Power Consumption Comparison of NetFPGA-based Routers

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Abstract—Energy efficiency is one of the most important issues in designing the future Internet. For examining an energy efficient router, in this paper, differnet routers such as rate control protocol (RCP) router, precision time protocol (PTP) router and reference router are compared in terms of the power consumption. The experimental measurements demonstrate that with varying the traffic load, the RCP router and the PTP router consume almost identical power which is about >1% higher than that of the reference router. This power degradation is observed to be from the 3.3V power component of the total power consumption and arises from the increased design complexity for implementing the RCP and the PTP onto the router. In addition, the down scaling of the NetFPGA core operational frequency is promising for reducing the energy consumption of the RCP router and PTP router.

Keywords-Power consumption; NetFPGA; Frequency scaling; Energy proportional network design.

I. INTRODUCTION

Internet has developed extremely fast in the past few decades. However, it is at the cost of consuming much resources of the world, in particular power. Currently, the telecommunication industry is responsible for about 5 percentage of the total power consumption in the developed nations. The total amount of the global power consumption is increased rapidly with the ever-increasing network size [1-3]. Therefore, the energy efficiency is one of the most important issues in designing the Internet.

To reduce the energy consumption of the Internet, people have focus on the router which is one of the most power consuming components in the networks. In the recent years, some green technologies [4-8] have been proposed for enabling energy-efficient routers, including for example, smart port sleeping and dynamic throughput adapting.

For having an insight into the power consumption distribution of the router and more importantly, for the future green technology design, the explorations have also been undertaken in the NetFPGA-enabled gigabit reference router [9,10].The reasons for adopting the NetFPGA as a router platform [10] include (1) NetFPGA can provide a fast and convenient way to implement a practical router; (2) NetFPGA is an open source and reprogrammable hardware platform, based on which researchers can easily realize novel power-optimized network algorithm; (3) NetFPGA can offer fine-grained energy measurements for per-byte storage and per-packet processing.

On the basis of the NetFPGA-based reference router, the work in [10] indicates that the power consumption of the router is proportional to the number of activated ports and the traffic rate, and the approach of significantly reducing the router's core frequency, namely frequency scaling, can considerably reduce its power consumption.

So far, few works on the NetFPGA has referred to the influence of the network algorithm on the power consumption. By introducing the network algorithms such as rate control protocol (RCP) and precision time protocol (PTP) into the reference router, the NetFPGA-enabled RCP router [11] and PTP router have been realized recently [12]. The RCP [11] involves explicit feedback from the router along the path, which can make the router adapt quickly to the network conditions; and the PTP timestamps the transmitted packets, estimates the clock difference between the master node and slave node, and allows two NetFPGAs to be synchronized down to a few 10s of nanoseconds [12]. Generally, the implementation of these network algorithms on the router can effectively improve the network performance, which however inevitably introduces changes to the router design and may subsequently affect the router's energy consumption.

Therefore, in this paper, comparative studies are executed between RCP router, PTP router and reference router, for the purpose of examining the energy performance of these three routers. These works is to identify the impact of the RCP and the PTP on the router's power consumption, demonstrate how large the impact is and simultaneously explore the origin of the impact. Moreover, the remaining work of the paper is to

investigate the frequency-dependent power consumption for both of the RCP router and PTP router. These works can provide more comprehensive information for future investigations of the energy-efficient and performance-robust routers.

The results shows that (1) with varying the traffic load, the power consumptions of RCP router and PTP router are almost identical, which are approximately >1% higher than that of the reference router; (2) the >1% power growth is from the FPGA chip power consumption and this amount corresponds to a growth in terms of the 3.3V power component (closely related with the power consumption of the FPGA chip); (3) the reduction of the NetFPGA core frequency is also promising for saving the energy of the RCP router and PTP router.

The paper is organized as follows. In Section 2, the RCP router, PTP router and reference router are outlined. In Section 3, the experimental setup for testing the RCP router, the PTP router and the reference router are described, which includes data source/sink, gigabit routers and energy measurement tool kits. In Section 4, experimental comparisons are undertaken among the three routers, in terms of power consumption. Finally, the paper is summarized in Section 5.

II. THE NETFPGA-ENABLED RCP ROUTER, PTP ROUTER AND REFERENCE ROUTER.

For obtaining the basic understanding of the RCP router and the PTP router in this section, the RCP router and PTP router are explicitly described. For comparison, the general background of the reference router is also presented.

A. *Reference Router*

The schematic diagram of the reference router is shown in Fig .1. First of all, the incoming packets from the networks (host CPU) are received by the MAC Rx (CPU Rx) in the Receive Queues. After read by the input arbiter via a round-robin algorithm, the packets are pushed into the module of Output Port Lookup. In the Output Port Lookup, the packets are processed by a number of router operations, including MAC address verification, TTL update, IP lookup and ARP lookup etc. After that, the Output Queues reads the processed packets, stores them into the SRAM and outputs them to the Transmit Queues. Finally, the Transmit Queues send the packets out to the networks (host CPU) through MAC Tx (CPU Tx).

