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Libre Router Connectivity Enhancement Interfacing the Hardware Capable of Cellular Connectivity

Ms. Sonali Vagadia[1], Mr. Nikunj Patel[2], Prof. Nirav Desai[3] and Dr. Hitesh Shah[4]
[1]Research Scholar, EC Dept., G.H. Patel College of Engineering & Technology
Email: sonali.vagadia97@gmail.com
[2]Team Lead, System Level Solutions (I) Pvt. Ltd
Email: nikunj.patel@slscorp.com
[3]Assistant Professor, EC Dept., G.H. Patel College of Engineering & Technology
Email: niravdesai@gcet.ac.in
[4]Professor & Head, EC Dept, G.H. Patel College of Engineering & Technology
Email: hiteshshah@gcet.ac.in

***Abstract*—Today the internet is a basic and worldwide requirement for each and every individual to access email and the world wide web. As on date the connectivity of internet services is provided via Wi-Fi or Ethernet. Here we are planning to expand the capabilities of the community network using the libre router to provide internet access to certain geographic locations like rural areas where they don't have internet access or localized access. In a nutshell, the LibreRouter is a weatherproof 3- radio wireless router, but it is much more than that. It comes from the factory with LibreMesh, an Operating System for Geek-Free Wireless Mesh Networks, that makes it easy for a non-technical community to do the deployment, maintenance and expansion of the network. Using its two 5 GHz radios and sector antennas, the Libre Router automatically forms a mesh network with other LibreRouters within range. Using the 2.4 GHz radio, it creates a hotspot around it for clients to connect to the network, and the resulting mesh network enables communication between all the devices connected to it. LibreRouter is an open-source hardware Wi-Fi router designed from the ground up for community networks. LibreRouter projects builds on available satellite or wired internet connection within a community and uses the RF routers for expanding the connection into the areas where it's required, thus forming a mesh network that anyone can use irrespective of their physical location. So, we will be interfacing hardware to the LibreRouter which should be capable of cellular connectivity, ultimately providing distance connectivity.**

***Index Terms*— LibreRouter connectivity enhancement, Rural cellular network connectivity, First responder network, Open source Wi-Fi router, LibreMesh, OpenWrt, Wi-Fi mesh protocol.**

I. INTRODUCTION

In this era of technological advancement, internet access for each and every individual has become a basic necessity. Today we are seeing a surge in internet users all over the globe whether it is in the urban area or the rural area. The internet service providers target well built-up areas, medium or large-scale businesses like online trading, e-trailers with a need for space on a server. They mainly focus on a more lucrative dedicated server as

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they have more profit and less overhead. Today 4G technology has become stable and the 4G base stations are installed almost everywhere with a need to use 4G handset. Now as technology is evolving towards the launch of 5G, people need to switch their 4G devices to 5G which is not affordable for the people living in rural areas. At the same time the internet service providers have planned to start the deployment of 5G in metro cities or areas which are densely populated. However, still there are certain rural or sparsely populated areas where people are not able to access either 4G or the web services [1][3]. An estimated 37,439 inhabited villages in India did not have 3G/4G mobile internet coverage in february 2021[2]. The 5G deployment is going to be completed in stages from urban to highways to rural area and rural villages in an expected span of 5-6 years. As 5G deployment will be time consuming and also expensive, there is a long wait for the rural area and rural villages to access good internet services [9]. 5G supported LibreRouter network has the ability to become the first responder and fulfill the current technology gap by solving relevant issues like High bandwidth source only wired, Low/no network issue, Approachability, Efficiency, Affordability, Low operating costs, Robustness, Geo location support. Looking to that, the plan is to use the LibreRouter for connecting the unconnected [9]. Here we are introducing a LibreRouter Device to solve the above mentioned issues. Now definitely a question rises here that why we choose LibreRouter and not any other router. The LibreRouter is an open source hardware Wi-Fi router designed by AlterMundi especially for the self-provisioned and rural community networks. With LibreRouter being an open source device, communities can build, own, and operate their own open IP based networks. It is a weatherproof 3-radio wireless router from the LibreMesh factory. Basically here the plan is to connect LibreRouter to a hardware device capable of cellular connectivity. A mesh network will be created with the use of two 5GHz radios and the 2.4GHz radio will provide hotspot to the target users of that particular area [9].

