Dynamic Energy Management for IP-over-WDM Networks

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Abstract—This paper proposes a new energy management framework for an IP over WDM network. A key constraint of our architecture is to maintain the logical IP topology while saving energy by infrastructure sleeping and virtual router migration. Since the traffic in a network typically has a regular diurnal pattern based on people’s activities, some virtual routers can be moved to a smaller set of physical router platforms so that the unused physical platforms can be switched off when the traffic demand is light. As the traffic demand increases the sleeping physical router platforms can be re-awakened and the virtual router functionality returned to the original physical platforms close to where the traffic load is rising. Since the IP-layer topology remains unchanged throughout the virtual router migration, there is no network disruption and discontinuity when the physical platforms enter or leave hibernation. However, this migration can place extra demand on the optical layer as additional connections are needed to preserve the logical IP topology whilst forwarding traffic to the new virtual router location. As these additional optical connections are used to forward traffic from the sleeping node to the remote location where the virtual router is present, this is akin to traffic grooming and the burden on the optical layer is greater the further the new router instance is from its original default location (where it still perceives itself to be). Although published work has hitherto considered how to migrate virtual routers from one physical platform to another, the goal has been to avoid downtime whilst the network undergoes planned maintenance. This paper considers virtualisation in the context of an energy saving architecture; and addresses the question of when to migrate, where to migrate to, and the means by which underlying optical connections are utilised.

Keywords: Virtual Router Migration, Energy Saving, Optical Network Grooming.

I. INTRODUCTION

In the last few years, energy consumption has become a popular topic and received considerable attention from the government, general public and telecommunication operators. For the government and general public, the energy consumption is closely related to our environment since the production of energy produce the carbon dioxide which cause the global warming. On the other hand, with the growing number of customers and continuing increase Internet applications and services, in order to maintain the network capacity and device functionality, the energy consumption of Internet is growing significantly. Furthermore, with the increasing price of electricity [1], telecommunication operators are also treating power saving as a key issue for lowering the operational expenditure (OPEX). To be sustainable means to save the money.

The power consumption of Information and Communication Technologies (ICT) includes the power consumption of servers, network infrastructure and end-user devices. It accounts for 2% of the world’s power consumption and 10% of the UK [2]. It is anticipated that this will increase notably over the next couple of years. For example, it is anticipated that the non-domestic energy consumption will increases by 40% by 2020 [3]. Although it seems a small fraction of overall power consumption, the absolute value of 900 Billion kWh per year which is equal to the power consumption of central and South America, and is strong motivation to ensure energy consumption is more efficient [4].

Within telecommunications, energy management can be divided into two sectors: wireless networks and wired (fixed) networks. Since the operation of nodes in many wireless networks is limited by battery power, considerable effort has been devoted to devising new energy management schemes. For example, there has been a lot of research in relation to energy-efficient schemes for wireless ad hoc sensor networks [6]-[9]. There is also much ongoing research into energy saving within cellular networks, including the use of low energy (and limited functionality) relay stations, beam steering and exploiting residential wired access points.

Conversely with wired networks, access to abundant power is a traditional assumption, implying there is no need to save energy. Actually, the energy consumption of wired network is not efficient [5] and there is considerable room for improvement. Therefore, more and more attention is being paid to energy management within wired networks [10]. Furthermore, technological advances, particular in respect to Dense-Wave Division Multiplexing (DWDM), mean that the bandwidth of physical devices is no longer a restriction on the capacity of the Internet; instead it is limitations in the achievable energy density [6].

There are many approaches for saving energy within wired networks, including: Network design and configuration [10],...
which considers the energy consumption factor while planning and configuring the network; infrastructure sleeping, e.g., routers and links [12]-[14] that switch off when network traffic demand is low; rate-adaptation [10], adjusting the power consumption to the required transmission rate of the traffic; network virtualization [15][16] or migration [17][18], which allows several network component instances to run on the same physical platform.

As routers consume the largest proportion of the energy consumed in the network [20], the approach of switching off routers when traffic demand is low has been regarded as a promising strategy and explored intensively in recent years. However, the main problem of this is that when a router is switched off, it loses the ability to exchange routing protocol signalling messages. In other words, it changes the logical IP layer topology, which in turn triggers reconvergence events. This can cause network discontinuities and disruption. Therefore, in order to overcome this problem, we propose an approach with the aim of avoiding changes to the logical IP topology whilst effectively turning off router instances using virtual router migration. Our idea is to combine the approaches of switching off unneeded equipment and migrating the functionality of router instance to another chassis that can accommodate it during quiet periods.

