METERING IN RAN TRANSPORT NETWORKS

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METERING IN RAN TRANSPORT NETWORKS

by NGMN Alliance

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01 EXECUTIVE SUMMARY

This publication presents a comprehensive analysis of energy consumption (EC) and energy efficiency (EE) observability within 5G mobile transport networks, with a specific focus on front-, mid-, and backhaul scenarios. As mobile network operators (MNOs) face increasing pressures from operational costs and sustainability targets, the need for detailed, function-specific energy metering in telecom infrastructure has become clear. The transition from basic energy consumption monitoring to advanced energy efficiency observability and management is essential for operators to validate improvement actions, optimise network performance, and reduce carbon footprint. The document underscores the importance of mapping energy consumption to individual network functions, services, and slices—particularly in the context of virtualized transport architectures.

The main findings and recommendations from this report are as follows:

FINDINGS:

- Transport network equipment is used in many industries – not just telecommunication services. Consequently, standardisation is distributed across several Standards Development Organisations (SDOs).
- Energy Metering is insufficiently covered in current standards.
- The lack of standardisation hinders operators' ability to collect and collate energy data and therefore their ability to optimally manage the energy footprint of their transport networks.

RECOMMENDATIONS:

- Further standardisation is needed – in particular in relation to defining data models and key performance values that enable energy efficiency to be derived at a network device / network function and (5G) slice level. Standards Development Organisations (SDOs) should:
  - Define an integrated KPI framework on the transport network level that enables the determination of energy consumption and energy efficiency of higher layer functions for link and network wide analysis.
  - Define a KPI framework that is applicable for fixed and mobile transport networks and that is appropriate for all common operating models.
  - Define an API that enables operators to expose and manage the capabilities of slices by a standardised API. This API shall include energy consumption and energy efficiency KPIs for each 5G-slice.
- The industry should consider consolidating and further harmonising standards where possible.

Through these measures, the publication aims to guide the industry toward a more sustainable and efficient future for mobile transport networks.

02 INTRODUCTION

2.1 STATE OF THE ART

As energy consumption becomes a top-of-mind topic for MNOs, in terms of operational costs and sustainability, detailed energy consumption observability is set to become a standard feature of Telecom equipment. The particulars of function specific energy related metering will be defined by various Telecom Standardisation Organisations (SDO's). Previous publications of NGMN Green Future Networks programme addressed metering aspects for Telecom facility equipment [1] and virtualised RAN infrastructure [2]; NGMN's recommendations are now being addressed by Work Items in ETSI Technical Committee (TC) Environmental Engineering (EE).

This new publication analyses the standards landscape for metering inside of transport equipment that is relevant for so-called mobile x-haul, which includes front-, mid-, and backhaul use-cases for connecting Radio Access Network (RAN) equipment with the mobile core network (see Figure 1). This includes the capability of taking energy-related measurements in the underlying HW and breaking down the overall consumption of the physical infrastructure components (xPU, PCI cards, fans etc.) into consumption of individual functions, services, slices, etc.

