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A survey on green routing protocols using sleep-scheduling in wired networks

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ABSTRACT

Over recent years, green communications have been proposed as an emerging strategy to reduce the Carbon footprint produced by the networking sector. It consists in using different software and hardware techniques allowing to minimize the energy consumption of network components. A significant amount of energy saving can be obtained by switching redundant or unused network components to inactive mode, referred to as sleep-scheduling. To achieve this, the routing algorithm should aggregate traffic flows over a subset of network routers and their links, allowing other components to be switched off. The objective of this paper is to present a holistic survey on existing sleep-scheduling based green routing protocols in wired networks. First, we propose a classification of main properties of sleep-scheduling based green routing protocols and use the proposed classification to categorize and describe the existing literature. Moreover, we provide a comprehensive comparison of existing green routing protocols and determine the main characteristics, assets and issues of each proposal. In addition, we identify and classify the main metrics for evaluating and comparing the efficiency of green routing protocols using sleep-scheduling. Finally, we identify the open issues and key guidelines towards an ideal green routing protocol for wired networks.

1. Introduction

Over recent years, green communications have been emerged as an important area of concern for communication research and industrial communities. It relates to any hardware or software technique allowing to reduce the energy consumption of Information and Communication Technology (ICT) sector. The relevance of this trend turns back to its impact on environmental pollution and economic cost. Indeed, recent studies estimated that the ICT is responsible for up to 10% of the global CO2 emissions, while its contribution is doubled from the year 2006 to the year 2011 (Beloglazov et al., 2011; Webb, 2008; Global Action Plan Report, 2007). An important amount of ICT energy is reported to be consumed in network components, reaching between 30–37% of Green Houses Gases (GHG) produced by the ICT sector (Webb, 2008; Gartner, 2007). Consequently, an important effort is required to reduce the energy consumption of networking environments.

Nowadays, network resources including bandwidth, processing power and memory are oversized to handle high traffic loads, with only 30–40% of utilization in low traffic periods (Nedevschi et al., 2008; Guichard et al., 2005; Adelin, 2010; Gupta and Singh, 2003). Consequently, an important energy saving can be obtained by switching off extra components during low traffic conditions (Bianzino et al., 2012; Eyupoglu and Aydin, 2015). To achieve this, the routing algorithm should aggregate traffic flows over a subset of network routers and their links, allowing other components to be switched off. In this paper, the technique of switching off extra components is designated as *sleep-scheduling*, while the routing algorithm using this technique to provide the network with green features is referred to as *sleep-scheduling based green routing protocol*. Due to the significant amount of energy conserved through sleep-scheduling, this paper mainly focuses on sleep-scheduling based green routing protocols.

Since the green communications' tentative has been launched, a number of sleep-scheduling based green routing protocols has been proposed by the research community (Cianfrani, 2010; Cianfrani et al., 2012; Amaldi et al., 2011; Bianzino et al., 2012; Cuomo et al., 2011; Shen et al., 2012). However, to the best of our knowledge, a holistic survey on works overviewing recent advances in sleep-scheduling based green routing in wired networks has not existed so far. To address the aforementioned shortage in current literature, we present a comprehensive survey on sleep-scheduling based green routing protocols. Moreover, we propose a classification on green properties highlighting different characteristics of existing proposals. Based on this

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classification, we identify the main advantages and issues of existing green routing proposals and compare them qualitatively based on their main features. Due to the relevant impact of quantitative evaluation and comparison towards an ideal solution, we also identify and classify the main numerical metrics for evaluating and comparing the efficiency of sleep-scheduling based green routing protocols. Finally, we raise a set of open issues and propose key guidelines towards an ideal solution.

The reminder of this paper is organized as follows. Section 2 provides background and related topics. Section 3 reports main related surveys relevant to the present study. Section 4 presents our proposed classification of main green properties. Section 5 surveys general green routing protocols using sleep-scheduling. Section 6 describes the main existing MPLS-based and SDN-based proposals. In addition, it presents existing protocols considering inter-domain routing aspects to optimize the network performance and the energy gain of sleep-scheduling decisions. Section 7 presents a classification on the identified metrics for evaluating and comparing the efficiency of green routing protocols using sleep-scheduling. Section 8 presents a qualitative comparison of surveyed literature and outlines some open issues and guidelines towards an optimal green solution. Finally, Section 9 concludes the paper.

2. Background

In this section, we determine the scope and main terminologies of the paper, providing a clear definition of the employed key terms and some highly related topics.