II. METHODOLOGIES

A. LibreRouter

LibreRouter is an open-source hardware Wi-Fi router designed for community networks. The LibreRouter project builds on existing satellite or wireless internet connection within the community and uses RF routers to extend connectivity to areas where it is needed, thus creating a mesh network that anyone can use irrespective of their physical location. It is designed and manufactured with features aiming to make it easier for communities to install their own mesh networks. LibreRouter is a weatherproof 3 radio wireless router from the original LibreMesh factory. It has two 5GHz radios and one 2.4GHz radio. Every part of the design, SoC, radio etc. designed to be libre. LibreRouter has its own firmware called LibreRouterOS based on LibreMesh and OpenWrt with official LibreRouter support. Most of the software development takes place directly in LibreMesh and OpenWrt projects. LibreRouter consists of dual-band Wi-Fi with additional 4G/5G module support. The router can easily extend the 4G/5G network to rural, remote areas with the help of 4G/5G towers situated on the highway or nearby area and it can be done with an existing Wi-Fi mesh protocols [9].

B. LibreMesh and OpenWrt

LibreMesh being modular framework supports in creating OpenWrt-based firmwares for wireless mesh nodes. Several communities around the world use LibreMesh as the foundation of their local mesh firmwares. The LibreMesh project includes the development of several tools. The firmware allows simple deployment of auto-configurable, yet versatile, multi-radio mesh networks [7].

Now let's see how LibreMesh works. The designed network architecture for LibreMesh is based on two layers. Cloud layer 2 uses the dynamic routing protocol BATMAN-ADV. BATMAN Advanced is a mesh routing protocol that runs in kernel space. Even if the network topology is made of multiple nodes and multiple hops, B.A.T.M.A.N. Advanced abstracts it to a single layer 2 broadcast domain. So, from the user's perspective the whole mesh is like a single LAN. This is a robust architecture for roaming purposes and hence even when moving and changing the access points, the TCP-UDP connections are not lost [7]. By default, entire network layer 3 uses the routing protocol BMX. BMX6 (or the new version BMX7) is an IPv6 native dynamic routing protocol that is offering very advanced features and a small network overhead, thanks to the distance-vector strategy and its set of optimizations. BMX7 (Batman experimental Version 7) has additional security routing extensions. By default, all nodes are running both routing protocols (BMX and BAT-ADV), but on different VLANs. Hence, the routing is isolated by the MAC layer [7]. OpenWrt (from open wireless router) is an open-source project for Linux-based embedded operating systems, used primarily for embedded devices to route the network traffic. The main components are Linux, util-linux, musl, and BusyBox. All the parts are designed to be small enough to fit within the limited storage space and memory available in the home routers. OpenWrt is setup

using the command line interface (ash shell) or web interface LuCI. Approximately 3500 software packages are available for installation with the opkg package management system. OpenWrt can work on a variety of devices, like CPE monitors, seat gates, smartphones, portable computers, etc. It is also possible to use OpenWrt on personal computers and laptops. OpenWrt has a writeable root file system, allowing users to edit any file and easily install additional software. This is in contrast to other firmware based on read-only file programs that won't let you modify installed software without rebuilding and flashing the entire firmware image [6]. This is achieved by covering a read-only compressed SquashFS file system with a writeable JFFS2 file system using overlayfs Additional software can be installed with the opkg package manager and package repository consists of approximately 6000 packages. The OpenWrt provides common bug fixes and security updates even for devices that are no longer supported by their manufacturers. OpenWrt provides full opportunities to configure common network-related features, such as IPv4, IPv6, DNS, DHCP, router, firewall, NAT, port forwarding and WPA. OpenWrt has a Mesh networking feature through B.A.T.M.A.N., OLSR and IEEE 802.11s-WNIC driver capabilities and other ad hoc mesh routing protocols implemented within Linux [6].

