On the Design of Affordable and Green High-Performance Routers for Community Networks

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ABSTRACT

We argue that large scale user-driven community networks are becoming viable in areas without access to telecommunication services due to lack of commercial interest. We discuss the design of a key component supporting this claim: a high-performance, low-power-consuming and affordable router with fibre optic and wifi interfaces capable of forwarding 2 Gbps, 220kpps, powered by only 25W, which is between 7% and 17% of the alternatives in our comparison. The cost of the one-off prototype was below a third of the prices of comparable proprietary solutions and half of other open source alternatives. It can be reduced further in series production. Future work will include widening of bottlenecks without increasing cost and field tests in rural African settings.

Categories and Subject Descriptors

D.2.6[Computer Communication Networks]: Internetwork *Routers*

General Terms

Design, Experimentation, Measurement, Performance.

Keywords

Router architecture, Open Source routing, Robust low-cost design, Developing Regions.

1. INTRODUCTION

Access to communication networks and services, broadband and mobile, is a prerequisite to keep up with your peers, whether you are a country, an organization or an individual.

There is the misconception that such access is provided by commercial markets, if there is only a demand. This may be true in densely populated areas of developed regions. It is, however, definitely not true in developing regions nor in sparsely populated areas of developed regions, and the definition of what is sparse varies considerably. Even in developed regions, like Europe, about 10% of the households live in areas without such access and operators require contributions from universal access funds to go there due to the requirements of their business models. In developing regions, including most of Africa, the number is closer to 90%, at least on the broadband side.

Currently, communication network services in the developing world are far less advanced than in the developed counterparts. There are many reasons behind this, including under-developed policies and regulatory frameworks creating political risks, lack of all sorts of infrastructures, such as copper and optical fibre wire-lines, electrical power and developed supply chains, as well as poor commercial viability of traditional business models for network operators and service provider leading to high perceived commercial risks, etc.

Another reason is that the network equipment manufacturers are also controlled by the business models of their customers, the operators, and thus focused on the development of complex and expensive proprietary technical solutions for extreme traffic volumes and quality of service requirements.

Equally problematic is the fact that most of the core network equipment is extremely power-hungry and dependent on electricity supplied from the power grid, which is often unstable. They are designed without consideration to power consumption and robustness required in sparsely populated areas. Little attempt has been made to utilize alternative sources of energy in ICT applications, which could provide sustainable, stable and reliable power supply for infrastructure network equipment.

The simplicity of the Internet technology, open source software solutions, increasingly powerful off-the-shelf standard hardware components and an increasing understanding about how to exploit alternative energy sources, such as the abundance of solar and wind energy, all contribute to changing this drastically.

It is becoming possible for under-served user communities to build their own sustainable high-performance but low-power-consuming community networks on shoestring budgets, including infrastructure-sharing based on passive wavelength division multiplexing, 1-10 Gbps routers and optical links up to 100 km, etc [3]. Once such networks are up and running, all sorts of risks are reduced and the commercial interest from operators and equipment vendors that want to survive will increase. The increasing availability of networking components based on open source software and selected reliable, high-quality off-the-.shelf standard hardware components, makes it possible to deliver technical solutions with a performance on the same level as proprietary systems, or even better [2, 6, 25].

To address these challenges, there is a need to organise a user-driven community networking action to develop technical solutions as well as guidelines for how to deploy, manage and maintain sustainable high-performance community networks in under-served areas. We advocate the use of open source software, selected standard hardware and renewable energy solutions. By levering the performance increases of standard hardware and the power of open source communities, open networking systems can provide solutions that achieve superior performance at a fraction of the cost of comparable proprietary systems. In addition, open source solutions are highly flexible and can be customized accordingly. They promote collaboration and sharing of resources, and enhances innovation in learning. We see novel companies [1, 12, 28] providing support in open source routers.

Our contribution in this paper is in the design of a low-cost, low-power infrastructure router based on open source software and selected standard hardware components. Another contribution is on the analysis of the routing performance and power consumption. We are in other contexts working on the development of guidelines discussed above.

1.1 DESIGN REQUIREMENTS

Before the actual design of the router discussed in this paper, we analysed and defined all the requirements that would serve as guidelines while selecting the appropriate components.

1.1.1 Modularity and flexibility

We wanted to design a minimal network element for building long-haul backbone networks with the modular flexibility providing the options to use either optical fibre links or, if fibre is not available, long-haul wifi links. Besides two ports for the backbone links we wanted two ports for local connections.