To perform the IPv4 forwarding and handle ARPs, the router SCONE (software component of NetFPGA) is utilized. SCONE is an user level software [13] which has telnet (port 23) and web (port 8080) interfaces to handle router control, and also implements a subset of open shortest path first (OSPF) named PW-OSPF. SCONE mirrors a copy of its MAC addresses, IP addresses, routing table and ARP table to the NetFPGA card which hardware accelerates the forwarding path.

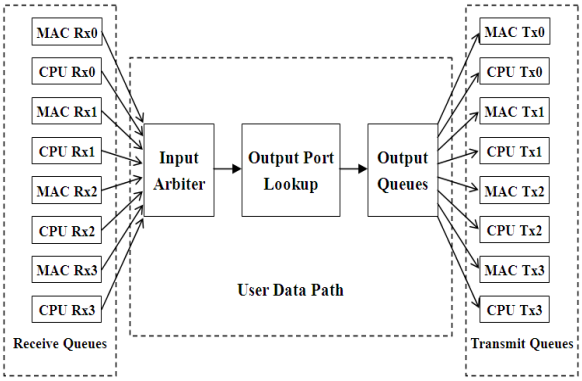


Figure 1. The diagram of reference router [13].

B. *RCP Router*

The RCP router improves the reference router with RCP. As mentioned in [11], RCP has a number of salient advantages including for example involving the feedback from the router along the path, allowing the sender to pick a fast starting rate, adapting quickly to the network condition, allowing performance stability under broad operating conditions and independence of flow-size distribution. The basic algorithm of the RCP can be summarized as follows [11]: (1) the RCP router maintains a single rate for each link; (2) the router updates both of the roundtrip time (RTT) and the aggregate traffic load per port; (3) the router updates the data rate and stamp the rate on each passing packet unless it already carries a slower rate value; (4) the router sends the value back to the sender device so that the sender knows the slowest rate along the path. By using this algorithm, the sender device can quickly find out the rate it should be using and adjust the sending rate.

C. *PTP Router*

The PTP router enhances the reference router with the IEEE-1588 PTP. This allows two NetFPGAs to be synchronized down to a few 10s of nanoseconds [12]. The IEEE-1588 PTP is a protocol that minimizes the time difference between the master node clock and the slave node clock and thus can precisely synchronize the slave clock with the master clock. The IEEE-1588 PTP can be simply described as follows: (1) the slave node timestamps the synchronization message received from the master node, compares it with the actual timestamp stored in the master's follow up message and gets the first time difference between these two timestamps; (2) the slave node timestamps the instant when a delay request message is sent to the master; (3) the master node timestamps the instant at the arrival of the delay request message and sends back a delay response message with the delay request arrival timestamp to the slave node; (4) the slave node gets the second time difference between the two timestamps, averages the first and second time difference and finally synchronizes the two nodes. The detailed description of the IEEE-1588 PTP can be found in [12,14].

III. EXPERIMENTAL SETUP

The experimental testing environment is utilized for measuring the power consumption of the three routers. The overall experimental system consists of a packet generator, gigabit routers and energy measurement tool kits. A PCI-based NetFPGA board is configured as a gigabit router, based on the open source project of the RCP router, the PTP router and the reference router respectively. The NetFPGA board is a low-cost reconfigurable hardware platform, which mainly contains one large Xilinx Virtex2-Pro 50 FPGA programmed with user-defined logic, one small Xilinx Spartan II FPGA holding the logic that implements the control logic for the PCI interface to the host processor, two 4.5Mbytes SRAM operating synchronously with the Virtex2-Pro 50 FPGA and four gigabit Ethernet interfaces. The clock frequency of the Virtex2-Pro 50 FPGA, which is the core logic frequency, can be toggled between 125MHz and 62.5MHz for enabling frequency scaling. To host the NetFPGA 1G router, one PC with an Intel CPU at 2.93GHz and CentOS 5.5 installed is used.

The packet generator performs as the traffic source and sink, with four ports connected to the gigabit router. It is realized by configuring another NetFPGA board based on the project of packet generator [15]. In the transmitter path, it can create packet stream with different packet sizes and adjustable data rate at each port. After forwarding through the gigabit router, in the receiver path, the received data rate can be calculated effectively at the corresponding destination port of the packet generator.