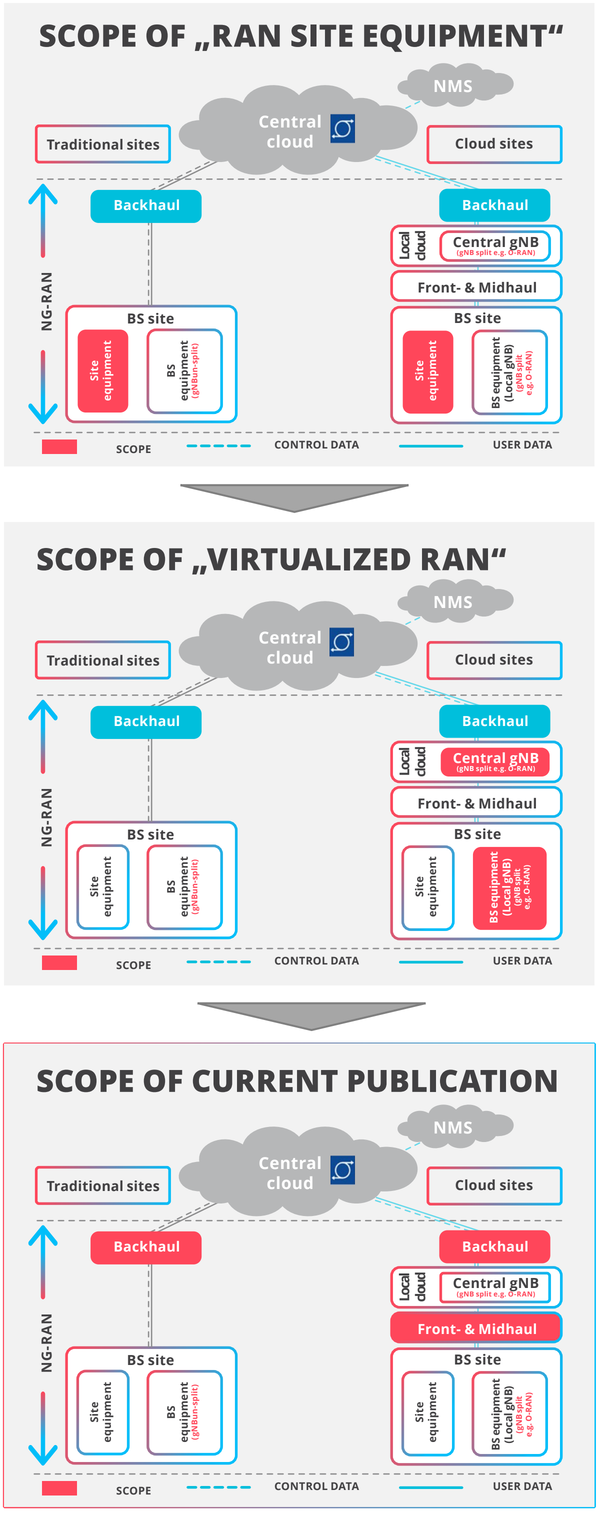

Figure 1: Overview of scope of the current publication ("Transport: Front-, Mid-, and Backhaul") and of the previous GFN Metering publications [1] ("Site equipment") and [2] ("Virtualised RAN equipment")

2.2 THE VALUE PROPOSITION OF ENERGY METERING IN THE NETWORK

The yearly global energy cost of running mobile networks was estimated to be USD 25 billion in 2020 [3]. From both cost and carbon footprint perspectives, energy consumption is one of our industry's biggest challenges.

Understanding the impact of newly deployed features or technologies on energy consumption of transport networks is crucial. For that, energy metering and the calculation of energy efficiency metrics is key helping to verify the effectiveness of improvement actions, ensuring optimised operation and maintenance while continuously enhancing Quality of Service (QoS) and improving the overall network utilisation. Virtualisation of radio– and transport network functions is progressing. The implementation into operational transport networks is in sight. Especially on Base Station (BS) sites, shared servers for radio and transport virtualised network functions (VNFs) will dilute architectural domains. A clear mapping of energy consumption to either radio or transport network supports analysing and optimising energy efficiency. An objective knowledge about the energy consumption of mobile transport networks will be essential for operators to increase the overall energy efficiency of RANs and to decrease the related energy costs.

2.3 AIM AND OBJECTIVES

Together with the migration from GSM (2G), WCDMA (3G), and LTE (4G) towards NR (5G), new architectural possibilities like split gNodeBs (gNB) and virtualisation of RAN functionalities are upcoming. The physical separation between BS site functionalities and access/aggregation network functionalities will become less clear. When mobile network operators plan future RAN deployments they will need to consider the energy efficiency of the implemented solution and hardware (see chapter 3.2). The insight into energy consumption of RAN equipment as well as transport components will be key. Focus areas of this publication are defined according to:

- **End to End (E2E) view**:
  This document describes the status and recommendations for standardisation for metering of RAN x-haul transport equipment as a basis for energy efficiency observability and management. Together with the previous NGMN Metering publications, a complete view on the achievements and challenges of energy metering in modern RANs are described for future energy efficiency, energy savings and energy cost reductions (see Figure 1).

- **radio access technologies:**
  Nearly every 10 years a new radio access technology (GSM, UMTS, LTE, NR, etc.) has been standardised, implemented and operated over years, partly in parallel with other technologies. The number of 5G capable networks is continuously growing. An increasing number of customers are equipped with 5G capable user equipment, and user traffic is shifted towards 5G networks. More and more spectrum bands, currently used for LTE (4G), get re-farmed to NR (5G). In parallel, 2G and 3G networks are losing importance and are switched off. This publication is focusing on LTE (4G) and NR (5G) architectural solutions as about 90% of the users of mobile services will use 4G and 5G networks soon (see Figure 2).

- **transport technologies:**
  According to GSMA [4], about 55% of the macro & small cell links are realised by microwave solutions, about 42% by fiber and the remaining 3% are distributed over technologies like xDSL (copper lines) and satellite links (see Figure 3). Therefore, this publication focuses on point-to-point fiber (mainly passive optical networks) and microwave in the access networks and fiber (CWDM/DWDM) networks in the aggregation network (see Figure 4). Findings and recommendations towards standardisation might also be applicable for transport in core networks (fixed and mobile).

- **communication protocols / protocol stacks:**
  Inside MNO transport networks, different communication protocols are in operation. Today's modern transport networks are operated based on the Internet protocol suite mainly consisting of the Transmission Control Protocol (TCP), the User Datagram Protocol (UDP), and the Internet Protocol (IP). In this publication, both the IP suite and the OSI model are referenced as protocol stacks.

