed in the direction of the parking lot to offer Wi-Fi service on another radio channel in the coverage area. Test conditions included clear weather and a semi-clear line of sight to the repeater. Figure 9 demonstrates that good data throughput is available at the unit itself as well as to remote clients that connected to the Internet through the unit.

![Figure 9: Throughput as seen when laptop is connected to the LINKROAMER via Ethernet (left) and throughput as by distant client thru the LINKROAMER (right)](image)

6. Conclusions
The Hybrid Powered Wi-Fi Repeater is directed at the markets where Wi-Fi access is desired but there is no AC power in the vicinity. It enables Internet service providers to offer near-ubiquitous access to the Internet. The system increases the range of wireless signals and provides non-line-of-site capability that makes system deployment and implementation very simple. The Hybrid-Powered Wi-Fi Repeater is a self-contained system that is easily deployable and requires minimal space. It can be operated completely without AC power, although, provisions were made for times where AC power would be available. The system is especially useful in remote areas where access to AC power is limited, such as campsites and hard to reach mountainous areas. Perhaps of more significance is that this device would make it possible for providing sustainable access to the Internet in many third world countries where access to electrical power sources is limited.