Sustainable Computing: Informatics and Systems 11 (2016) 16–25

Contents lists available at ScienceDirect

Sustainable Computing: Informatics and Systems

journal homepage: www.elsevier.com/locate/suscom

Towards eco-friendly home networking

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ARTICLE INFO

Article history:
Received 14 May 2015
Accepted 21 November 2015
Available online 14 December 2015

Keywords:
Home networks
Energy efficiency
Trace analysis

ABSTRACT

Home networking is becoming increasingly sophisticated as users connect ever more networked devices. In the past, home networks typically consisted of a simple router and maybe a few computers. Now, high speed wireless networks are commonplace in homes with a large number of devices: TVs, game consoles, home theater systems, and even home automation systems. This is in addition to standard computing devices such as desktops, laptops, tablets, smart phones and network-attached storage. Smart homes with many wireless sensors to improve quality of life are also emerging. However, home network devices such as routers and broadband modems have been designed for maximum performance with limited consideration of energy optimization when the devices are idle or serving low bandwidth traffic. The goal of this paper is to analyze network activity of wireless home routers, investigate opportunities for energy saving, and present mechanisms for improving the energy efficiency of wireless home routers. We analyzed five week-long traces of home network traffic and identified a number of energy saving opportunities. Through detailed trace-based simulation and implementation measurements we are able to reduce the wireless energy consumption of the home router by 12–59% while incurring only minor delay of the initial packet delivery after leaving the low energy state. Modification of an actual router's behavior shows that the proposed energy optimizations are feasible with existing clients.

1. Introduction

Energy efficiency has become a critical issue in all aspects of computing, from large data centers and the Internet to cellphones and home devices. According to the SMART-2020 report [1], information and communication technologies consumed hundreds of terawatt-hours of energy in the United States in 2006, which cost billions of dollars and generated a CO_2 footprint similar to that of the aviation industry. While data centers and large telecom infrastructures have high power densities, we cannot ignore the growing home networking infrastructure and the large number of these networks. Though individual home networks may not be seen as a significant energy consumer, the vast number of households with growing network infrastructure can account for a sizable fraction of energy consumption in the United States. A 2013 report states that there are 122 million housing units in the United States and that 88 million of them have a high speed broadband connection [2]. Assuming each broadband connected household has a single modern wireless router such as the Asus RT-AC66U with a measured power consumption of 9.7 W [3], we can estimate energy consumption in the United States due to home networking to be roughly 7480 GWh per year. For comparison, this much energy could power 690 average US households for an entire year [4].

This number may not seem alarming right now, but it will be in the near future given current trends in home networking. First, individual home networks are becoming more sophisticated, resulting in home routers consuming more and more power as we demand higher performance and functionality. Furthermore, there is a wide range of power demand among home routers as shown in a recent comparison [5]. Second, the number of home networks is growing quickly worldwide. In the United States, the federal government has invested $7.2 billion to improve broadband infrastructure via the American Recovery and Reinvestment Act. In parallel, the Federal Communications Commission is defining a national strategy to improve national broadband coverage and quality. The United States, however, is only ranked 15th in terms of broadband penetration in the world. Thus, if we consider all home networks in the entire world, improving their energy efficiency would have significant positive impacts on our environment.

Manufacturers are striving to make their networking components more energy efficient and many home networking components are labeled with an energy star rating. However, an energy star rating does not necessarily imply that networking

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http://dx.doi.org/10.1016/j.suscom.2015.11.003
2210-5379/

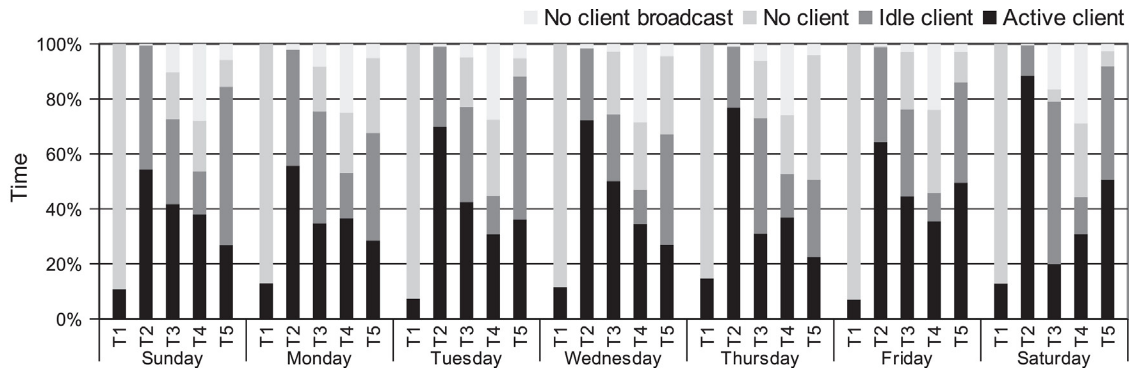

Fig. 1. Wireless network activity in home routers.

equipment is operating in the most efficient power state. Currently, home routers operate at full power even if there are no devices active on the network, in order to guarantee high performance and good connectivity. This approach is not very energy efficient, as the networking devices in an idle state are not taking advantage of powering down their internal components to reduce energy consumption.