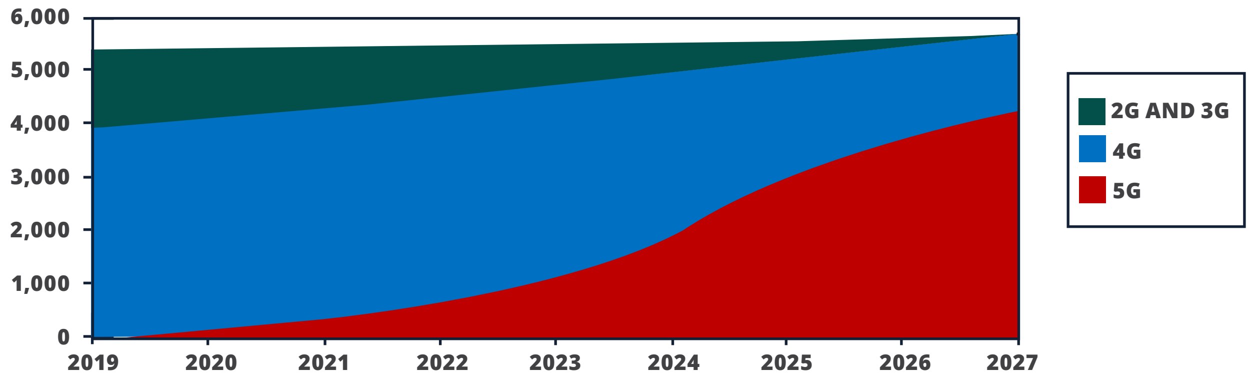

Figure 2: 4G & 5G -Technologies in focus based on cellular mobile subscriptions: Technical generation split in billions of users (source: GSMA Report on Wireless Backhaul Evolution [5], chapter 2.2)

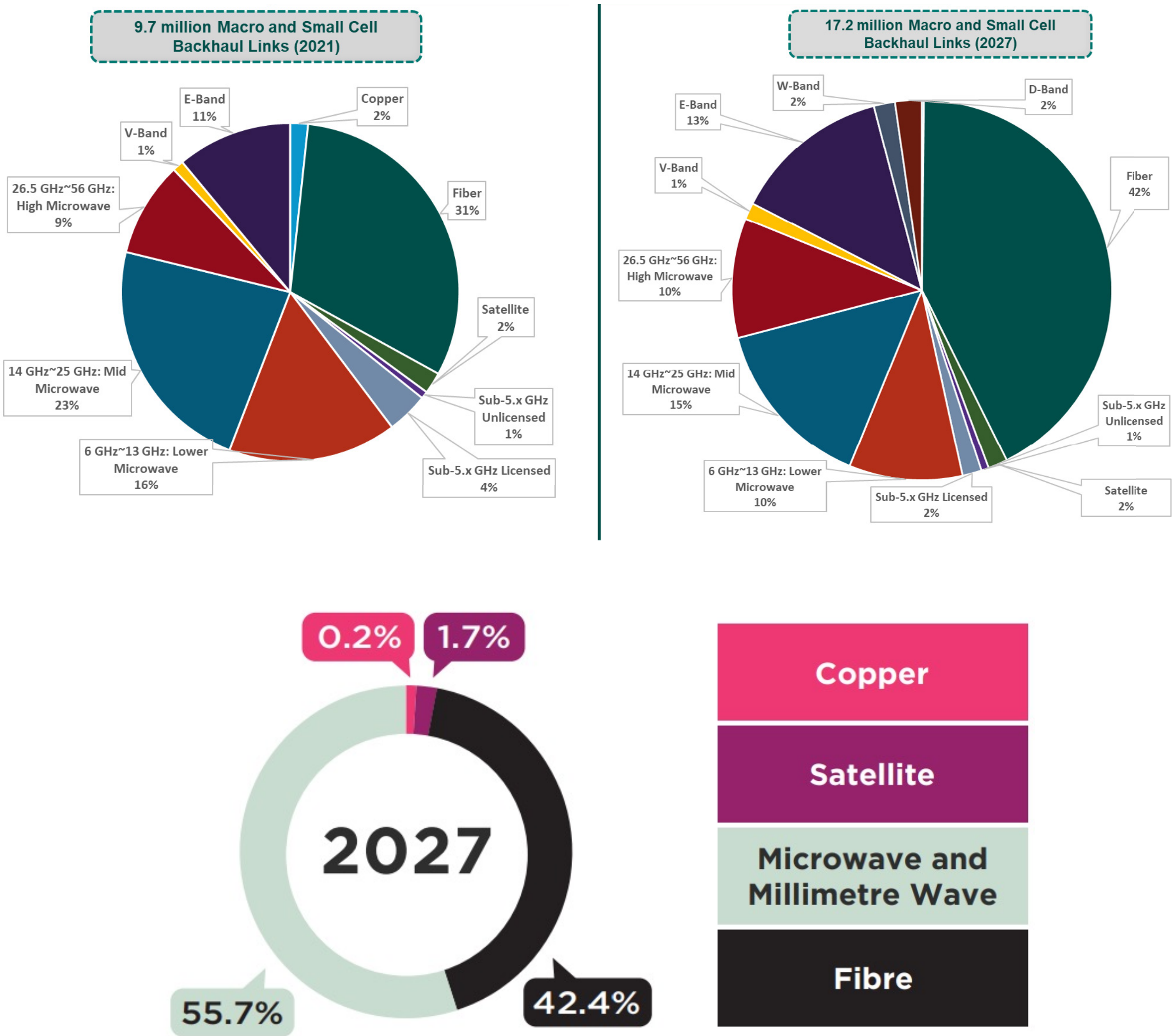

Figure 3: Installed macro and small cell backhaul links by technology 2021 vs 2027 (source: GSMA [5] figure 20 and [4])