The rest of the paper is organized as follows. Section 2 reviews the state-of-art of these two areas. Next in Section 3 we describe our novel dynamic energy saving approach. In Section 4, we provide the initial results of approach. The conclusions are finally presented in Section 5.

II. RELATED WORK

Infrastructure sleeping means that when equipment is idle, it enters the low power consumption state whilst retaining the operational information for maintaining its operation after it again wakes up. An example is the “hibernation” state of personal computers. The network equipment does not typically possess such a sleeping mode at present; however, hardware support for this function is becoming evident, for instance, the IEEE 802.3az Energy-Efficient Ethernet (EEE) standard has been approved [20]. There are two types of sleeping, uncoordinated sleeping and coordinated sleeping. The former lets the equipment enter a sleep state based on local information, e.g. during the idle inter-arrival time between packet transmissions. The other is to take a global perspective and allocate traffic demands via some equipment in order to let other devices enter a sleep mode.

Since a router still consumes about 60% of its full-load energy when it is idle, approaches that turn off unneeded devices or permit equipment to enter a coordinated sleep state have considerable potential for saving energy in the network. Considerable research has been done considering this principle. For example, in [13], several simple heuristic algorithms are employed which sort all the nodes depending on the number of links, the amount of flows they accommodate or using a simple random order for switching off to save energy. The same author extends the work to consider a real-world case in [12], which shows that it is possible to switch off between 30% to 50% of links and nodes and reduce energy consumption by more than 23%. However, these approaches all suffer from the problem of losing the present state of network and triggering routing protocol reconvergence events.

W. Fisher et al. proposes another form of infrastructure sleeping where they shut down the redundant cables and the line-cards instead of the whole router during periods of low utilization. Nevertheless in a router, the major source power consumption is the base system (chassis, processor and switching fabric), which consumes about 50% of the total [11].

Another field related to our work is virtual router migration. A virtual router is a logical router that separates behavioural functionality from the physical platform that hosts the entity, including mechanisms and tools for management, configuration, monitoring and maintenance. Once router virtualisation is introduced it is straightforward to accommodate multiple logical routers within the same physical platform. However, total separation of logic router from the physical platform is not possible as some means of moving information between the various communication layers still required. Many researchers have devoted effort to considering virtual router migration for reducing the impact of planned maintenance. In [16], virtual router migration is realised by re-instantiating a router instance at the destination physical platform, which may result in downtime for both the data-plane and control-plane. Unlike [16], [17] proposes a new migration scheme called VROOM (Virtual RoutOn the Move) that allows logical routers to move among different physical platforms without causing network discontinuities and instabilities. However, it does not consider the events needed to trigger the virtual router migration and the algorithm needed to determine the appropriate physical destination platform for the migration. The work that is closest to ours in spirit is [21], which also uses the virtual migration concept to maintain the IP layer topology unchanged. The key difference is that it migrates the functionality of line-cards within a physical router instead of migrating the entire virtual router functionality to another physical platform.

III. DYNAMIC ENERGY MANAGEMENT SCHEME

The main idea of proposed dynamic energy management scheme is to combine virtual router migration and the turning off of unneeded routers together with automatic optical layer grooming to enable resources to be used in an efficient manner, whilst remaining transparent to the Layer-3 entities that are being moved on an as-needed basis. To our knowledge, no published work combines these elements, especially in the context of energy-efficient networking.

In this section, the dynamic energy management scheme is described as follows. First, an example network scenario is given. Then the use of the new optical connection management is illustrated. Following this, the mechanism for triggering the virtual router migration and the algorithm for choosing the appropriate destination physical platform are considered. Finally the overall energy management procedure is described.
A. Network Scenario

The network scenario that our research is based on is IP over WDM. This can be abstracted as a structure that the node is composed by a set of network equipment, e.g. a router that is connected by line equipment, e.g. optical fibre and amplifiers. From the aspect of power consumption, both of node and line equipment should be considered. However, in practice, the consumption of line equipment can be omitted [22]. The WDM links consumes about 1.2% to 5.8% of Internet power consumption varying with the average access rate.[7] Furthermore, compared with the router, the power consumption of the underlying optical transport is low. So, we mainly discuss the power consumption of the router when deploying the proposed dynamic energy management.

As mentioned above, the network node consists of a router and optical transport switch. For a router, it can be regarded as a modular architecture that is composed by the base system (switch fabric, router processor and chassis) and multiple line-cards. We assume that the line-cards have the capabilities of processing information in layer 2 and layer 3. For the optical transport switch, it is responsible for sending packets to router (via its add / drop functionality) or forwarding the wavelength channels. Therefore, there are two possibilities concerning packets are dealt with:

- Packets bypass the node optically,
- The optical connection is terminated and the packets in the payload are processed electronically by the router function.

