Authors: A. Clemm   L. Dong   G. Mirsky   L. Ciavaglia
         Futurewei   Futurewei   Ericsson   Nokia
         J. Tantsura   M-P. Odini
         Microsoft

Green Networking Metrics

Abstract

This document explains the need for network instrumentation that
allows to assess the power consumption, energy efficiency, and
carbon footprint associated with a network, its equipment, and the
services that are provided over it. It also suggests a set of
related metrics that, when provided visibility into, can help to
optimize a network's energy efficiency and "greenness".

Status of This Memo

This Internet-Draft is submitted in full conformance with the
provisions of BCP 78 and BCP 79.

Internet-Drafts are working documents of the Internet Engineering
Task Force (IETF). Note that other groups may also distribute
working documents as Internet-Drafts. The list of current Internet-
Drafts is at https://datatracker.ietf.org/drafts/current/.

Internet-Drafts are draft documents valid for a maximum of six
months and may be updated, replaced, or obsoleted by other documents
at any time. It is inappropriate to use Internet-Drafts as reference
material or to cite them other than as "work in progress."

This Internet-Draft will expire on 23 April 2023.

Copyright Notice

Section 4.e of the Trust Legal Provisions and are provided without
warranty as described in the Revised BSD License.

Table of Contents

1. Introduction

Climate change and the need to curb greenhouse emissions have been
recognized by the United Nations and by most governments as one of
the big challenges of our time. As a result, improving energy
efficiency and reducing power consumption are becoming of increasing
importance for society and for many industries. The networking
industry is no exception.

Networks themselves consume significant amounts of energy.
Therefore, the networking industry has an important role to play in
meeting sustainability goals. Future networking advances will
increasingly need to focus on becoming more energy-efficient and
reducing carbon footprint, both for economic reasons and for reasons
of corporate responsibility. This shift has already begun and
sustainability is already becoming an important concern for network
providers [telefonica2020].

There are many vectors along which networks can be made "greener".
At its foundation, it involves network equipment itself. Making such
equipment more energy-efficient is a big factor in helping networks
become greener. However, opportunities also exist at the level of
protocols themselves (e.g. reduction of transmission waste and

enabling of rapid control loops), at the level of the overall network (e.g. path optimization under consideration of energy efficiency as a cost factor), and architecture level (e.g. placement of contents and functions) [I.D.draft-cwx-green-ps].

However, regardless of any particular approach that is chosen, in order to assess its impact, there is a need to have visibility into the actual energy consumption that is occurring and to ideally be able to attribute that consumption to its sources. As the adage goes, you cannot manage what you cannot measure. By extension, you cannot optimize what you have no visibility of. The ability to instrument networks in a way that allows for the assessment of energy consumption is hence an important enabler for potential energy optimizations, allowing to assess the effectiveness of measures that are being taken and enabling (for example) control loops that involve energy as an input. Before instrumenting, it needs to be clear, however, what the proper metrics are that network providers will be interested in and that applications will seek to optimize.

This document defines a set of metrics that allow to assess the "greenness" of networks and that form the basis for optimizing energy efficiency, carbon footprint, and environmental sustainability of networks and the services provided. These metrics are intended to serve the foundation for possible later IETF standardization activities, such as the definition of related YANG modules [RFC7950] or energy-related control protocol extensions. It should be noted that the metrics introduced here are not intended to be used to manage applications such as Power over Ethernet, requirements and instrumentation for which have been defined in other contexts (e.g. [RFC6988][RFC7460]).

Please note that throughout this document, we will be using the terms "green" and "energy efficient" interchangeably. In general, we will be use these terms in a broad sense, encompassing also carbon footprint and sustainability except when explicitly mentioned otherwise. Likewise, we treat "energy efficiency" as synonymous with "energy utilization efficiency", broadly speaking referring to the efficiency with which energy is being utilized.