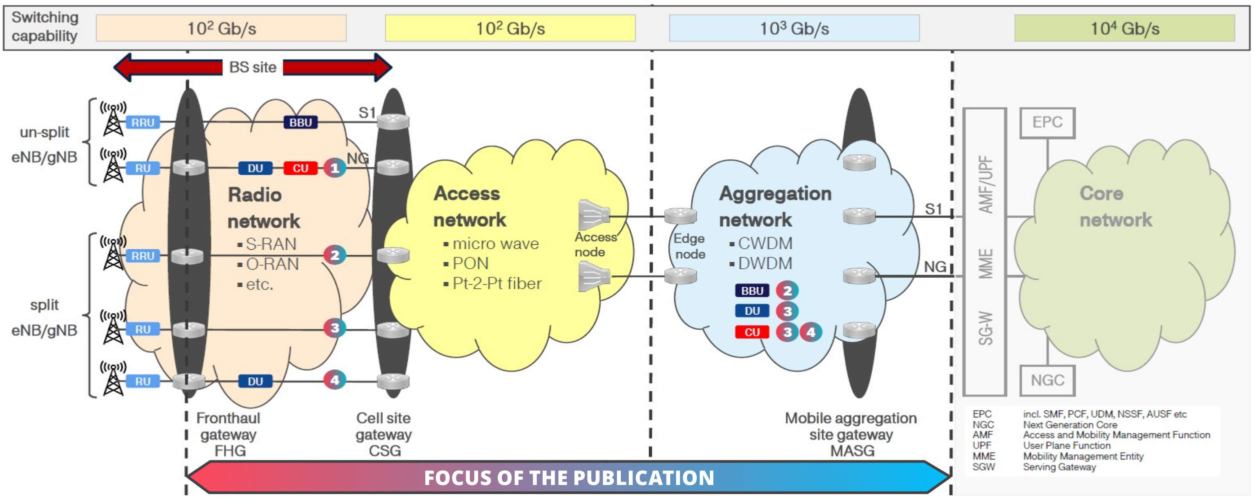

Figure 4: Architectural view enriched with radio and transport functions based on BBF TR-293 Energy Efficient Mobile Backhaul [9]

2.4 RAN ARCHITECTURAL SCOPE

Figure 4 depicts a simplified overview showing the three RAN x-haul transport segments and the major implemented technologies and functionalities:

- transport network at Base Station (BS) sites with front haul gateways and cell site gateways
- access networks to collect and concentrate traffic from BS-sites at access nodes
- aggregation network with edge nodes and mobile aggregation site gateway

The distribution of the split elements of eNB/gNB is indicatively shown in Figure 4. The definition of the interfaces (e.g. S1, NG, etc.) by the relevant SDOs sufficiently describes the transport network requirements (latency, throughput, etc.).
As mentioned in chapter 2.3 (see Figure 3), microwave, PON and point-to-point fibre are the dominant technologies in access networks. Aggregation networks are often realised by CWDM/DWDM fibre networks that come into place as transport networks for x-haul links. The term "x-haul" in the context of RAN transport networks refers to different types of transport networks used to connect various RAN components as shown in Figure 4.

2.5 SDO LANDSCAPE

Microwave and PON are the technologies predominantly used by MNOs in their access networks. Standardisation bodies like ITU, ETSI and Broadband Forum (BBF) are providing standards for these technologies. As most of the mobile x-haul transport networks are IP/Ethernet-networks, IETF is relevant as well. In addition, IEEE is providing standards for Ethernet networking and synchronisation.

The commonly used fibre optic technologies for aggregation networks are CWDM & DWDM (defined in ITU, ETSI and IEEE). As the aggregation network is an IP/Ethernet based network, IETF and IEEE are contributing to the standardisation of the used equipment - also other companies beside TelCo operators are using the same equipment but with different physical interfaces.

The Metro Ethernet Forum (MEF) is also covers – from the perspective of Carrier Ethernet - the underlying optical, IP transport and overlay SD-WANs.
Any IP and Ethernet based RAN transport equipment includes physical, data link, network and transport layer functionalities plus synchronisation and security functionality (see Figure 5):

- The network layer is based on Internet Protocol (IP) with TCP and UDP in the transport layer - both are described in RFCs by the IETF.
- As MNO networks are based on Ethernet standards the driving standardisation body for the data link layer (OSI model) is IEEE 802.3.
- The standards for the major implemented technologies at the physical layer in access and aggregation networks are defined by ETSI, ITU and IEEE 802.1. A mutual alignment including naming conventions, referencing and quotation is ongoing.
- Power/energy and voltage/current measurements are standardised by national standardisation bodies (China, Japan, etc.) and international bodies like IEC, ETSI, ATIS etc.