The links between the routers are WDM transmission systems, which have many optical connections employing different wavelengths concurrently within the fibres. In this model, we also consider the wavelength continuity constraint, whereby when the optical connection passes through the optical transport switch, it is required to be on the same wavelength channel from the ingress to the egress. The channel remains in the optical domain and Optical-Electrical-Optical (OEO) conversion is avoided.

B. Optical Connection Management Scheme

The prerequisite of the proposed energy management scheme is to save energy without changing the logical IP topology. In order to satisfy the requirement, additional optical connections are needed for forwarding the traffic to the remote virtual router that will perform the packet processing whilst maintaining the same logical IP topology.

We impose certain migration restrictions on the new location of virtual router, such as limiting the hop count from its default location and ensuring the utilization of physical platform that accommodates the virtual router(s) is within safe bounds. Once this is taken into account new potential locations for the virtual router can be sought and the corresponding optical connection requirements evaluated. This includes searching for suitable wavelength channels to forward the data. After this, the revised energy consumption of the network can be ascertained.

Figure 1 provides an example illustrating how and why the new architecture places additional demands on the optical connectivity resources. Figure 1(i) shows the path taken by traffic from host A to host B, which passes through the virtual routers (VR) 1, 2, 3, 4, respectively, on the physical platforms A, B, C, D. Assuming the volume of traffic is relatively light, in Figure 1 (ii) VR 1 is migrated to physical platform C in order to allow physical platform A to sleep. Now, VR1 and VR3 are hosted in the same physical platform C, but they do not know the existence of each other. So, extra optical connections are added to maintain VR1 and VR3 logically separated from each other. Conversely, if this was not the case, and VR1 and VR3 were made be visibly adjacent to each other at Layer-3, by permitting information to flow directly between them, they would exchange routing information and thus result in a change to the logical topology. This is something we aim to avoid and so prevent reconvergence issues.

In the figure it is seen that one optical connection now forwards traffic from customer (Host A) directly to the new location of VR1 without passing through the Layer-3 functionality of platform B. A new connection is then used to send traffic from VR1 to VR2. The location and number of optical connections that must be created is decided by the location of where the VR migrates to and the number of Layer-3 interconnections that the VR possesses. Therefore, our scheme imposes a cost associated with adding some new optical connections before we actually migrate the VR in order to save energy. This is a multi-commodity problem as although it is beneficial to pack multiple VR instances on the same platform, the additional optical resources it consumes offset this benefit.

As these additional optical connections are used to forward traffic from the sleeping node to the remote location where the virtual router is present, this is akin to traffic grooming and the burden on the optical layer is greater the further the new router instance is from its original default location (where it perceives itself still to be).

C. Triggering Router Migration

Since the traffic in a network typically has a regular diurnal pattern based on people’s activities, which is high during the
daytime and lower at night, some virtual routers can be moved to a smaller set of physical router platforms when the traffic demand is light. Much of the functionality in the unused physical platforms can then be switched off to save energy. As the traffic demand increases the sleeping physical router platforms can be re-awoken and the virtual router functionality returned to these original physical platforms close to where the traffic load is rising. Since the IP-layer topology remains unchanged throughout the virtual routers migration, there is no network disruption and discontinuities are avoided when the physical platforms enter or leave their hibernation state.

An individual router is not best placed itself to decide when to migrate since it does not know the overall network situation. Our energy management scheme requires the coordinated sleeping/functioning of the router platforms in a network. We propose the use of a centralized control unit for collecting the related data and managing the migration triggering based on observed events. The control unit, which could be an adjunct to the Network Management Station, collects the information from all the routers in the network using a combination of Simple Network Management Protocol (SNMP) get and trap messages. This includes utilization information over specific intervals, e.g., every 10mins, associated with each link in the network. Since the daily pattern of moving averaged smoothed traffic demand is quite predictable, thresholds are set according to different load conditions of the router. For example, thresholds set to 30%, 50% and 70% of peak load are typical. When the traffic demand crosses these thresholds, the trap messages are used to trigger the energy management algorithm to consider whether VR migration should be undertaken and, if so, where to migrate.

Given statistical variations in the scenario, it is not necessarily possible to always choose the same migration plan from one day to the next. Instead, conditions are checked by invoking an algorithm to choose the destination physical platform. This needs to take into account the migration plan for the entire network to ensure traffic does not have to be redirected an excessive number of hops and that the VR placement provides a sensible consolidation of resources. Finally the virtual router migration is triggered by the use of dedicated signalling and operational state transfer messages.