C. Routing Protocols

The main task of the routing protocols is to find reliable routes in multi-hop networks using a mostly unreliable wireless medium. The WMN routing protocols have been extensively studied in the literature [11-13]. Below is the brief about different routing protocols supporting us in routing and network management for the created LibreRouter mesh network.

BATMAN Advanced

B.A.T.M.A.N. advanced (often referenced as batman-adv) is an implementation of the B.A.T.M.A.N. routing protocol in the form of a linux kernel module operating on layer 2. Most other wireless routing protocol implementations (e.g., the batman daemon) operate on layer 3 which means they exchange routing information by sending UDP packets and bring their routing decision into effect by manipulating the kernel routing table. Batman-adv operates entirely on ISO/OSI Layer 2 - not only the routing information is transported using raw Ethernet frames but also the data traffic is handled by batman-adv. It encapsulates and forwards all traffic until it reaches the destination, hence emulating a virtual network switch of all nodes participating. Therefore, all nodes appear to be link local and are unaware of the network's topology as well as unaffected by any network changes. The easiest way to think about a batman-adv mesh network is to imagine it as a distributed switch. Each system (often called "node") running batman-adv is equal to a switch port. Each node is running an instance of batman-adv. Such an instance is a virtual network interface (often called "bat0") which looks to the system like a switch port that allows access to the distributed switch. The actual details of the (direct or indirect) communication between the node is then hidden behind the "bat0" network interface. To make communication possible between the different bat0 interfaces on the different nodes, batman-adv relies on Ethernet compatible network interfaces which gets attached to bat0 as so called (lower) hard interfaces. This concept should already be known by Linux bridges [8].

BMX6 (BATMAN Experimental)

BatMan eXperimental version 6 is an open-source mesh routing protocol, an advanced version of BMX daemon(BMXd) which came as an individual branch out of BATMAN routing protocol. Being a mesh routing protocol, BMX6 distributes node descriptions which can contain node-specific configurations. It optimizes communication between neighboring nodes for minimal protocol overhead. Design and development this new version was driven for the purpose of better coping the situation with extended address space provided for IPv6 addresses, enable node configuration while specifying management of conflicting node declarations (e.g., duplicate address allocation), and allow effective state distribution (thus reduced to the top of the protocol) with a sharp contrast between the local and global environment and the static and dynamic state [14]. BMX6 is a proactive, distance vector, table-driven, layer 3 wireless protocol with a goal of composing path from source to the destination via making a decision on each node that which node will be the next hop. It is a distance vector protocol, since the information managed by each node is a list of tuples of nodes' identifiers and its cost of reaching there while choosing a concrete link: destination node, next hop, cost. The BMX6 uses a dissemination mechanism to propagate information. The protocol is inspired by the human social networks that are scalable as people tend to learn more about their neighborhood and abstract and filter out information about others [14]. BMX6 has an optimized communication scheme where each node has its own compact vocabulary to talk about other nodes in the network which ultimately reduces overall protocol overhead. This vocabulary is local and is known only by the neighboring nodes. Learning of this vocabulary happens in the transient state. The protocol can be in the transient or the steady state. In transient state, each node distributes its own information over the

network in form of descriptions and the vocabulary of the neighboring node is learnt. Once each and every node knows the descriptions of all the other nodes in mesh, the protocol will move to the steady state and will disseminate only the periodic packets to calculate link metric and end to end path metric values. As the work is done in the transient state the periodic packets are compact[15].

BMX7 (BATMAN Experimental)

BMX7(BMX6+SEMTOR) is an extension of BMX6 routing protocol which is currently used in production community wireless mesh networks. It operates on layer 3 of OSI extending the concepts of receiver-driven routing and the principles of DSDV routing. The goal of BMX7 is to provide secure mechanisms to ensure that non-trusted nodes in an open network are effectively prevented from disrupting the routing between trusted nodes. It's achieved by enforcing the exclusion of a given set of identified faulty nodes. The routing update of BMX7 (in contrast to traditional DSDV) contains a single and verifiable heartbeat value which unambiguously identifies a particular node of the network and a specific version of this nodes' self-defined description and routing-update version [16].