1.1.2 High performance

Since backbones carry aggregated traffic, we wanted to use at least 1Gbps backbone links, in the optical fibre case, and achieve a routing performance of at least 2 Gbps.

1.1.3 Low Power

This is one of the most important requirements that also differentiates our work from all previous work done with open-source routing implementations. The low-power consumption requirement is related to the use of alternative power supply.

1.1.4 Robustness

We are designing a router that can be used for infrastructure networking, it should be able to survive under heavy network traffic conditions and operate 24 hours a day. Finding reliable components is translated to finding quality hardware and using reliable software (operating system and drivers).

1.1.5 Low Cost

As we aim for developing countries, we would like to design a router that is significantly less costly compared to commercial products of similar performance.

1.1.6 Open Source Software

Open-source routing software has many advantages compared to proprietary solutions, since it is freely available and continuously maintained and improved by communities of numerous highly skilled developers.

1.1.7 Standard components

We want the router to be comprised of standard components available in the market, not from custom-made ones.

2. IMPLEMENTATION

2.1 Software Considerations

We started by selecting software because the software highly affects the selection of hardware components. This is due to hardware compatibility issues as well as availability of drivers. As the operating system, we chose the Bifrost/Linux distribution [5], which is optimized for routing focusing on infrastructure networks. Like any Linux, it can run on standard x86-based, PC hardware. Some of the highlights of Bifrost/Linux include the following:

2.1.1 Stability

Bifrost/Linux has been used in mission-critical application for more than ten years and is proven to be an excellent choice for infrastructure networks [7].

2.1.2 Network performance

By using Bifrost/Linux, the maximum network performance and throughput that our hardware can support can be achieved [6].

2.1.3 Simplicity

Bifrost/Linux offers a structured file system that facilitates configuration. One script is used to set up the machine in a simple way when the router boots for the first time. For advanced configuration we can use other scripts and additional packages like *Quagga* [8] for routing, *Netperf* [9] and *Pktgen* [10] for measuring networking performances.

2.1.4 Dependency reduction

Since Bifrost/Linux can run on any standard PC-platform, the user can select the hardware available when building a router. Bifrost developers, however, suggest a list of network adapters [13] for which there are optimised drivers with very good performance and stability.

2.2 Hardware Consideration

After selecting Bifrost/Linux as the operating system, we performed extensive research for selecting the appropriate hardware components, based on the requirements we had already defined. The main components that generally comprise a software router are the Motherboard, Central Processing Unit (CPU), Network Interface Card (NIC), Main Memory and Storage Media.

2.2.1 Motherboard/CPU

The motherboard is the heart of PC-based router. It is basically the interconnection circuit between the CPU, the main memory and the NIC. Most of the low-power motherboards available in the market today include an embedded CPU.

It has been noted in [2] that the architecture and specifications of the CPU highly affect the routing performance of a software router. In addition, the available expansion slot(s) and the I/O bus architecture (PCI, PCI-X or PCIe) are very important, as they allow network cards to be added and affect the speed with which data is transferred between the network card and the CPU.

2.2.2 Network interface card (NIC)

The network card provides the required ports for interconnecting different types of links. The hardware specifications and the driver capabilities of the network card also affects the performance of the router. For some cards, additional pluggable modules are required for connecting copper or fibre links.

2.2.3 *Main memory*

Memory is not an issue in software routers as they never store packets but process them directly whether forwarded or dropped. Some memory is needed if there is a big routing table like when using full Internet routing with BGP. This takes some hundred megabytes, which is not a problem on a PC-platform since they nowadays normally have Gigabytes of memory. [2, 26]. The type and the specifications of the motherboard define the suitable type of memory.

2.2.4 *Storage Media*

This is where the operating system is installed. Bifrost/Linux is preferably installed on a USB stick. The general design of motherboards make them external. It could be an advantage to have the removable USB inside the case.

2.3 Hardware Selection Process

Firstly, we describe choices for the main components of the router, namely the network card and the motherboard. After choosing these two, the selection of all the components, i.e. the main memory or the permanent storage, is trivial.

2.3.1 *Network card*

Taking in mind all the requirements explained previously with a focus on modularity, flexibility, reliability and performance we have chosen the Interface Masters Niagara 4NE-76-4SFP NIC [14].