2.1. Green communications

Green communications consist in an emerging approach to respond to the increasing economic cost and environmental pollution produced by the ICT industry. In 2007, the ICT sector was estimated to be responsible for about 10% of total energy consumption in UK (ITWales, 2007). Other estimations showed that the Italian Telecom consumed about 1% of its total energy consumption in 2006, which was increased 7.95% and 12.08% with respect to the years 2005 and 2004 (Bianco et al., 2007; Telecom Italia Website; British Telecom Group, 2009). Due to the increasing network usage and further requirements for network infrastructures, the contribution of ICT sector in GHG emissions is expected to increase significantly in next years. Global e-Sustainability Initiative (GeSI) estimated that network infrastructures will emit about 350 million tons of CO_2 in 2020 (Global e-Sustainibility Initiative). As illustrated in Fig. 1, the CO_2 emissions of telecommunications devices (e.g. routers, switches) are estimated to increase from 12–22% in 2020 compared to 2002. Consequently, an important deal of attention should be concentrated on reducing the energy consumption of networking components.

Due to this importance, we carried out an extensive literature study on mechanisms applicable to reduce the energy consumption of networking components. Identified approaches can be classified in four categories, as described in the following:

- *Re-engineering*: The aim of this approach is to use more energy-efficient hardware components for network architectures, especially through reducing the internal complexity of elements (Chabarek et al., 2008; Ceuppens et al., 2008).
- *Interface proxying*: This approach consists in switching an inactive end device to the sleep/standby state and delegating the processing of its background traffic either locally to the low-energy processor onboard of the NIC of the same device, or to an external entity (Jimeno and Christensen, 2007; Sabhanatarajan and Gordon-Ross, 2008; Agarwal et al., 2009).
- *Power-proportional* or *Adaptive Link Rate (ALR)*: In this approach, the Ethernet link capacity is adapted with its local current flow load (Bilal et al., 2013). For instance, several transmission rates are predefined for each link and the more appropriate one is adaptively set according to the current traffic (Gunaratne et al., 2005, 2008; Gunaratne and Christensen, 2006).
- *Sleep-scheduling*: This approach consists in switching off some unnecessary network components (node or link) to preserve the energy consumed for keeping them awake during inactive periods (Bolla et al., 2011; Bianzino et al., 2012; Sarigiannidis et al., 2015).

Although the re-engineering approach can increase the hardware energy efficiency of individual network components, other green approaches are required to optimize the effective utilization of such devices. In this regard, the interface proxying suffers from its restriction to end devices, ignoring the components of the core network as the main sources of permanent and extensive energy consumption. Besides, the management complexity of the power-proportional approach is an obstacle to its wide development (Meisner et al., 2009; Wierman et al., 2009). Moreover, recent studies show that the amount of energy conservation obtained by the power-proportional approach is significantly lower than the one obtained by the sleep-scheduling technique (Nedevschi et al., 2008). Consequently, in the present survey, we mainly emphasize on green routing protocols using sleep-scheduling. In the following, the principles of IP routing and its relation to sleep-scheduling are described.

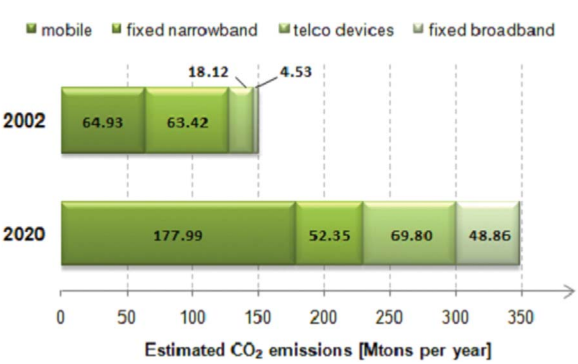

Fig. 1. GeSI estimation on GHG emission (Global e-Sustainibility Initiative).

2.2. Routing protocol

A routing protocol specifies how routers exchange routing information with each other, enabling them to determine routes between any two nodes on a computer network. As a result of receiving a routing packet, the router updates its routing table to indicate an appropriate next hop for any destination. Due to the large scale of today's Internet, its management is undertaken by different administrative domains, called Autonomous Systems (AS). Each AS may use a different routing protocol, which can be Routing Information Protocol (RIP) (Malkin, 1998), Open Shortest Path First (OSPF) (Moy, 1998) or Intermediate System to Intermediate System (IS-IS) (Oran, 1990). The routing protocol executed inside an AS is called *intra-domain* (*interior*) *routing* protocol. OSPF, as the most common interior routing protocol, broadcasts Link State Advertisement (LSA) messages to whole the network to provide any router with information of link states of other routers. LSA reports connectivity information of the router and may also carry Quality of Service (QoS) information such as its link utilization or bandwidth, just to mention a few. Based on the received LSAs from other nodes, each router constructs the network topology as a weighted graph. The weight represents the cost of a link which is equal to 1 when the default hop count metric is considered. The well-known shortest path algorithm is then executed on the constructed graph to find a tree of shortest paths to any destination, with itself as root.

In addition to the interior routing protocol, an *inter-domain* (*exterior*) *routing* protocol is also required to route between different ASs, ensuring end-to-end data transmissions. Border Gateway Protocol