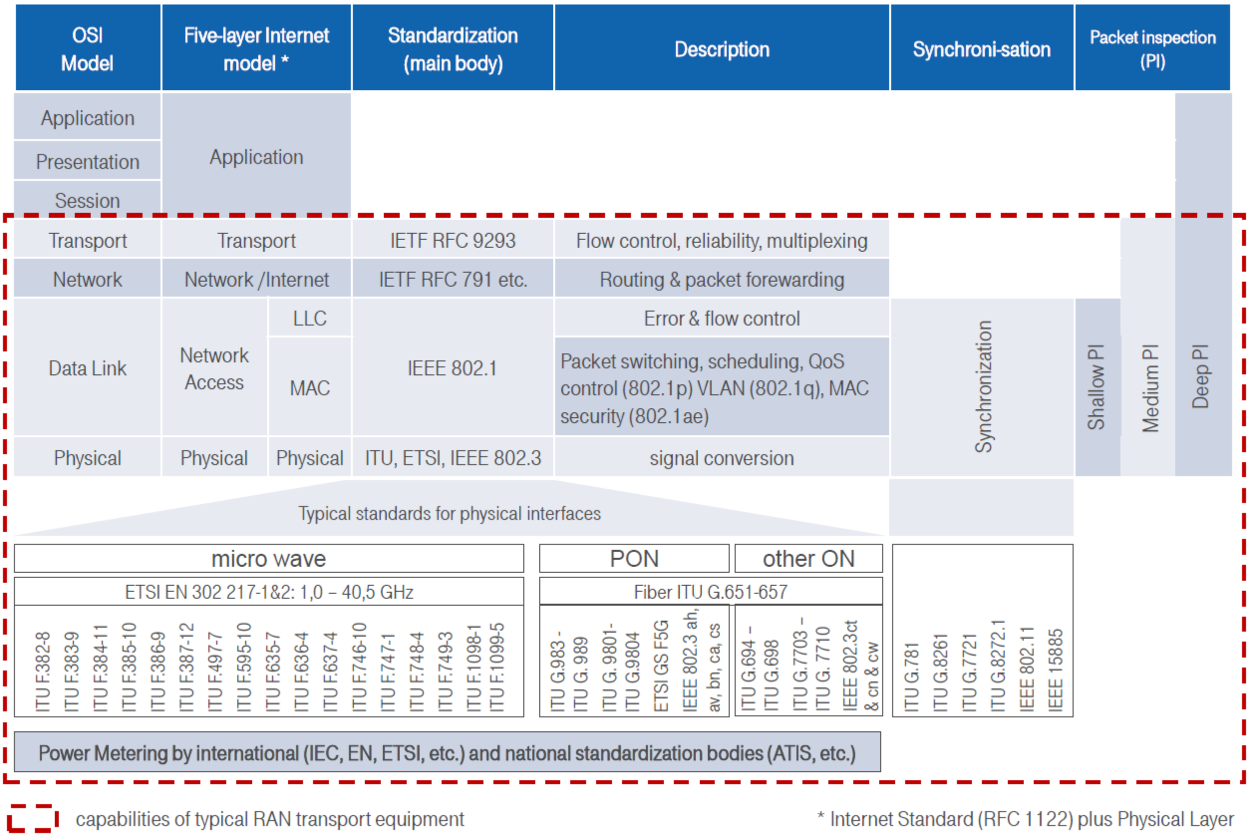

Figure 5: Functionalities of routing/switching equipment and the related standards (exemplary not complete)

Currently, none of the above listed ITU-T, ETSI and IEEE standards covers energy consumption related measurements as part of performance management (PM) for transport equipment. Therefore, energy consumption related measurements are either supported in a proprietary way and are accessible via supplier-specific management systems, or energy consumption (e.g. max, typical, ...) information is provided in technical product documentation or test reports.

Note: Transport networks are carrying traffic for mobile and fixed operators, but also for non-TelCo Ethernet carriers. There is no homogeneous naming of domains between - and sometimes also inside - various SDOs. It is strongly recommended to consider harmonised architectural definitions at least inside TelCo industry.

03 FROM METERING OF POWER / ENERGY TO MONITORING OF ENERGY CONSUMPTION AND ENERGY EFFICIENCY

The focus of this chapter is about metering, monitoring of energy consumption (EC), defining functional KPIs and determining the energy efficiency of transport functions at the device level and exposing related metrics to northbound management functions.

Metering voltage and current are the basis for deriving power measurements and the aggregated values are the energy consumption over a defined time period. All sensors are metering voltage and current, but the exposed data might be power [W] and/or energy consumption [Ws], [kWh], etc. Optimising energy efficiency (see chapter 5.2) requires insights into the energy consumption of the different transport network functions with sufficient granularity and accuracy.

Monitoring energy consumption and computing energy efficiency consumes computational resources, potentially affecting the performance of the hardware resource. As networks scale, this overhead can grow, making it essential to balance the trade-off between collection of detailed energy measurements and efficient network operation. If live measurements and usage data are not available, model-based computations can be used to derive the approximated energy consumption per transport function:

- The calculation of EC and EE of a transport function on the device level can be done on the device itself ("on-box"), as well as outside ("off-box") in a controller (as currently discussed in IETF [10]), which is comparable to the element management domain (EM) or network management domain (NM) level (see Figure 6 and Figure 7).
- Network level EE has to be calculated in the controller or on the Network Management (NM) level ("off-box"), with EE related data collected from all relevant transport infrastructure devices that are providing the respective transport function.

As standards for metering power & energy consumption with accuracy better than 5% require short sampling time-intervals down to [ms]; the calculation of EC on the transport function level is best done close to the source of the data, inside the respective device.

Although transport functions are standardised (see Figure 5), the related key values out of the performance parameters are missing to a wide extent, and APIs for EE from device to link and to network level are presently missing from standards (see chapter 3.2 and chapter 3.5).