2. Definitions and Acronyms

Carbon footprint: as used in this document, the amount of carbon emissions associated with the use or deployment of technology, usually directly correlated with the associated energy consumption

CPU: Central Processing Unit

IPFIX: IP Flow Information eXport

TCAM: Ternary Content-Addressable Memory

pWh: pico Watt hour

Wh: Watt hour

3. Energy Metrics

In the following, we categorize energy metrics as follows:

*At the device/equipment level. This concerns aspects such as energy consumption of a device as a whole, of equipment components such as line cards or individual ports. It includes metrics that would, for example, be found in equipment data sheets.

*At the flow level. This concerns aspects about energy consumption by flows. Metrics at this level attribute energy consumption to a flow.

*At the path level. These metrics attest to the end-to-end energy efficiency of paths, attesting to their energy intensity (reflecting e.g. the amount of energy drawn when the path is selected) and taking into account, for example, whether a given path includes segments known to be energy-intensive.

*At the network level. These metrics aggregate energy consumption across a network to provide a holistic picture of the "network as a system".

3.1. Energy Metrics related to Equipment

3.1.1. Energy Consumption Metrics

Arguably the most relevant energy metrics relate to equipment as a whole. After all, power is drawn from devices.

The power consumption of the device can be divided into the consumption of the core components (e.g. the backplane and CPU) as well as additional consumption incurred per port and line card. In [I.D.draft-manral-bmwg-power-usage], the device factors affecting power consumption are summarized: base chassis power, number of line cards, number of active ports, port settings, port utilization, implementation of packet classification of Ternary Content-Addressable Memory (TCAM) and the size of TCAM, firmware version.

Furthermore it is important to understand the difference between power consumption when a resource is idling versus when it is under

load. This helps to understand the incremental cost of additional
transmission versus the initial cost of transmission. Generally, the
cost of the first bit could be considered very high, as it requires
powering up a device, port, etc. The cost of transmission of
additional bits (beyond the first) is many orders of magnitude
lower. Likewise, the incremental cost of CPU and memory that will be
needed to process additional packets becomes fairly negligible.

The first set of metrics corresponds to ratings of the device:

  *Power consumption when idle (e.g. Watts)

  *Power consumption when fully loaded (e.g. Watts)

  *Power consumption at various loads: e.g. power consumption at 50%
   utilization, power consumption at 90% utilization

These metrics should be maintained for the device as a whole, and
for the subcomponents: i.e. for the chassis by itself, for each line
card, for each port. They should also take into account aspects such
as the current memory configuration, as the overall energy
consumption of a device is a function of the energy consumption of
the components the system is comprised of.

The metrics could be provided by the data sheet associated with the
device or they could be measured as part of a deployment. For
maximum accuracy and comparability, they should reflect pre-defined
environmental setting, e.g., operating temperature, relative
humidity, barometric pressure. For example, ATIS (Alliance for
Telecommunications Industry Solutions) [ATIS0600015.02] defines a
reference environment under which to measure router power
consumption: temperature of 25 celsius degree (within 3 celsius
degree deviation), relative humidity of 30% to 75%, barometric
pressure between 1020 and 812 mbar. In the AC power configuration,
the router should be evaluated at 230 VAC or within 1% deviation, 50
or 60 Hz or within 1% deviation [Ahn2014].

The second set of metrics reflects the actual power being drawn
during operation. It is the type of data that might be provided as
management data. Again, it should be provided for the device as a
whole, as well as for the subcomponents reflected in the device
hierarchy: line cards, ports, etc.

  *Current power consumption (e.g. Watts)

  *Power drawn since system start (or module insertion, if at the
   level of a line card, or port activation, if at the level of a
   port), for the past minute (e.g. Watt hours)

The third set of metrics are derived from the earlier metrics. They
normalize the power consumption relative to the line speeds
respectively amount of traffic that is passed.

   *Current power consumption / kilooctet

The fourth set of metrics reflects expectation values about
incremental energy usage. It could be relevant for use cases that
assess the cost of additional traffic. [Bolla2011] and [Ahn2014]
found that the power consumption of a router is in direct proportion
of the link utilization as well as the packet sizes.