Figure 1. The Interface Masters Niagara 4NE-76-4SFP NIC

It is based on the Intel 82576 chipset, which together with the igb driver for Linux has already been extensively tested on Bifrost/Linux and proven to be reliable and robust. The ability to insert different types of modules (called small form-factor pluggable transceivers – SFPs) for different types of links adds to the modularity of the whole router design. This card can support 1 Gbps, copper Ethernet links or single-mode and multi-mode fibre links by plugging different types of modules that are commercially available up tp 160km. In addition, this board supports Digital Optical Monitoring (DOM) for collecting the physical layer statistics of the optical fibre. DOM is a feature supported by Bifrost/Linux as well.

For lower power consumption, we selected the version that does not include a crypto chip [15]. This NIC has 4 SFP ports with nominal power consumption of 7.5W, higher when all four SFP ports are used. A picture of the card is shown on Figure 1.

2.3.2 *Motherboard/CPU*

After selecting the network card, we conducted extensive research to find an appropriate motherboard and CPU. Two additional requirement arose of: 1) existence of a PCI express slot on the motherboard to support the NIC and 2) an x86-compatible architecture supporting the Bifrost/Linux operating system. The Intel Atom family of CPUs seemed to suit our needs. We came up with two alternative motherboard/CPU solutions, each one with its benefits and drawbacks.

The first candidate was the Quanmax KEEX-2030 board [16], pictured in figure 2. This motherboard has a low power consumption (AVG=7.4W/ MAX=10.8W) [17] and a PCIe x4 expansion slot that allows the NIC to fit without any need for converters. It is also inexpensive and does not need a power supply unit (PSU), since it takes plain 12V DC voltage as input. In addition, this motherboard is completely fanless and uses only passive heat sinks for cooling.

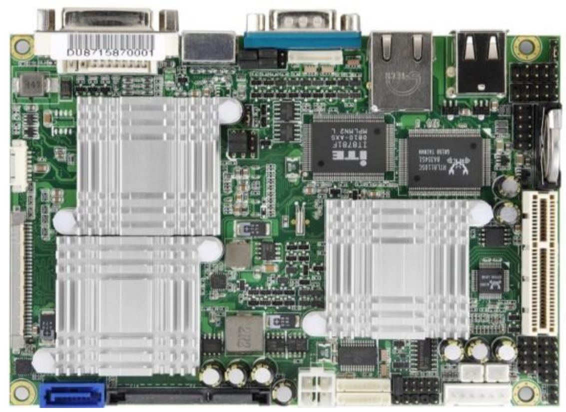

Figure 2. The Quanmax KEEX-2030 motherboard

The second alternative was the Portwell NANO-8044 board [18]. This motherboard has a much lower average power consumption compared to previous one (AVG=5.7/MAX=10.8W) [17]. However, it is twice as expensive and has a PCIe x1 expansion slot requiring a converter to connect the NIC to the motherboard. Further to that, it required a power supply unit (PSU).

Since both motherboards seemed attractive choices, we decided to test both in different router configuration. The Quanmax KEEX-2030 gave the best routing performance.

2.3.3 *Main Memory and Media Storage*

Our chosen motherboard supports DDR2 400/533 SODIMM (small outline dual in-line memory module), up to 2GB. Thus, we use a Kingston 1GB SODIMM RAM from [23] as main memory. Since Bifrost/Linux can run from a flash disk, we use a Sandisk Cruzer slice USB 2.0 2GB [24] as media storage.

2.3.4 *Casing, Cooling and Physical Considerations*

We chose a rack mounted casing for our router, as this is the common type of casing used by commercial router products that are placed inside racks or cabinets. We also wanted it to be as compact and lightweight as possible while at the same time being able to hold the motherboard and the NIC securely. We decided to use the Travla C159 1U rack mounted chassis [19]. This casing is made mostly of aluminium and has a much shorter depth compared to regular 1U products. Due to low power consumption, active cooling is not required, eliminating the need for fans which has short lifetimes.

2.4 Flexible Power options

The system is designed to be powered by 12 Volt DC. This is attractive for all sorts of renewable energy option from solar panel charging a lead acid battery to a small wind turbine. The system was tested using ultra-capacitors instead of batteries.