The power consumption of the NetFPGA router is measured through the collaboration of a PCI bus extender, a National Instruments DAQ and LabView software. The PCI bus extender (coded PCIEXT64UB by Ultraview Inc. [16]), is plugged into the motherboard slot of the host PC. The NetFPGA router card is then inserted into the PCI bus extender. The National Instruments DAQ (NI USB-6251 [17]), is connected to the PCI bus extender for collecting the instant power and the total power consumption can be calculated by accumulating the energy from the 5v and 3.3v pins on the PCI bus extender [10,16]. The 3.3v power component is related with the FPGA chip and SRAMs, and the 5v power component represents the power consumption of the PHY and MAC chips. For automatically collecting the power consumption data from the National Instruments DAQ, LabView is running on a separate PC and the DAQ is connected to this separate PC via a USB link.

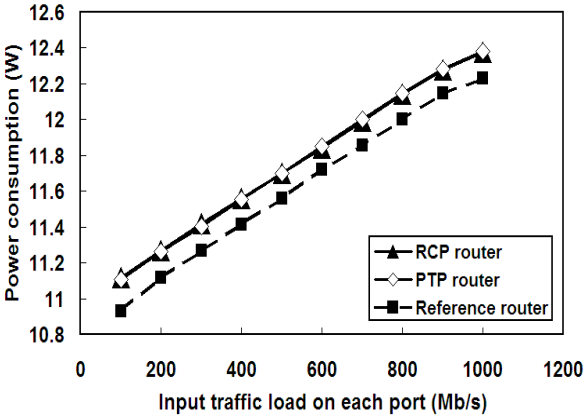
IV. EXPERIMENTAL RESULTS

For demonstrating the impact of the RCP and the PTP on the power consumption, in this section, the experimental comparisons are undertaken among the RCP router, PTP router and reference router. The packet generator software is utilized to generate the input traffic load with various packet sizes at different traffic rate from 100Mb/s/port to 1000Mb/s/port by 100Mb/s. For each test, all the NetFPGA Ethernet ports of the packet generator and the router are active and working under a specific traffic rate.

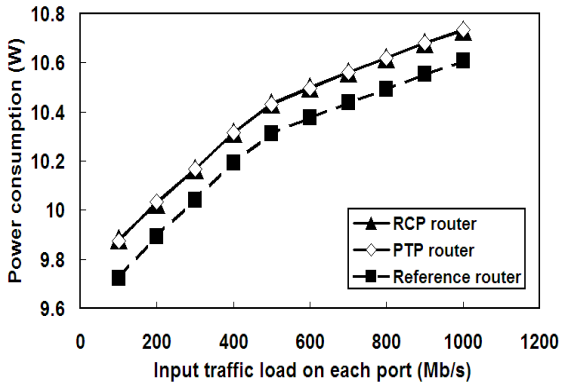
A. Comparisons of Power Consumption between the Three Routers

In Fig .2, the power consumptions versus input traffic rate are shown for the RCP router, the PTP router and the reference router. The Fig .2 (a) and (b) are measured with the operating frequencies of 125MHz and 62.5MHz respectively. At the core frequency of 125MHz or 62.5MHz, the power consumptions of the RCP router and the PTP router grow rapidly with increasing traffic load and almost identical values for both routers are found across all the traffic load rates. These values are approximately >1% more than those of the reference router at the corresponding traffic rate. Such power growth represents the influence of the RCP and the PTP on the router's power consumption and indicates that the RCP router and the PTP router degrade the power consumption performance when compared with the reference router. It should be mentioned that, in our experiments, the measurements are carried on with a number of packet sizes such as 1500 bytes, 1200 bytes, 760 bytes, 580 bytes and 60 bytes and the power growth is observed for all these packet sizes. This confirms the degradation impact of the RCP and the PTP on the router's power consumption performance. In Section 4.2, from the view of the router design, the origin of the degradation impact will be explained in detail.

Moreover, the Fig .2 (a) and (b) also show that the RCP and the PTP do not affect the effectiveness of the frequency scaling [9,10]. With the RCP router as an example, its power consumption at 125MHz occupies the range of about 11.1W~12.3W with varying the traffic load from 100Mb/s to 1000Mb/s, and significantly reducing the core frequency, from 125MHz to 62.5MHz, can considerably lower the power to the range of 9.9W~10.7W over the same traffic load region. This corresponds to significant reduction in terms of the total power, which suggests that the frequency scaling is also a promising way for compensating the power growth of the RCP router and the PTP router.



(a) 125MHz



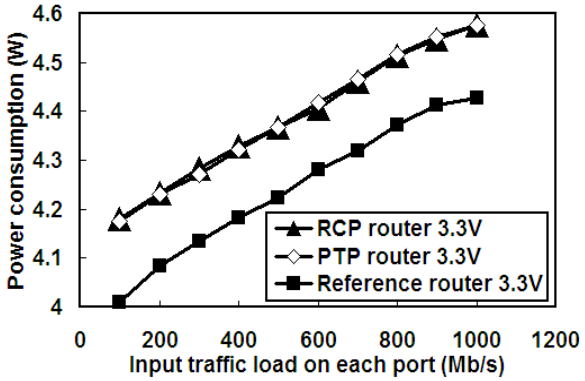
(b) 62.5MHz

Figure 2. Power consumption comparisons between the three routers for various input traffic load at different frequencies.