   *Incremental power per packet, per kilooctet, per gigaoctet.
    (Possible units might be pJ - pico Joules)

3.1.2. Other Metrics

In addition to consumption metrics, it is conceivable to also have
the device reflect other context of relevance. An important aspect
concerns the power source. In most cases, devices will be agnostic
to the power source and depend on the specific deployment.
Nonetheless, for a holistic picture, it makes sense to have the
sustainability of the device power source reflected. This can occur,
for example, via a sustainability rating of the power source. This
sustainability rating might reflect sustainability on a scale
ranging from diesel-generator powered, via conventional power grid,
to renewable (powered by windmill, capture of excess heat, etc). It
may be possible to obtain such a rating from the energy operator and
(if not attributable to a single source) reflect the operator's mix
of energy sources.

Also, the environmental status of the device could be taken into
consideration, such as whether it is deployed in a data center and
its share in contributing to the need for cooling. It is conceivable
to, for example, introduce corresponding metrics that attribute a
share of the general power consumption of the environment that the
device is deployed in to the device - an "energy tax" attributed to
the device, so to speak.

3.1.3. Virtualization Considerations

Instrumentation should also take into account the possibility of
virtualization. This is important in particular as networking
functions may increasingly be virtualized and hosted (for example)
in a data center. Overlay networks may be formed. Likewise, many
applications expected to optimize energy consumption may be hosted
on controllers and applied to soft switches, VNFs (Virtual Network
Functions), or networking slices. The attribution of actual power
consumed to such virtualized entities is a non-trivial task. It
involves navigating layers of indirection to assess actual energy

usage and contribution by individual entities. While it would be possible in such cases to simply revert to energy metrics of CPUs and data centers as a whole, this loses the ability to account for those metrics on the basis of networking decisions being made.

For example, virtualized networking functions could be hosted on containers or virtual machines which are hosted on a CPU in a data center instead of a regular network appliance such as a router or a switch, leading to very different power consumption characteristics. A data center CPU could be more power efficient and consume power more proportionally to actual CPU load. Virtualization could result in using fewer servers. [Energystar] reports that one watt-hour of energy savings at the server level results in roughly 1.9 watt-hours of facility-level energy savings by reducing energy waste in the power infrastructure and reducing energy needed to cool the waste heat produced by the server.

Instrumentation needs to reflect these facts and facilitate attributing power consumption in a correct manner. Alternatively, a simpler solution may be to simply forgo energy metrics for virtualized functions entirely, instead focus on instrumenting and relying on optimizing the energy footprint of the underlying hosting infrastructure. In the meantime, the attribution of energy consumption and carbon footprint to individual functions that run on top of that infrastructure may be a topic for further research.

3.2. Energy Metrics related to Flows

Energy metrics related to flows attempt to capture the contribution of a given flow to energy consumption. In its basic incarnation, those metrics reflect the energy consumption at a given device. They could be used in conjunction with IPFIX [RFC7011] and modeled as Information Elements to be treated analogous to other flow statistics [RFC7012]. The following is a corresponding set of flow energy metrics at a device:

  *Incremental energy consumed over the duration of the flow.

   This is the incremental energy consumption that is directly caused by the flow, representing the difference between the amount of energy consumed with the flow and the amount of energy that would have been consumed without the flow. (It should be noted that this metric may be difficult to assess in practice.)

  *Amortized energy consumed over the duration of the flow.

   This is the portion of the flow's energy consumption for the duration of the flow, effectively computed by computing the proportion of flow traffic to overall traffic and multiplying it

with the total energy consumption incurred by the device for that
time.

A second set of energy metrics related to flow might aggregate the
flow's energy consumption over the entire flow path. In that case,
the flow energy consumption is added up along the systems of the
traversed path. In practice, this will be more difficult to assess
with reasonable accuracy for many reasons, including impacts of load
balancing, PREOF (Packet Replication, Elimination, and Ordering
Functions [RFC8655]) which may lead to replicated packets for
certain segments of a path, packet loss (the power consumption of
which still needs to be attributed to their respective flow),
challenges to trace actual routes taken by production traffic, and
more.