2.5 The final product

The hardware components of the router were assembled inside the chosen chassis. Minor modifications were needed in order for all the components to be securely put in place. Specifically:

- Holes were drilled on the bottom of the chassis in order to secure the motherboard using distance screws. The reason for this modification is because the chassis was compatible with mini-ITX motherboard, whereas our motherboard had a different from factor (3.5'').
- The configurable back-panel was modified in order to fit exactly to the I/O ports of the motherboard. No ready-made back-panel was available.
- A PCIe riser card [20] was used to hold the network card steady in place when removing or adding SFPs. A hole had to be drilled in this riser so that it could be screwed to the metal PCI bracket of the chassis.
- The DC-DC included in the chassis was removed and the DC cable was directly connected to the P4 connector of the motherboard.

An internal view of the chassis with the components is depicted in figure 3. The final product is shown in figure 4.

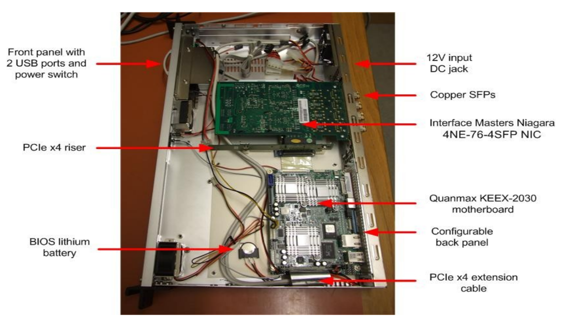

Figure 3. Internal view of the casing with the components

Figure 4. External view of the router

2.6 Total Cost

The total cost of the router is USD 1118.3, by summing up prices for the individual components bought. A summary of all components is provided in table 1.

Table 1: Hardware equipment cost - (2009)

serial	Item	Price (USD)
1	NIC (Interface masters Niagara 4NE-76-4SFP with DOM support)	422.5
2	Motherboard/CPU (Quanmax KEEX-2030)	211.3
3	Main Memory (Kingston 1 GB SODIMM RAM)	21
4	Storage (SanDisk Cruzer USB 2.0 2GB	13.3
5	AC/DC configurable power adapter	21
6	Travla C-159 rackmount chassis	239.4
7	PCI express extension cable PE-FLEX4-15''	70.4
8	PCI express right-angled extension cable PE-FLEX4-12''	70.4
9	Sweden Telecoms Copper SFP module	42.3
	TOTAL COST	**1,111.6**

3. PERFORMANCE EVALUATION

The purpose of the tests described in this paragraph is to accurately measure and evaluate the power consumption and routing performance of our low power router. We also wanted to make sure that the router can handle excessive traffic, i.e. is reliable and robust.

Although not part of the router, a monitor and keyboard was connected for output and input purposes. Also, the two laptops used were HP Compaq 8510W and ASUS M51Ta.

3.1 Routing Performance

For determining the throughput of our router and its power consumption under load, we constructed the test topology shown in figure 5.

Figure 5. Topology for testing two copper interfaces

All three machines running the latest Bifrost/Linux distribution (v.6.0.1, 32-bit Kernel). Tools used for generating traffic were netperf and pktgen, while ifstat2 was used for measurement. When using pktgen, we generated traffic using various packet sizes according to appendix B of [21]. The same guideline was used to calculate the router's wire speed.

The test results are summarized in table 2 while Figure 6 show the throughput versus packet size, when generating traffic from both host A to B with different packet sizes.

Table 2. Routing performance and power consumption

Characteristic	Amount
Routing throughput (packet rate)	223Kpps
Routing throughput (data rate)	1860 Mbps
Power Consumption when idle (two copper interfaces)	18.75W
Power Consumption when routing in maximum packet rate (two copper interfaces)	21.65W

In bidirectional pktgen tests using 1514 bytes, we see an aggregated forwarding performance of 1858 Mbps.

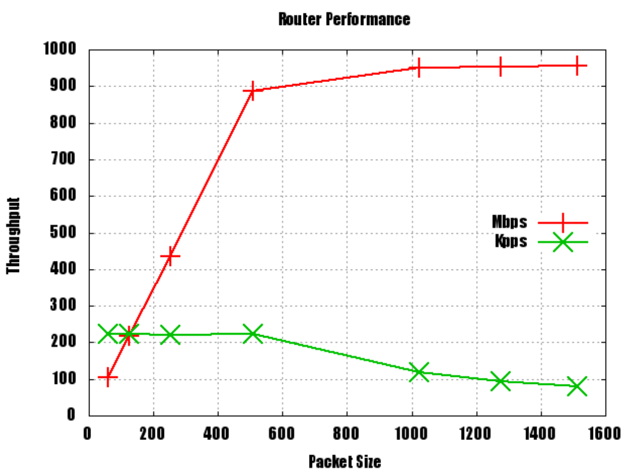

Figure 6. routing throughput in different packet sizes.