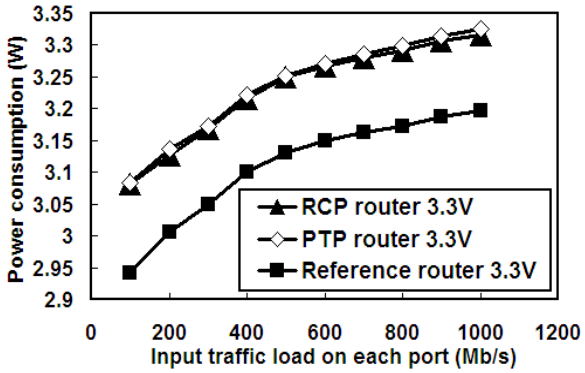
B. *Comparisons of Power Consumption Originating from 3.3V and 5V Pins*

The total power consumption of the NetFPGA-enabled router is obtained by accumulating the energy from the 5v and 3.3V pins. By separating those components in Fig .2, the power consumptions for the 3.3V and 5V power components are shown in Fig .3 and Fig .4. In Fig .3, it can be clearly seen that the 3.3V power components of the RCP router and the PTP router is about 0.1W-0.2W larger than that of the reference router, while in Fig .4, almost no difference is found for the 5V power component among the three routers. This indicates that the 3.3V power component contributes to the power consumption growth observed for the RCP router and the PTP router in Fig .2.

The 3.3V power component reflects the power consumption of the FPGA chip and SRAM on the NetFPGA board. In our experiments, the SRAM is used for packet buffering, which is common for the three routers. Thus for different routers, the power fluctuations occurs in the FPGA. As the power consumption of the FPGA varies with varying the design, it can be understood that the observed power performance for the RCP router and the PTP router is mainly induced by increased logic elements and circuit switching activities via introducing the extra RCP and PTP relevant modules into the reference router pipeline. This suggests that the simplification of the router design and/or optimization of the implementation algorithms are one of the ways to reduce the power consumption of the router. From Fig .3 and Fig .4, it is also interesting to note that the frequency lowering-induced power reduction mainly comes from the 3.3V power component. This can be explained by the fact that the frequency scaling is undertaken by toggling the core frequency of the FPGA and the SRAM [8, 9].

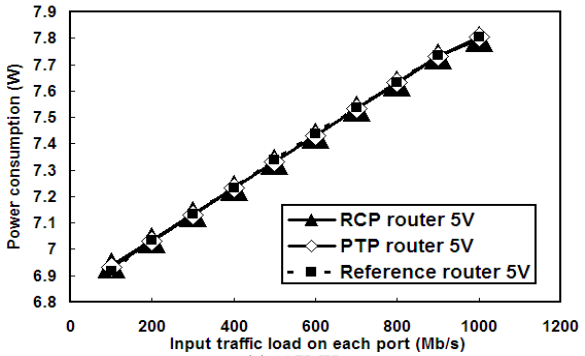


(a) 125MHz

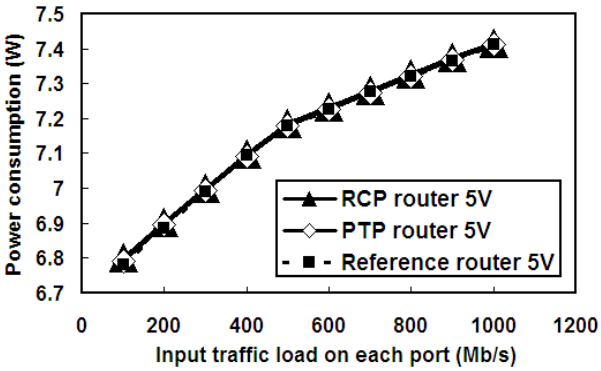


(b) 62.5MHz

Figure 3. The power consumption originating from the 3.3V pin.



(a) 125MHz



(b) 62.5MHz

Figure 4. The power consumption originating from the 5V pin.

V. CONCLUSION

Extensive experimental comparisons have been undertaken among the NetFPGA-enabled RCP router, PTP router and reference router. It has shown that the power consumption of the RCP router and the PTP router are almost identical, which are about >1% higher than that of the reference router. Such an amount of extra power has been observed from the 3.3V power component of the total power consumption and identified to be caused by the introduction of the RCP or PTP-relevant logic units into the reference router. In addition, the reduction of the NetFPGA core operational frequency is promising for reducing the energy consumption of the RCP router and PTP router.

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