3.3. Energy Metrics related to Paths

Energy metrics related to paths involve assessing the carbon
footprints of paths and optimizing those paths so that overall
footprint is minimized, then applying techniques such as path-aware
networking [I.D.draft-chunduri-rtgwg-preferred-path-routing] or
segment routing [RFC8402] to steer traffic along those paths that
are deemed "the greenest" among alternatives. It also includes
aspects such as considering the incremental energy usage in routing
decisions.

Optimizing cost has a long tradition in networking; many of the
existing mechanisms can be leveraged for greener networking simply
by introducing energy footprint as a cost factor. Low-hanging fruit
includes the inclusion of energy-related parameters as a cost
parameter in control planes, whether distributed (e.g. IGP) or
conceptually centralized via SDN controllers.

In addition to power consumption over a path itself, other factors
such as paths involving intermediate routers that are powered by
renewable energy resources might be considered, as might be
determined by an aggregate sustainability score. After all, paths
with devices that are powered by solar, wind, or geothermal might be
preferable over paths involving devices powered by conventional
energy that may include fossil fuel or nuclear resources.

The following are a corresponding set of candidate metrics:

  *Energy rating of a path. (This could be computed as a function of
   energy ratings of different hops along the path.)

  *Current power consumption across a path. (This could be computed
   by aggregating the current power per packet (or per kilo octet
   etc) of each of the hops along the path.)

*Incremental power for a packet over a path. (This could be
  computed by aggregating the incremental power per packet of each
  of the hops along the path.)

3.4. Energy Metrics related to the Network-at-Large

Ultimately, the goal of energy optimization and reduction of carbon
footprint is to minimize the aggregate amount of energy used across
the entire network, as well as to minimize the overall carbon
footprint of the network as a whole. Accordingly, metrics that
aggregate the energy usage across the network as a whole are needed.
In order to account for changing traffic profiles, growth in user
traffic etc, additional metrics are needed that normalize the total
over the volume of services supported and volume of traffic passed.
Corresponding metrics will generally be computed at the level of
Operational Support Systems (or Business Support Systems) for the
entire network.

Some of the metrics used include the following [telefonica2020]:

  *Total energy consumption (MWh)

  *Electricity from renewable sources (%)

  *Network energy efficiency (MWh/PB)

4. Other considerations and discussion items

This document is intended to spark discussion about what energy
metrics will be useful to reduce the carbon footprint of networks -
that provide visibility into energy consumption, that help
optimization of networks under green criteria, that enable the next
generation of energy-aware controllers and services. Clearly, other
metrics are conceivable and more considerations apply beyond those
that are currently reflected in this document. The following
subsections highlight items that warrant further discussion and that
might be addressed in greater detail in future revisions of this
document.

4.1. User perspective

Arguably, attributing energy usage to individual users and making
users aware of the energy-implications of their communication
behavior may provide interesting possibilities to reduce energy
footprint by guiding their behavior accordingly. For example, the
network could present clients with energy statistics related to
their communication usage. This could be supported by metrics
related to service instances, such as energy usage statistics beyond
statistics regarding volume, duration, number of transactions. Such
approaches would raise questions about how to actually collect such

statistics accurately (versus just computing them via a formula) or
what to actually include as part of those statistics (amortized vs
incuremental energy contribution, attribution of cost for path
resilience or retransmissions due to congestion, etc). They also
raise questions about how they would in practice be used. For
example, energy-based charging might be explored as an alternative
for volume-based charging; however, in practice the two may be
strongly correlated and rejected by customers for similar reasons
that volume-based charging is frequently rejected.

4.2. Holistic perspective

The network itself is only one contributor to a network's carbon
footprint. Arguably just as important are aspects outside the
network itself, such as cooling and ventilation. These aspects need
to be taken into account as part of a holistic perspective. However,
reflecting such aspects here would arguably result in "boiling the
ocean" and are therefore not addressed here.

