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Towards an Energy-Efficient Internet
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Abstract

Climate change and cost drives all sectors of industry and society as a whole towards more energy-efficient technology, products and life styles. The collection of Internet infrastructure and the attached devices are a large user of electrical energy and therefore of course are no exception regarding this trend. This memo attempts to identify obstacles and more importantly technology options for an energy-efficient Internet with a focus on the protocols that are the product of the IETF.

Status of this Memo

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1. Introduction

Regarding energy efficiency, many people regard the role of the Internet to be an enabler for it in sectors other than communications, e.g. the potential for dematerialization (e.g. replacing letters with Email or DVDs with video streaming), the potential to reduce travel (e.g. by allowing employees to work from home rather to commute to work or by replacing physcial meetings with video conferencing) just to name two areas.

More recently, the energy use of the Internet itself, and more generally Information and Communication Technology (ICT), has attracted quite some attention which has lead to technologies such as

Energy Efficient Ethernet [EEE] or the ProxZZZy Standard [PROXZZZY] and a large body of scientific publications.

The question is how can the IETF/IRTF help with existing and/or future protocol standards to support, exploit or enhance these developments that happen outside of the IETF. Even without these external technologies, can IETF protocols with or without modifications help to lower the energy use of the global Internet? This memo is intended to identify existing obstacles and potential places in the IETF protocol landscape where there is potential to achieve this goal: lowering the energy use of the Internet as a whole from end host to core router.

2. Conventions and Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

3. State of Affairs

Energy-efficiency certainly is important. But is the Internet infrastructure a good place to look at and what is already out there that addresses energy-efficient communication?

3.1. The Current Network Energy Use

For a long time now, the Information Communications Technology (ICT) sector as a whole has experienced a rapid growth. With this growth however comes a steep increase in power demand. According to an ITU-T report [ITU] from 2008, wired and wireless networks consume a significant fraction of the overall electrical power. Consequently, the fraction of green-house gas emissions that can be attributed to the ICT sector is significant and is currently estimated to be 2% of the overall man-made emissions.

A report issued by the European Commission in 2008 [EC] is slightly more detailed regarding the energy use of ICT and makes forecasts regarding the development of the sector's energy use till 2020. In a scenario the report calls "business as usual" (BAU), the electricity consumption of ICT is predicted to double based on data from 2005. That equals over 10% of the total electricity consumption in the 25 EU member states under observation. It is this energy trend that is alarming. It has to be noted however that consumer devices are part of this calculation but even when these devices are removed from this calaculation, the trend remains the same and over 50% of the energy budget remains. Another large, and increasingly important consumer

in this whole mix of technologies are data centers.

3.2. IETF/IRTF Work on Energy-Efficiency

It would be wrong to say that energy-efficiency has not yet been considered within the IETF/IRTF. E.g. during the 81st IETF meeting the very first IRTF Applied Networking Research Prize was awarded to work on energy-efficient traffic engineering [ANRP]. In addition the IETF EMAN working group is actively working on standards to measure and control energy-related aspects of powered entities. Also, a growing number of internet drafts are being submitted that address energy issues and energy-efficiency such as [I-D.chakrabarti-nordmark-energy-aware-nd], [I-D.manral-bmwg-power-usage] and [I-D .okamoto-ccamp-midori-gmpls-extension-reqs] to name just a few. Finally, there are a number of other activities that face similar problems such as the Internet of Things [RFC6574] which likely would benefit from general energy-efficiency methods that are applicable in a wider context.