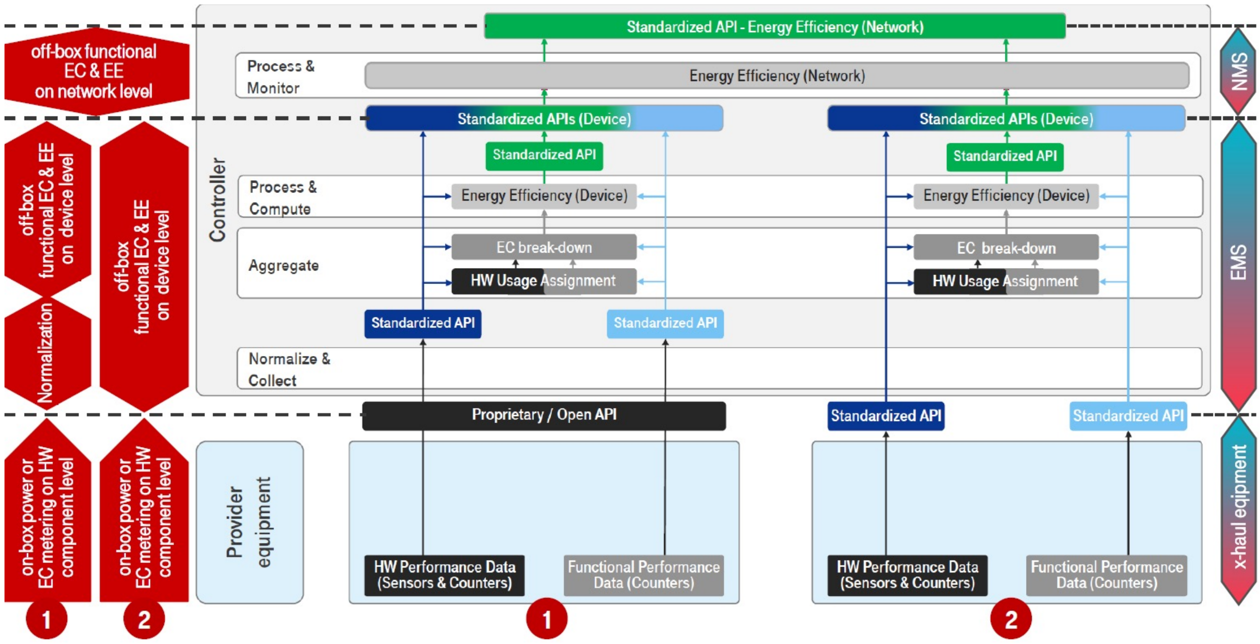

Figure 6: Possible implementations of determining energy consumption and efficiency for devices “off-box”

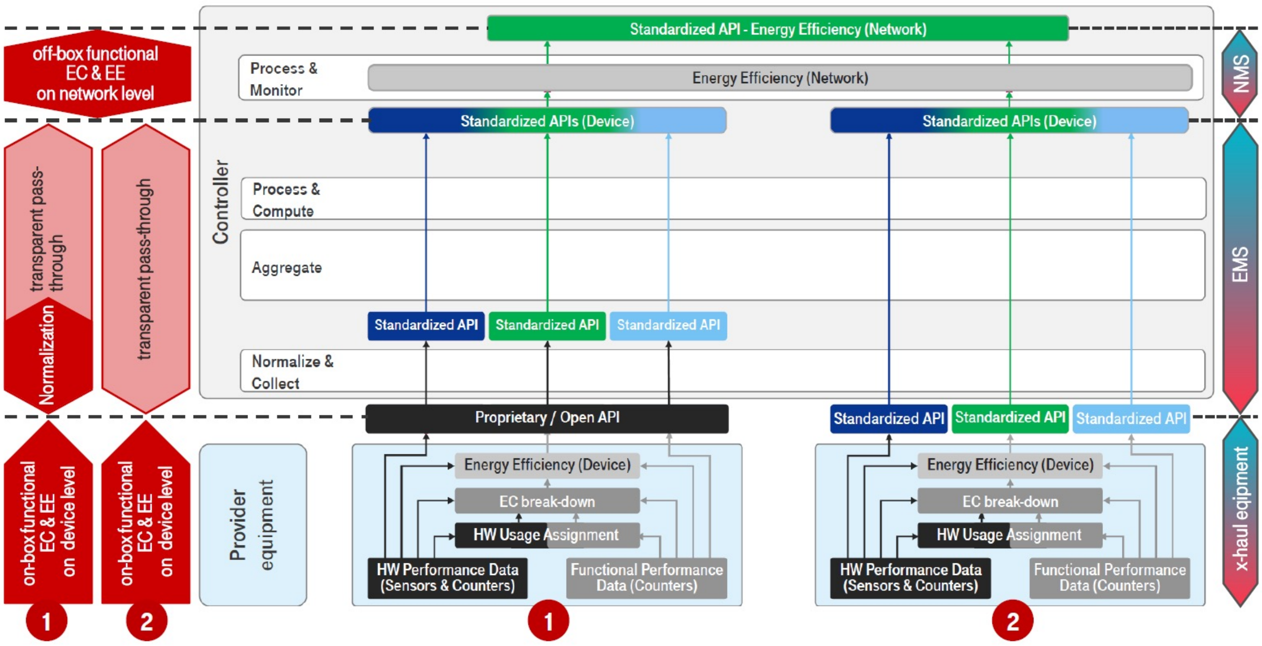

Figure 7: Possible implementations of determining energy consumption and efficiency for devices “on-box”