4.3. Sustainable equipment production

Internet energy consumption may constitute two major components
[Raghavan2011]: (1) the energy of the devices that construct the
Internet, including the infrastructure devices: routers, LAN
devices, cellular and telecommunication infrastructure, (2) More
broadly, with the rise of peer-to-peer applications and cloud
services, it also considers the energy consumption of the end
systems, including desktops, laptops, smart phones, cloud servers,
and application servers that are not in the cloud.

For those two components, the following factors need to take into
consideration for energy consumption calculation:

  *Energy consumed in manufacturing of the devices and end-systems,
   as well as the contribution from their components and materials.
   It is conceivable to amortize the associated energy consumption
   over the lifetime of the device.

  *The replacement lifespan of the devices and end-systems: desktops
   and laptops are typically replaced in 3-4 years, smartphones in 2
   years, application servers and cloud servers in 3 years, routers
   and WiFi-LAN switches in 3 years, cellular towers and
   telecommunication switches in 10 years, fiber optics in 10 years,
   copper in 30 years, etc. With the incremental growth rate of the
   technology advancement, the replacement lifespan might be
   decreased over time.

  *Operational maintenance: the network would not be functional
   without various software and implementation of protocols. The
   energy consumed in creating software is complicated because it is

overwhelmingly human involved, which usually include the energy
used for the facilities of the software companies and human
energy of the programmers.

  *Replacement: The energy consumed in replacement of devices and
  end-systems could vary. Some could be very energy intensive for
  those large devices, e.g., cellular towers, or environmental
  unfriendly equipment, such as submarine communication cables.

  *Disposal: There is substantial energy cost in disposing and
  recycling the old devices and equipment.

By combining the energy consumption for running each device that
builds the Internet [JuniperRouterPower], and the energy consumption
of the end systems, in the meantime counting the energy consumption
of manufacturing, operational maintenance, replacement and lifespan,
disposal of those devices and equipment, we may have an estimate of
the energy consumption for the network as a whole.

4.4. Certification

Some of the metrics that are mentioned in this document may be
difficult to assess and verify in practice, such as sustainability
ratings or device power ratings. As far as these metrics are used to
optimize the sustainability of network deployments, special
consideration needs to be given to ensure that those metrics are
indeed reflected correctly and accurately. Decisions that are based
on incorrect assumptions and data may lead to ineffective or even
counterproductive courses of actions. Where assessment and
specifically verification of certain metrics are difficult, solution
approaches that involve certification of those metrics (for example,
of sustainability ratings) by a trusted authority could be
considered.

5. IANA Considerations

This document does not have any IANA requests.

6. Security Considerations

When instrumenting a network for energy metrics, it is important
that implementations are secured to ensure that data is accurately
measured and cannot be tampered with. For example, an attacker might
try to tamper energy readings to confuse controller trying to minize
power consumption, leading to increased power consumption instead.
In addition, access to the data needs to be secured in similar ways
as for other sensitive management data, for example using secure
management protocols and subjecting energy data that is maintained
in YANG datastores via NACM (NETCONF Access Control Model).

However, it should be noted that this draft specifies only metrics themselves, not how to instrument networks accordingly. For the definition of metrics themselves, security considerations do thus not really apply.

7. Acknowledgments

Acknowledgments will be added when the time comes.

8. Informative References

[Ahn2014]   Ahn, J. and H. S. Park, "Measurement and modeling the power consumption of router interface", DOI: 10.1109/ICACT.2014.6779082, 16th International Conference on Advanced Communication Technology, pp. 860-863, 2014, <https://ieeexplore.ieee.org/document/6779082>.

[ATIS0600015.02] AITS, "Energy Efficiency for Telecommunication Equipment: Methodology for Measurement and Reporting - Transport and Optical Access Requirements", March 2016.