3.3. Taxonomy

The following represents a classification based on the one found in [GREENR] and lists examples for each category.

o Adaptive layer-2 technology: Most current types of network equipment show a constant power consumption profile largely irrespective of their actual utilization. The computing world on the other hand has long embraced methods to approximate energy-proportional computing. In the networking world we see first steps into energy-proportional communications. Adaptive link rate technology is such a step where the energy use changes with link utilization. Also, IEEE Energy Efficient Ethernet is a step into this direction. The respective Task Force has devoted considerable efforts in this area and has published IEEE Std 802.3az-2010 (Amendment to IEEE 802.3-2008) [EEE]. The amendment describes modifications to existing physical layer specifications in order to make Ethernet more energy efficient. The amendment covers various technologies such as 10BASE-T or 100BASE-TX. It also proposes a new Low Power Idle (LPI) mode and related mechanisms and protocols in order to energy efficiently manage Ethernet links.

o Network interface proxy technology: Proxying describes technologies that maintain network connectivity for other devices so that these can go into low power sleep modes. This mainly targets the reduction of unnecessary energy waste through edge devices. ECMA has published a proxying document [PROXZZZY]. This specification describes an overall architecture for network proxying and provides capabilities that a proxy may expose to a host. Also, information that must be exchanged between a host and a proxy, and required and optional behavior of a proxy during its operation are described.

- Energy-aware infrastructure: in order to achieve a further reduction in energy use, coordination and manangement of larger parts of the network appears to be a promising idea. Energy-aware infrastructure describes a class of techniques to this end. Energy-aware routing is one example that falls into this category. Energy-aware routing makes use of the fact that traffic follows certain patterns. Based on this knowledge, in times where network traffic is low, a number of routers can be put to sleep while the network as a whole still preserves connectivity and an adequate service level. Requirements for an energy-aware control plane are outlined in [I-D.retana-rtgwg-eacp].

4. Potential Obstacles for Realizing an Energy-Efficient Internet

The following is a short list of problems that need to be addressed in order to introduce techniques that make the Internet more energy-efficient.

4.1. Problems Caused by Sleep Modes

A sleep mode is a kind of "deep" idle state which results in significant power savings but also requires a significant amount of time in order to wake the sleeping node up. When not in use, network nodes could go to sleep in order to save power. Sleep mode operation is a common practice e.g. in cellular networks where mobile terminals spend most of their time in a sleep mode to conserve energy. Many Internet protocols however could break if sleep modes would be introduced because they operate based on the assumption that the participating nodes are always-on [RFC4861] [RFC4862].

Current networking services and applications are commonly designed to be fully available at all times with minimal response times. If network nodes are allowed to go into a sleep mode, they effectively lose network connectivity and their applications and services stop working. When these nodes wake up again, they have to re-initialize their applications and services potentially resulting in a non-negligible amount of signalling overhead [EEFI].

Several IETF protocols require a node to keep constant network presence and process periodic or event-driven messages in order to maintain a persistent configuration or state. For example, if an IPv6 node goes to sleep, it cannot perform Duplicate Address Detection (DAD) to defend its configured addresses. In that case some other node may usurp its addresses [RFC4862]. Upon waking up,

the node needs to go through a costly re-attachment procedure resulting in even larger delays until network connectivity is restored.

Even when a node is idle with no running applications, background traffic is received that needs to be processed which inhibits the node from sleeping. The good news is that common message exchanges during otherwise idle periods such as ARP processing or DAD, can either simply be dropped or be dealt with using minimal computational resources through a 3rd party - a Network Connectivity Proxy (NCP) [Wasserman] [SCE] [NCP].

The issues described above can also be addressed by designing sleep-compatible protocols or by extending existing protocols (where possible) to include the ability to distinguish sleep form failure.

4.2. The Lack of Efficiency Metrics and Evaluation Methodologies

The mechanism side of energy-efficient protocol design is only one aspect that will lead to a greener Internet. Another aspect is the evaluation of and the comparision between different possible approaches. Currently, there is a lack of standard energy-efficiency metrics that are applicable to Internet protocols.

There are a number of metrics and some of these actually attempt to quantify energy use with a direct reference to networking (e.g. [I-D .manral-bmwg-power-usage]). Right now however, it is challenging at best to perform an objective and useful comparision of mechanisms that attempt to increase the energy-efficiency of a protocol.