By observing figure 6, we see that for small packet sizes the routing throughput reaches a limit of about 220 Kpps. This limit is set by the processing capability of the system (mainly CPU), which cannot forward more than 220 Kpps. With larger size packets, the motherboard should be able to achieve more than 2 Gbps. Using the 220Kpps limit, calculated maximum routing throughput is 2650 Mbps with 1500 byte packets.

3.2 Power Consumption

To measure the power consumption of our router, we constructed the topology shown below, where the measuring tool is a DC power meter.

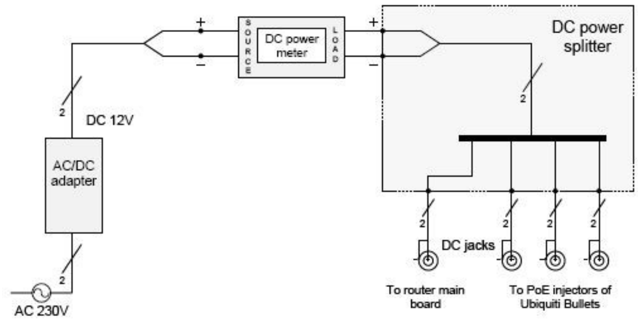

Fig 7: Topology of a DC power measurement

We first measured the power consumption of the router in idle state in order to estimate the individual consumption of various components. By following a simple methodology, where we measured the power consumption before and after adding a hardware component, we were able to estimate the power consumption of some components. The results are summarized in table 3.

Table 3. Power consumption of various components

Component	Power
Motherboard (idle)	8.4W
4-SFP port NIC with no SFP module installed (idle)	7.5W
Copper SFP module (no link and idle)	0.2W
Copper SFP module (link up and idle)	1.5W
Onboard Gigabit Ethernet interface (link up and idle	0.5W

3.3 Stress testing of the router

By generating traffic with pktgen for about 24h, where our router was forwarding packets at full speed, we concluded that there were no issues at all. The router had the same performance throughout the test, without any hangs or malfunctions.

3.4 Comparison with other Products

Table 4. Features and power comparison

	Minne	Cisco 2821	Vyatta 2501	Juniper J4350	Huawei AR49
Power Consumption	25W	240W	345W	143W	350W
License	Open Source	Proprietary	Open Source	Proprietary	Proprietary
Performance	2Gbps	~2Gbps	2 Gbps	2Gbps	~2Gbps
Cost($)	1,111	3,282	2,310	3,732	N/A

4. RELATED WORK

To the best our knowledge, a complete design including analysis of routing performance, energy efficiency and cost of open source routers have never been performed before. Vyatta [1], the open source alternative to Cisco routers are providing price-performance comparison only to Cisco routers. Really Nice Routers [12] is another company providing open source routers, but there is not much information on their website.

On the software side, the open-router project [22] seems not active any more. Some of the bottlenecks raised in [2] about PC-based open source software routers have been taken care of by the advancement in the hardware. The Click modular router [4], is interesting but not ready for production. The authors in [25] discussed more about open source router virtualization on commodity hardware.

5. DISCUSSION AND FUTURE WORK

The goal of our work is to define and build low cost, low power, high performance routers to be used in community networks. Such networks are emerging in many rural areas where purchasing power is very low and power supply is problematic. Also, we are creating a platform based on open source software and standard hardware to allow students to learn, as well as the research community to test their new ideas.

In the work behind this paper, we have designed and implemented a reliable, high performance, low-cost, low-power, completely fan-less router that uses an average power of 25 watts, supports fibre and copper links at Gbps speeds with a throughput of 2 Gbps or 220 Kpps. The router is housed inside a lightweight, rack mounted aluminium chassis.

When executing the routing performance and power consumption tests we did not have many routes on the routing table, neither did we have any other services such as NAT or VPN running. Thus, future work will include routing performance tests in the existence of a big routing table and other CPU-intensive services running on the router. In this way we could provide estimations for the routing performance under different conditions. Also, we plan to deploy the routers into our production network in Serengeti [3] Tanzania to further test it in a live network.

6. ACKNOWLEDGMENTS

The contribution of the MinNE student team making the actual implementation and testing of the prototype [26] in the Communication Systems Design framework (CSD) [27] is gratefully acknowledged.

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