[Bolla2011] Bolla, R., Bruschi, R., Lombardo, C., and D. Suino, "Evaluating the energy-awareness of future Internet devices", DOI: 10.1109/HPSR.2011.5986001, 2011 IEEE 12th International Conference on High Performance Switching and Routing, pp. 36-43, 2011, <https://ieeexplore.ieee.org/document/5986001>.

[Energystar] EnergyStar, "12 Ways to Save Energy in the Data Center, Server Virtualization", 2022, <https://www.energystar.gov/products/low_carbon_it_campaign/12_ways_save_energy_data_center/server_virtualization>.

[I.D.draft-chunduri-rtgwg-preferred-path-routing] Bryant, S. E., Chunduri, U., and A. Clemm, "Preferred Path Routing Framework", May 2022, <https://datatracker.ietf.org/doc/html/draft-chunduri-rtgwg-preferred-path-routing-01>.

[I.D.draft-cwx-green-ps] Clemm, A. and C. Westphal, "Challenges and Opportunities in Green Networking", June 2022.

[I.D.draft-manral-bmwg-power-usage] Manral, V., "Benchmarking Power usage of networking devices", January 2011.

[JuniperRouterPower] Juniper, "Power Requirements for an MX960 Router", 2021.

[Raghavan2011] Raghavan, B. and J. Ma, "The energy and emergy of the Internet", HotNets-X: Proceedings of the 10th ACM

Workshop on Hot Topics in Networks, pp. 1-6, 2011,
<https://dl.acm.org/doi/10.1145/2070562.2070571>.

[RFC6988]   Quittek, J., Chandramouli, M., Winter, R., Dietz, T.,
            and B. Claise, "Requirements for Energy Management", RFC
            6988, September 2013, <https://datatracker.ietf.org/doc/
            html/rfc6988>.

[RFC7011]   (Ed.), B. C., (Ed.), B. T., and P. Aitken, "Specification
            of the IP Flow Information Export (IPFIX) Protocol for
            the Exchange of Flow Information", RFC 7011, September
            2013, <https://datatracker.ietf.org/doc/html/rfc7011>.

[RFC7012]   (Ed.), B. C. and B. T. (Ed.), "Information Model for IP
            Flow Information Export (IPFIX)", RFC 7012, September
            2013, <https://datatracker.ietf.org/doc/html/rfc7012>.

[RFC7460]   Chandramouli, M., Claise, B., Schoening, B., Quittek, J.,
            and T. Dietz, "Monitoring and Control MIB for Power and
            Energy", RFC 7460, March 2015, <https://
            datatracker.ietf.org/doc/html/rfc7460>.

[RFC7950]   Bjorklund, M. E., "The YANG 1.1 Data Modeling Language",
            RFC 7950, August 2016, <https://datatracker.ietf.org/doc/
            html/rfc7950>.

[RFC8402]   (Ed.), C. F., (Ed.), S. P., Ginsberg, L., Decraene, B.,
            Decraene, B., Litkowski, S., and R. Shakir, "Segment
            Routing Architecture", RFC 8402, July 2018, <https://
            datatracker.ietf.org/doc/html/rfc8402>.

[RFC8655]   Finn, N., Thubert, P., Varga, B., and J. Farkas,
            "Deterministic Networking Architecture", RFC 8655,
            October 2019, <https://datatracker.ietf.org/doc/html/
            rfc8655>.

[telefonica2020] Telefonica, "Telefonica Consolidated Annual Report
            2020.", 2020.

Authors' Addresses

Alexander Clemm
Futurewei
2220 Central Expressway
Santa Clara, CA 95050
United States of America

Email: ludwig@clemm.org

Lijun Dong

Futurewei
2220 Central Expressway
Santa Clara, CA 95050
United States of America

Email: lijun.dong@futurewei.com

Greg Mirsky
Ericsson

Email: gregimirsky@gmail.com

Laurent Ciavaglia
Nokia

Email: laurent.ciavaglia@nokia.com

Jeff Tantsura
Microsoft

Email: jefftant.ietf@gmail.com

Marie-Paule Odini

Email: mp.odini@orange.fr