D. Community Networks

The development of 5G networks in the rural areas and rural villages can be achieved with Community Based Networks [5]. Community Networks are large scale, self-organized and decentralized networks, built and operated by citizens for citizens [4]. Community networks consist of many nodes, links, content and services. They are extremely dynamic and diverse, as they are built in a decentralized manner, mixing wireless and wired links with diverse routing schemes with a diverse range of services and applications. There are various existing community networks, like guifi.net in Spain, AWMN in Greece to name a few. Community Networks are studied substantially in [4] & [5]. The paper on community based networks and 5G [5] discusses how community based networks are beneficial in providing wireless standard benefits to the end user. With their research on community based network and 5G they discovered and concluded that the 5G connectivity can be stretched out to remote places like rural areas and rural villages via the vehicle of community networks. The paper on a case for research with and on community networks [4] briefs about what is community network and the benefits of using community networks. They have also explored the relation of community networks with the community lab for the purpose of research advancement. Community network is an emerging model for citizens to build, operate and own open IP based networks and it can be self-owned, self-governed and self-managed by the members of the community [4][5].

E. Practical Considerations

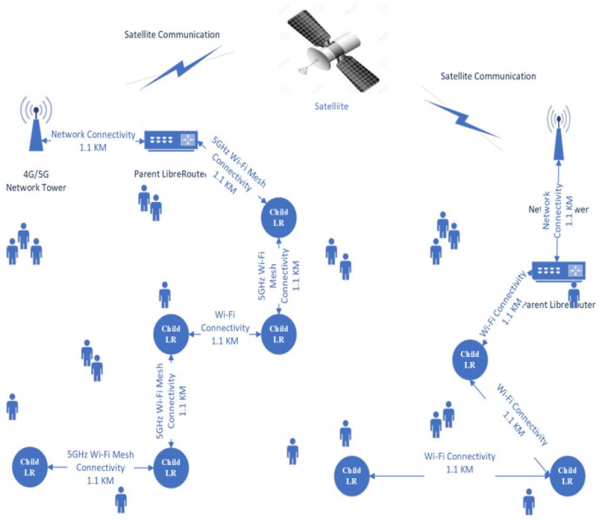

Figure 1 : LibreRouter network connectivity diagram

LibreRouter consists of a combination of 2.4GHz and 5GHz dual band Wi-Fi support and further it can also provide us with support to the 4G/5G modules. The router is capable enough to stretch the 4G/5G network to the remote/rural areas with the help of nearby 4G/5G towers which possibly might be located on the highways and it