3.1 METERING AND MONITORING OF ENERGY CONSUMPTION (EC)

Defining the energy consumption of transport functions requires insights into power metrics as well as hardware utilisation percentage of this transport function. Energy consumption can be determined in a three-step approach:

i. **Hardware performance data** including energy consumption data are measured and collected on infrastructure component level (see chapter 3.1.1);
ii. the respective **transport function's infrastructure component usage** (HW utilisation percentage) is determined, and finally (see chapter 3.1.2);
iii. these measurements are broken down to an overall **consumption of that function** as several functions may run in parallel on the same infrastructure components (see chapter 3.1.2).

Energy efficiency is calculated using a function that relates a relevant performance parameter to energy consumption metrics (see chapter 3.2).
The following two sections describe the required steps for breaking down the energy consumption of a physical device into energy consumption of individual transport functions.

3.1.1 Hardware performance data - energy metering

Because the energy is consumed at the physical layer, energy consumption can only be measured for components of a hardware device, which is made possible by sensors integrated into the components themself to provide continuous monitoring of the electrical properties.
The integration of sensors into transport equipment may increase the cost of the equipment. Therefore, the granularity of installed sensors for energy-related measurements is strongly depending on the necessity, for instance imposed by the regulatory and governance framework of a transport network operator, to monitor & report energy consumption & efficiency and on the need of operators to monitor and reduce energy costs.
Any transport equipment consists of hardware providing:

- power supply and cooling,
- transceivers for the physical medium, and
- processing capabilities to provide various transport functions from the Physical, Data-link, Network and Transport layer (OSI model layers 1-4).

In the ideal case, all hardware components are equipped with power sensors, and the energy consumption of each hardware component is directly exposed. Figure 8 shows an example of energy consumption monitoring i.e., rising ambient temperature causes very different energy consumption increase for different HW components.

In general, not every hardware component is equipped with a power sensor, but energy consumption data for unmetered components can be derived e.g. by model driven break-down of measured energy consumption data to the remaining and unmetered hardware components. Measured as well as model-based energy consumption data can be exposed to the controller or element management function EMF via a standardised API (see Figure 6 and Figure 7).

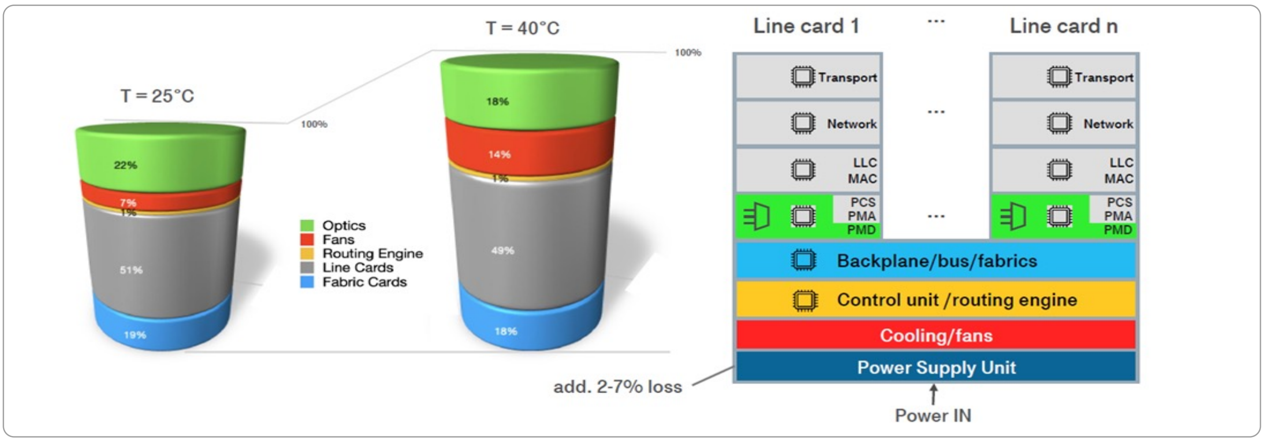

Figure 8: Exemplary insight gained with energy consumption monitoring on hardware component level, based on a contribution to IETF 120 for GREEN [15]

3.1.2. Hardware usage and energy consumption break-down

Determining the utilisation percentage of individual hardware components by the different transport functions is supported by typical Operating Systems for COTS servers (COTS = Commercial-off-the-shelf). (For the case of "Monolithic hardware" and "White Box hardware" please see chapter 3.3 / figure 9).

Once the energy consumption of various hardware components and their usage by transport functions is known, the energy consumption of transport functions can be determined. In cases where COTS-x86 based virtualised routers are used to provide transport functions (see also Figure 9 in chapter 3.3), the energy consumption breakdown to dedicated virtualised functions can be done by tools like for example Kepler (Kubernetes-based Energy Efficient Power Level Exporter) that offers a way to estimate energy consumption of applications hosted on cloud-native infrastructures (i.e. workloads deployed in a Kubernetes cluster). By leveraging software counters, machine learning (ML) models, and the cloud-native benchmark suite, Kepler offers accurate estimated energy consumption measurements on a process, container, and Kubernetes pod level.

