

Position paper: Green Networking Metrics

Alexander Clemm (ludwig@clemm.org) on behalf of the coauthors of draft-cx-green-metrics (including Lijun Dong (lijun.dong@futurewei.com), Greg Mirsky (gregimirsky@gmail.com), Laurent Ciavaglia (laurent.ciavaglia@nokia.com), Jeff Tantsura (jefftant.ietf@gmail.com), Marie-Paule Odiini (mp.odini@orange.fr))

We would like to submit the Internet Draft "Green Networking Metrics" (draft-cx-green-metrics) as a position paper contribution for discussion at the workshop. The 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". We argue that the document provides a good foundation for possible later IETF standardization activities in support for more sustainable networking technology, such as the definition of energy-related control protocol extensions or of YANG modules to facilitate management in ways that optimize sustainability.

The Internet Draft can be found here: <https://datatracker.ietf.org/doc/draft-cx-green-metrics/>. It constitutes an individual draft submission that is currently looking for the right landing spot in IETF/IRTF. We believe that it fits in well with the objectives of the workshop and is suitable for discussion there.

In the following, we will outline how the document fits in with the goals and objectives of the Workshop, as stated in the workshop announcement (<https://www.iab.org/activities/workshops/e-impact/>). For easier reference, we will number the bullet items from the announcement as (1) - (7):

(1) "Discuss the direct environmental impacts of the Internet, including but not limited to energy usage by Internet systems themselves, energy usage of the relevant end-user devices, resources needed for manufacturing the associated devices, or the environmental impacts throughout the lifecycle of Internet systems. Discuss the breakdown of those impacts across different system components and operations. Predict potential future trends for these impacts based on changed usage patterns and emerging technologies."

Response: The document does not discuss the environmental impact per se, however, it does discuss the need for network operators to get clear visibility of these aspects in order to optimize networks from the angle of sustainability, and makes concrete suggestions for how to approach this, specifically metrics to be collected. The document emphasizes the need for a holistic picture, i.e. not limiting this to assessing energy usage efficiency, but accounting also for aspects such as equipment lifecycle and sustainability of energy sources.

(2) "Discuss the indirect environmental impacts of the Internet, i.e., its effects on society overall, through enabling communications, virtual services, or global commerce."

Response: The document does not focus on this, although it does mention the fact that the Internet itself enables applications that help improve sustainability to a great degree. This is contrasted with the fact that at the same time, it is also a considerable contributor to carbon footprint that should be improved on, which serves as a motivator to the metrics and instrumentation being proposed.

(3) “Share information about relevant measurement metrics and data, and identify the need for additional metric or measurements.”

Response: This aspect is at the core of the document. It proposes and discusses a set of relevant metrics, which are further categorized into metrics at the device/equipment level, at the flow level (for example, to allow to attribute sustainability metrics at the level of services), at the path level (for example, attesting to the energy intensity of paths and network segments to aid in their selection and optimization), and at the network level (to provide the most holistic picture of the "network as a system").

(4) “Discuss the need for improvements or associated new functionality.”

Response: The document discusses the need for instrumenting networks with those metrics as a way to enable applications which optimize networks for purposes of sustainability, or that at least allow to take these metrics into account and provide visibility to network operators as part of future management and control applications. Today, such functionality is sorely missing.

(5) “Share information about the societal, business, and regulatory situation, to help identify areas of opportunity.”

Response: The document makes the case for the role that standardization can play in this area, such as defining standardized data models that facilitate the development of applications that will take advantage of visibility into metrics being provided.

(6) “Identify areas where further technical work would be most impactful.”

Response: The document proposes instrumentation of networks with sustainability-related metrics (including but not limited to metrics relating to energy consumption) as an important enabler for other applications that will rely on such instrumentation to optimize those metrics. An example are applications that rely on control loops to assess the sustainability impact of management and control actions, which are then used to refine those actions. In addition, other aspects are identified, such as the need and required technical support for certification, as well as the accommodation of metrics that take into account the sustainability of equipment lifecycle and network equipment production for an even more holistic picture.

(7) “Discuss specific improvement proposals.”

Response: Please see response to (6).

Reference: A. Clemm, L. Dong, G. Mirsky, L. Ciavaglia, J. Tantsura, M.-P. Odini: “Green Networking Metrics”, <https://datatracker.ietf.org/doc/draft-cx-green-metrics/>, October 2022.

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A. Clemm
L. Dong
Futurewei
G. Mirsky
Ericsson
L. Ciavaglia
Nokia
J. Tantsura
Microsoft
M-P. Oadini
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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".

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Internet-Draft

Green Networking Metrics

October 2022

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[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 incremental 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.

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Authors' Addresses

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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