can be possible via creating a mesh network with the help of Wi-Fi mesh protocol. LibreRouter can work as an AP as well as Master device which can be helpful in creating a mesh network with a purpose to cover large geographic area [9]. As shown in Fig. 1, the first step towards connecting the unconnected is creating a network connectivity of LibreRouter with the nearest 4G/5G towers who gain their network connectivity via satellite communication. With the help of the tower, we gain access to the 4G/5G internet services available at the towers. The router accessing the network connectivity directly via 4G/5G towers is said to be the Parent router. The Parent router is connected to the 4G/5G towers over the radio communication supported by the two 5GHz radios of LibreRouter. Likewise, to gain Wi-Fi connectivity for the rest of the LibreRouter devices to be connected in the mesh network, they are connected via Parent LibreRouter and hence automatically forming a mesh network. Here LibreMesh modular framework helps in generating OpenWrt-based firmwares for the existing wireless mesh nodes within the LibreRouter mesh network. Routing in the mesh network is supported by the routing protocols under the layers of LibreMesh. LibreMesh network architecture design is based on two layers. Cloud layer 2 and Network layer 3. The Cloud layer 2 uses the dynamic routing protocol BATMAN-ADV and the Network layer 3 uses the dynamic routing protocol BMX(Bamtan experimental). LibreRouter has a 2.4GHz radio which gives the users a provision of Wi-Fi services via connecting to the available hotspot network on the respective LibreRouter. Lime is an application that becomes a medium of support for the users to access the Wi-Fi services. A network is to be created for each and every node in the mesh over the lime app whose hotspot can be accessed by the target users. Conventionally, internet services were provided via Ethernet (Wired) or Wi-Fi (limited Wi-Fi range) in a particular region of target. Here for accessing the internet services we have planned to design/adopt a hardware device capable of cellular network connectivity and USB/PCIe support. Ultimately this will be done by utilizing the LibreRouter capabilities of supporting the 4G/5G modules. The USB/PCIe supported hardware device can be connected to the parent LibreRouter and hence provides network connectivity. The network connectivity available at the Parent LibreRouter is accessed by the Child Node/ Next LibreRouter in the mesh as a Wi-Fi connectivity. The internet speed would be bifurcated at each router connecting to the mesh network. Although, we found that the range of distance to be kept between the mesh nodes for providing the LibreRouter Wi-Fi connectivity from one node to another is to be within the range of 1.1km practically, which will eventually serve the end users in the remote and sparsely populated areas and hence would save the deployment cost of 4G/5G towers in different remote locations.

III. Experimental Results

A thorough LibreRouter testing is done to recognize the hardware and software capabilities of the module. Below are shown the after-test results with the LibreRouter.

1) Device Booted Successfully : The Fig. 2 shows that the device is updated successfully and shows the existing firmware within the device.

2) Firmware Update : Here as shown in Fig. 3, we have performed the firmware update for the router. The steps to be followed for updating the firmware are noticeable from the above image.

3) Ethernet and WI-FI Test : We need to check the status of Ethernet and Wi-Fi connection and its availability. Fig. 4 shows that the Ethernet and Wi-Fi are connected successfully and showing ”OK” status for both.

4) Eth0, Eth1 and LEDs Test

Eth0 Test : To commence Eth0 test, one needs to make an Ethernet connection between the PC/Laptop and the LAN port of the LibreRouter device. Now boot the LibreRouter and after successful booting of the device, test whether you are able to access the lime app web page or not. Also ping the IP address over the command prompt. Connections for Eth0 test are displayed in Fig. 5 and test results for Eth0 are shown in Fig. 6 and Fig. 7

Eth1 Test : Now for testing Eth1, just connect Ethernet cable to the WAN port of the LibreRouter and boot the device. Once booting process ends, check the IP address of the router which will be reflected over the com port window as shown in Fig. 8. The test results for the LEDs are shown in Fig. 9.

5) USB Test : To access the USB slot of LibreRouter for connecting the device capable of cellular network connectivity, we have to test the USB slots to see whether they could support us with USB communication with the external USB modules or not. The LibreRouter has two USB slots- Upper USB slot and Lower USB slot. We connected a USB Pen drive to both the LibreRouter USB slots individually and observed the successful test results as shown in Fig. 10.

6) Practical Results showing Wi-Fi Hotspot Connection : The Fig. 11 shows a number of Wi-Fi devices connected simultaneously to the LibreRouter network. Here we have connected 11 simultaneous Wi-Fi devices with a LibreRouter network for accessing the internet services. The testing for the greater number of nodes is

under test. Hence, we can expect at least 45-50 nodes to be able to connect to the Wi-Fi network of a single LibreRouter device which can easily serve the remote and sparsely populated areas.
7) Speed Test : Fig. 12 shows the internet speed test results for the available Wi-Fi network.
8) Watchdog Programming Test : Once the watchdog is programmed, we need to connect a jumper to the jumper pins on the LibreRouter to test whether the watchdog is programmed successfully or not. After connecting the jumper, wait for at least 12-13 minutes and check the uptime. If it does not reboot by now, then we can say that the watchdog is programmed successfully. Fig. 13 reveals the successful completion of Watchdog programming and tested it via a jumper connection.
9) Hardware Reboot Test : The S2 switch as shown in Fig. 14 is accessed to test the hardware reboot. Press the S2 switch once and your device will start performing the reboot whose logs are visible on the com port window as shown in Fig. 14.
10) Mac Address Test : The Fig. 16 shows the mac addresses that we specified onto the device.
11) Factory Reset Test – Switch(S2) : To attempt factory reset, there is a S2 switch on the LibreRouter device as shown in Fig. 17. Factory reset can be executed by pressing S2 switch for 5 seconds and you can observe the device initiating the factory reset over the com port window as shown in Fig. 18.