D. Destination Physical Platform Selection

Before a virtual router moves, there are many constraints that need to be considered for selecting the destination physical platform. For example, the source and destination platform should be compatible with each other. Then, the destination physical platform should also be able to accommodate the new virtual router without detrimentally impacting on the performance of any VRs it is currently hosting. Virtual router relocation for saving energy is complex. It can be treated as an optimization problem whose objective is to save energy, considering various restrictions. In our scheme, the new location of virtual routers is not necessarily directly adjacent to the original physical platform. We allow for the migration to take place to a platform that is further away from the source, provided the energy-saving benefits are considered to be sufficiently large. This process must take into account the additional optical connectivity and forwarding resources that such a migration imposes.

The algorithm for choosing the destination physical platform is based on many factors and is described with the following sequence of steps:

1. Bearing in mind the constraints, e.g., the number of hops, the operational system state, obtain the list of candidate migration destinations for every router.
2. Examine the optical switch table to see whether there are suitable free wavelength channels for establishing the new optical connection(s) considering the wavelength continuity constraint. Some unsatisfactory candidates will be eliminated.
3. According to a fitness-function that includes the utilization of the destination platform and the additional path hop count that would result from the migration, rank the remaining candidates.
4. Select a source router to migrate and choose the best destination platform from candidates list.
5. Update the platform status and revise the candidate list based on the VR loading statistics. Also update the optical switch table statistics that would result.
6. Reapply Step 2 onwards for the next router until the candidate list is empty.

After obtaining the migration list, the new optical connections are established and virtual routers move to their new physical destination.

E. Overall Energy Management Procedure

After describing the different parts of dynamic energy management framework, the operating procedure for the whole scheme is summarised as follows:

- Analyze the traffic demand matrix and obtain a list of the physical platforms that may be suitable for turning off (or on)
- Select the destination physical platform for migration based on the algorithm above
- Establish the new optical connection(s) between the source and destination physical platforms
- Migrate the virtual router(s) from the source to destination physical platforms
- Where appropriate, switch off the source physical platform to save energy
- If the traffic demand increases beyond a certain threshold, or according to some other form of trigger, migrate the virtual router back to its original source physical platform

IV. Example Scenario

After briefly describing the dynamic energy management process in Section 3, an example scenario is now presented. As the network energy management framework is considered in Section 3, we now focus our attention on the power consumption of the routers.

We use data presented in [11], which provides the power consumption of a Cisco GSR 12008 router. It shows that the base system (chassis, router processor and switching fabric) consumes about 430W. It has 8 slots for line-cards. The power
consumption of the line-cards is independent of the base system and is primarily based on the type of line-card used. The average consumption of a line-card is about 70W. The overall power consumption is 990W when the router is operating at full load.

Researchers in [23] discuss the power consumption of sleeping devices if the devices (home gateway, router and Digital Subscriber Line Access Multiplexers) possess sleep capabilities. They consume about 60% of full load power consumption when it is idle and from 10% to 20% when the devices are into sleeping state. Based on the data above, we assume that when a router is sleeping, it only consumes 150W (the full power is 990W). We also assume that a line-card consumes 70W when working, 40W in an idle state and 10W while sleeping. However, it can only enter a sleeping state when the entire router is switched off. When using the proposed dynamic energy management, we also consider the extra power consumption required by the destination physical platform whilst running the new virtual router.

So, in an example scenario, assume there are 100 routers in the network and when traffic is about 50% of the maximum load, we assume that 30% of routers are moved to the new destination physical platforms and the source physical platforms are placed in a sleeping state. Furthermore, assume that in the scenario without the proposed dynamic energy management, there are 2 line-cards per router that are working and the remaining 6 line-cards are in the idle state. The overall power consumption of network is 81 kW.

After deploying dynamic network management, 30 routers are placed in a sleeping state, 30 router platforms are running the new virtual routers and 40 routers platform are in the new state. The overall power consumption is 63 kW. Therefore, a power consumption saving of about 23% is achievable even in this simple example.

V. CONCLUSIONS

In the paper, a new dynamic energy management framework for IP over WDM networks is proposed that combines virtual router migration and infrastructure sleeping. The overall aim is to move virtual router instances to other physical platforms whilst the network load is light in order to let the original physical router enter a standby state to save power. At the same time, since the IP layer topology stays the same by virtue of the optical layer traffic grooming, there are no discontinuity and reconvergence events within the network whilst router platforms move to and from their sleeping state.

VI. REFERENCES