Home network activity can vary and can offer different opportunities for energy optimizations. Subsequently, we investigate home network traffic patterns and explore the opportunity for energy efficiency optimizations. We make the following contributions in this paper: (1) trace and evaluate several household traffic patterns to identify opportunities for energy optimization, (2) propose different energy management techniques to expose the challenges of energy management in home networking, and (3) identify requirements for future research in home networking efficiency.

2. Motivation

Consumer routers today resemble minicomputers that can run a basic operating system, have a significant amount of memory, and can utilize attached devices, like hard drives or printers, in addition to providing high bandwidth wired and wireless interfaces. The router is responsible for routing traffic between home devices and the Internet, as well as optionally providing many other functionalities such as a DLNA multimedia server, a file server, a firewall and so on. Households are also becoming more and more connected. Most multimedia devices (TV, Blu-ray players, gaming consoles, etc.), smart appliances, and security systems require some sort of network connectivity for full functionality. This is in addition to mobile phones, tablets, and portable computers which have become commonplace. While most of these devices require network connectivity, many households are not prewired for network connections. As a result, wireless connectivity has become a very popular option for providing a flexible networking infrastructure. As the number of wireless-enabled devices continues to grow, the prevalence of wireless networks will increase to satisfy demand.

While a wireless connection is convenient, the wireless interfaces need to provide high bandwidth to satisfy the demand of all connected devices, which increases design complexity and power demand of the router. Modern wireless routers have been found to consume 4–11 W, depending on what features are enabled and the wireless specification provided [3,5]. Generally speaking, newer 802.11AC-type wireless networks will consume more energy than the older 802.11N-type networks.

A significant amount of research has focused on the power consumption of large Internet routers which consist of multiple chassis each containing multiple line cards that have over provisioned connections to provide performance and reliability. In this scenario, the line cards can be simply turned off when links are not used [6]. Even in home networking, wired network interfaces can be powered down when inactive, and the router utilizes a link sense signal to detect the presence of a client on the network. Wireless network interfaces, on the other hand, cannot be easily powered down because the router needs to broadcast its presence and listen for any clients that will attempt to connect over the shared medium of the wireless signal. However, long periods of idle time, both with and without any clients present, can offer energy saving opportunities if properly realized.

Table 1
Wireless trace characteristics.

Trace	T1	T2	T3	T4	T5
Average concurrent devices	1	5	4	4	2
Maximum concurrent devices	1	9	7	6	3
Initial associations	13	16	14	31	35
Average time with no client (h)	10.7	0.08	2.07	1.32	0.92
Traffic volume (GB)	5.57	40.21	4.22	3.52	12.97

2.1. *Potential for energy optimization*

Before we consider any optimizations, we need to understand the frequency and type of traffic that is seen in personal home networks. While there are existing databases of wireless traces for research purposes, such as CRAWDAD [7], they do not contain the details that would help us understand the traffic patterns between devices or study optimizations in a home network setting. To incorporate all traffic details that would allow us a detailed trace driven analysis of home network traffic, we collected network traces from five diverse households: single occupants, many roommates sharing an apartment and individual families. The traffic was captured using `tcpdump` over a period of one week from modified home routers. The volunteers were instructed to use their network as they would normally to help ensure a representative trace from each household. To protect the privacy of the users and reduce the capture file size, only the headers of each packet were saved. These headers contain information such as IP addresses, a timestamp, and total packet size, but not actual data like URLs or form submissions.

Fig. 1 presents the wireless network utilization for each distinct trace over the week-long period (labeled T1–5). The activity was categorized into one of four groups: *active client* periods when there is active communication between the router and the wireless clients; *idle client* periods when the clients are connected but there is no network communication; *no client* idle periods when there are no wireless clients connected; and finally, *no client broadcast* periods when there is broadcast activity, originating from the wired network, present on wireless interfaces but there are no clients to receive these packets. Table 1 complements the statistics