Figure 2 : Device boot result

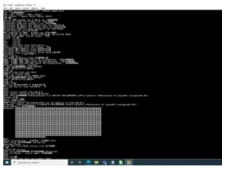

Figure 3 : Firmware update result

Figure 4 : Wi-Fi / Ethernet test result

Figure 5 : Board connection for Eth0

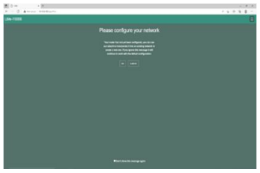

Figure 6 : Lime app web page

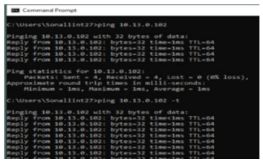

Figure 7 : Eth0 connectivity test result over cmd

SYSTEM1 :

STATUS1:

2G WLAN1:

Figure 8 : Eth1 test result

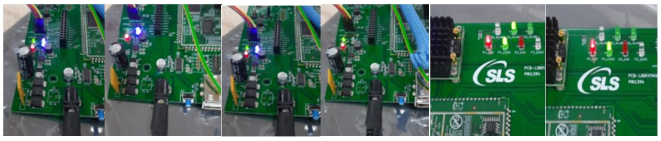

Figure 9 : LED test results

USB Drive_Upper USB Slot Test :

USB Drive_Lower USB Slot Test :

Figure 10 : USB drive Upper/Lower USB slot test result

Figure 11 : Practical result showing number of devices connected to the hotspot

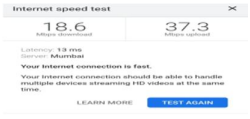

Figure 12 : Internet speed

Figure 13 : Watchdog programming

Figure 14 : S2 switch to perform hardware reboot test

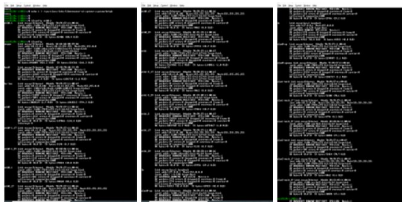

Figure 16 : MAC address test result

Figure 17 : S2 switch on the LibreRouter for performing factory reset

Figure 18 : Factory reset test

IV. Conclusions

Conventional methods of accessing internet services via Ethernet and Wi-Fi have limitations in providing services to remote and sparsely populated areas and serving distant connectivity as remote areas are sparsely populated leading to less financial benefits to the service providers. This paper suggests an effective solution to fill the gap in providing good internet services to remote locations like rural areas and rural villages. LibreRouter is a promising open source hardware Wi-Fi router which builds a mesh network with several other routers in the network. After every 1 kilometer a node should be placed in a mesh network to provide long range connectivity. Rather than providing wired or short range Wi-Fi internet services, we have planned to introduce a hardware device capable of cellular connectivity to be connected to the parent node to serve the network connectivity. The network connectivity available to the parent router would become the Wi-Fi connectivity for the rest of the nodes in the network bifurcating the internet speed for each router connected in the mesh. This would help us reach and serve the remote and sparsely populated areas with modern and efficient internet services available. It will also result in saving the deployment cost for the users every time there is an advancement in technology.

Future Work

In contrast to the conventional method of using the wired connections for providing internet services, LibreRouter is under test with the Hardware device to support wireless network connectivity. This leads us to lower the deployment cost and allow the community to deploy their own network and modify it based on their requirements.

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