Energy-efficiency is a metric that should be evaluated in a holistic way, taking into account consideration across various aspects of the network. The central problem is that there is a looming danger that savings in one part of the network can be the cause for an increased use in another.

In addition, the use cases can vary drastically which might call for a range of metrics each suitable for a different scenario. For example, the energy-efficiency of data centers is commonly evaluated using the Power Usage Effectiveness (PUE) but there are many other metrics such as the IT Equipment Energy Efficiency (ITEE), IT

Equipment Utilization (ITEU), and so on [GGrid]. While many of these metrics have a significant value in isolation , a holistic methodology for measuring the energy-efficiency spanning multiple such metrics would be beneficial.

The first big step, which to some degree is already been taken, is to assess current power consumption patterns and to come to an understanding how the power consumption is distributed in the network, in devices, in device components and how the utilization of the network impacts these patterns [PowerTrend] [GTC].

4.3. Problems due to Common Network Operation Practices

Many of the networks that constitute the Internet are over-provisioned and offer a large degree of redundancy, which, while contributing to the overall quality of the Internet service, results in low energy-efficiency.

A lot of people feel that the QoS support of the Internet architecture itself is inadequate and see over-provisioning a the only sensible means to achieve it. And indeed, it is a common practice. Usually network traffic shows significant temporal fluctuations and, during low traffic periods, an over-provisioned network uses unnessecarily large quantaties of energy.

Experimental measurements have showen that the energy consumption of some devices and components (such as Ethernet links) depend mainly on their capacity, not on actual utilization. Most devices keep drawing a certain amount of power even in the absence of traffic, i.e. without providing a meaningful service.

Moreover, for resiliency and fault-tolerance purposes, certain equipment is put into the infrastructure solely for backup purposes. Such redundancy also decreases the effective network energy-efficiency further [GREENR] [GTC] [EARTH].

The above certainly is important and vital in many cases. Often strong requirement make the above necessary (e.g. switch-over times in the range of 50ms). It is not just a technical issue that needs to be solved here but also an issue of operation principles. Putting nodes into sleep operation or incorprating energy-efficiency considerations into network operations will be challenging for the reasons stated above and there will be reluctance to allow energy-efficiency mechanisms to profoundly change the way networks are operated today.

5. Potential IETF/IRTF Work Items

The following is an (incomplete) list of potential work items where the IETF/IRTF might start to pave a path for energy-efficient protocol desgin and network operations.

5.1. Load-adaptive Resource Management

In common networks that are provisioned for peak traffic load, a substantial amount of energy can be saved by dynamically allocating resources according to actual traffic.

Conceptually, network resources may be shut down when there is no traffic or scaled down when there is little traffic to improve the overall energy-efficiency [GreenInternet]. Network equipment, such as base stations, may be turned off when there is no user within coverage or link capacity may be reduced when traffic demand is low. This type of approach potentially has a broad applicability to various areas not just wireless network, but also core routers/ switches, optical transmission equipment and office networks. Simply turning equipment off clearly would result in service degradation, instability and in the worst case loss of connectivity. The overall optimization goal therefore is to minimize the network power consumption while maintain network performance resulting in a non-trivial contraint optimization problem [ANRP] [OptMgmt].

In this area, the IETF/IRTF could work on algorithms to solve the above described optimization problem and on protocol support for it. Measuring and monitoring is already being worked on in the EMAN working group. The control side, i.e. acting on the measurements and configuring the network accordingly is still very much an open question. While the EMAN MIBs allow control, the whole "how" is not addressed right now. Also a set of best current practices can be developed.

5.2. Energy-efficient Protocol Design

Energy-efficiency is one of these topics that need to be a design goal or otherwise it will be difficult to retrofit it into a protocol specification. The question is what are the factors that need to be considered. It might well be that there are certain design patterns and options that can be distilled that are vital and a protocol specification can be checked against these. Such a list could be the product of the IETF/IRTF. The security aspects of the IETF underwent a similar evolution and security considerations are now a mandatory part of every new protocol specification. This is not to say the there should be an Energy-Efficiency Considerations section in each new Internet draft, but there are a lot of lessons learned from this example. There are a number of important security principles such as crypto-agility and it would be beneficial if something similar could be established for energy-effciency. A trivial example would be to require that nodes can re-negotiate timeouts (in protocols that make use of timeouts) so that a node might be able to go into sleep mode or to attempt to synchronize periodic messages across a number of protocols so that these messages all fall into a certain timeframe and inbetween the node can sleep.

In addition, it IETF/IRTF could pick a number of existing protocols and attempt to extend them so as to make them more energy-efficient, or more likely allow the underlying technology to be more energy-efficient without breaking communication. In some cases, entirely new protocols may be needed to support the sleep mode of nodes.

Also, the IETF/IRTF can start to develop proxying solutions as discussed before. Before going into sleep, a node delegates its functionalites to such a proxy, which will then respond to routine network traffic on behalf of the sleeping node and it will wake the node up when it is needed. Proxys could handle traffic for network connectivity-related operations such as (ARP, ICMP, DHCP) and also proxy functions that are application specific could be developed (P2P). . The IETF/IRTF would need to define the protocols and procedures for proxy operation such as discovery, selection, delegation and wake-up [SCE] [NCP].

5.3. Energy-efficiency Metrics and Standard Benchmarking Methodologies

Energy-efficient research and development needs standard performance metrics in order to evaluate and quantatively compare the effectiveness of energy-efficient solutions.

Energy-efficiency of a network and the devices therein can be assessed using measures of energy per sent data unit (e.g. in the unit of joule/bit) or power per date rate (watt/bps). In principle, these measures indicate how much energy is needed to send a bit. Many approaches to network energy-efficiency are limited to the power consumption of a single device (router, switch or base station). This scope is comparably easy to specify and measure, but fails to capture performance aspects such as daily traffic fluctuation or network under-utilization [GTC].

There are various options to approach this problem. Energy-efficiency metrics could be extracted e.g. from reference scenarios such as network topologies and traffic profiles (similar to what the automobile industry does).

6. Conclusion

Energy-efficiency cerainly is a buzz word right now but beyond the hype it indeed becomes an important economical and societal aspect. This document is an attempt to discern a number of work items in this space for the IETF/IRTF to consider. While the IETF/IRTF is clearly not able to work on all of the above, some of the mentioned mechanisms are clearly more far reaching than others and some of the topics are surely outside of what the IETF/IRTF usually works on, there are a number of things that the IETF/IRTF can and should take on as work items to investigate.

We present these ideas for discussion in the community and hope to extract a number of realistic action items to work on in the near future.

7. Security Considerations

The draft covers a range of potential work items and research activities, each with its own security considerations. These will be addressed once their actual form and nature become more concrete.

8. IANA Considerations

This document does not require any action from IANA.

9. References

9.1. Normative References

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9.2. Informative References

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Appendix A. Other energy-related IETF documents

Below is a list of other relevant documents the authors are aware of (in no particlar order).

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B. Nordman, K. Christensen, "Nanogrids", draft-nordman-nanogrids-00 (work in progress)

T. Suzuki, T. Tarui, "Requirements for an Energy-Efficient Network System", draft-suzuki-eens-requirements (work in progress)

Z. Cao, "Synchronization Layer: an Implementation Method for Energy Efficient Sensor Stack", draft-cao-lwig-syn-layer (work in progress)

A. Junior, R. Sofia, "Energy-awareness metrics global applicability guideline", draft-ajunior-energy-awareness-00 (work in progress)

B. Zhang, J. Shi, M. Zhang, J. Dong, "Power-aware Routing and Traffic Engineering: Requirements, Approaches, and Issues", draft-zhang-greennet (work in progress)

T. Suganuma, N. Nakamura, S. Izumi, H. Tsunoda, M. Matsuda, K. Ohta, "Green Usage Monitoring Information Base", draft-suganuma-greenmib (work in progress)

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