Collection of data for energy consumption of hardware components, the utilisation percentage of hardware components (see above) and the breakdown of energy consumption to transport functions/functionalities can be provided by external (see Figure 6) or internal management functions (see Figure 7). Internal management functions (running inside the device = on-box) have access to lots of inbuilt power sensors and counters with sampling rates in the range of milliseconds. External management functions (= off-box), located at the controller (= EM) have a limited access to counters & sensor data as the sampling rates are reduced to minutes or even longer time intervals. Consequently, the accuracy of the results of internal functions is higher than from external ones.

3.2 PERFORMANCE DATA AND MONITORING OF ENERGY EFFICIENCY (EE)

Functional performance metrics - standardised definition of key values per function- including a data model for exposing them is a prerequisite to define uniform and transparent EE KPIs through various layers, especially when moving from the device / hardware component level to a link / network layer (physical and logical).

3.2.1 Functional performance data

Functional performance data is essential for both understanding how well a system or component is functioning and determining EE out of the consumed energy in relation to the relevant functional performance. Without this data, it is challenging to identify areas for improvement, to set benchmarks, and to develop strategies to enhance functional efficiency.

As shown in Figure 5, any equipment in Ethernet/IP based transport networks is following specifications from various standardisation bodies – at least RFCs from IETF and standards from IEEE 802.1. For physical interfaces and time synchronisation, ITU and ETSI provide additional commonly used standards for TelCos. Although the functions are standardised, the content and the way to expose performance KPIs are rudimentary or not at all defined. The absence of standards-based APIs for performance data is a significant blocking point for establishing a harmonised definition of functional efficiency and energy efficiency determination e.g., on network management level.

ITU started an initiative for fixed access networks by recommending an Optical Network Unit (ONU) management and control interface (OMCI) specification [11]. Since 2022, ETSI ISG F5G has been continuously publishing documents to define the Telemetry Framework and Requirements for the Fifth Generation Fixed Network (F5G) Access Network [12]. In these documents interfaces and related performance data are defined and described for OSI layers 1-4.

BBF defined a YANG model in TR-383 [13] to provide a standardised data model for managing and configuring broadband network devices and services. TR-383 specifies the YANG data models for various broadband network functions, enabling interoperability and efficient management of broadband networks. Additionally, TR-383 provides a high-level view of the data models covered by BBF and how they relate to data models defined by other Standards Developing Organisations, i.e., RFCs by IETF for YANG model [14].

From an operator's perspective, this is a good starting point to further harmonise functional key performance indicators paving the road towards harmonisation of energy efficiency monitoring for different types of telecommunication infrastructure.

3.2.2 Energy efficiency

Following a definition of ETSI, whereas the EE is the relation between the useful output and related energy consumption as defined in ETSI ES 203 228 [8], there are various ways of determining the useful output needed for energy efficiency (EE) monitoring according to the OSI layer model:

- **Layer 1 (Physical Layer):** received/transmitted (bytes / octets) bits per kWh (per equipment, physical port, wavelength, etc.)

- **Layer 2 (Data Link Layer):** received/transmitted frames per kWh (per equipment, physical port, wavelength, etc.).
  - with sub-categories for QoS (green/orange/passed/dropped), for security (e.g. packet inspection), etc.

- **Layer 3 (Network Layer):** received/transmitted packets per kWh (per equipment, physical port, wavelength, etc.).

- **Layer 4 (Transport Layer):** received/transmitted TCP segments/datagrams per kWh (per equipment, physical port, wavelength, etc.).

- **Layer 5 (Session Layer)** is responsible for the connection between two network resources (hardware nodes) to exchange / sync on data (NOTE: not in scope of this publication).

- **Layer 6 - 7 (Presentation & Application Layer)** are not limited to exchange data between a single access or aggregation network resources (hardware nodes) (NOTE: not in scope of this publication).

Conclusion: Once the relevant KPIs for standardised transport functions are defined, consistent APIs for EE from device to link and to network level can be standardised (see chapter 3.2.1). Without consistent EE data, it is challenging for operators to identify areas for improvement, to set benchmarks, and to develop strategies to enhance energy efficiency.

3.3 MONITORING OF EC AND EE IN HETEROGENEOUS TRANSPORT NETWORKS

Operational transport networks have a certain level of heterogeneity of the deployed devices, with multiple suppliers and HW generations.

One relevant new technology trend is the disaggregation of transport networks. The term disaggregation can have a different meaning to people in the network and IT domain. In the scope of this publication, disaggregation is discussed mainly in the sense of router software being separated from the underlying hardware (e.g., White Box approach). Three main implementation types of equipment can be found in transport networks (see Figure 9):

i. Non disaggregated where HW and SW is tightly coupled ("Monolithic solutions");
ii. White Box based hardware systems with either "Software Separation" or "Software Modularisation (Disaggregation)" solutions; and
iii. Virtualised transport solutions based on x86 COTS hardware.

Heterogenous networks require a harmonised approach to energy monitoring & EE observability across both virtualised and physical transport function implementations to enable operators to manage their transport network with all different types of equipment in a harmonised way.

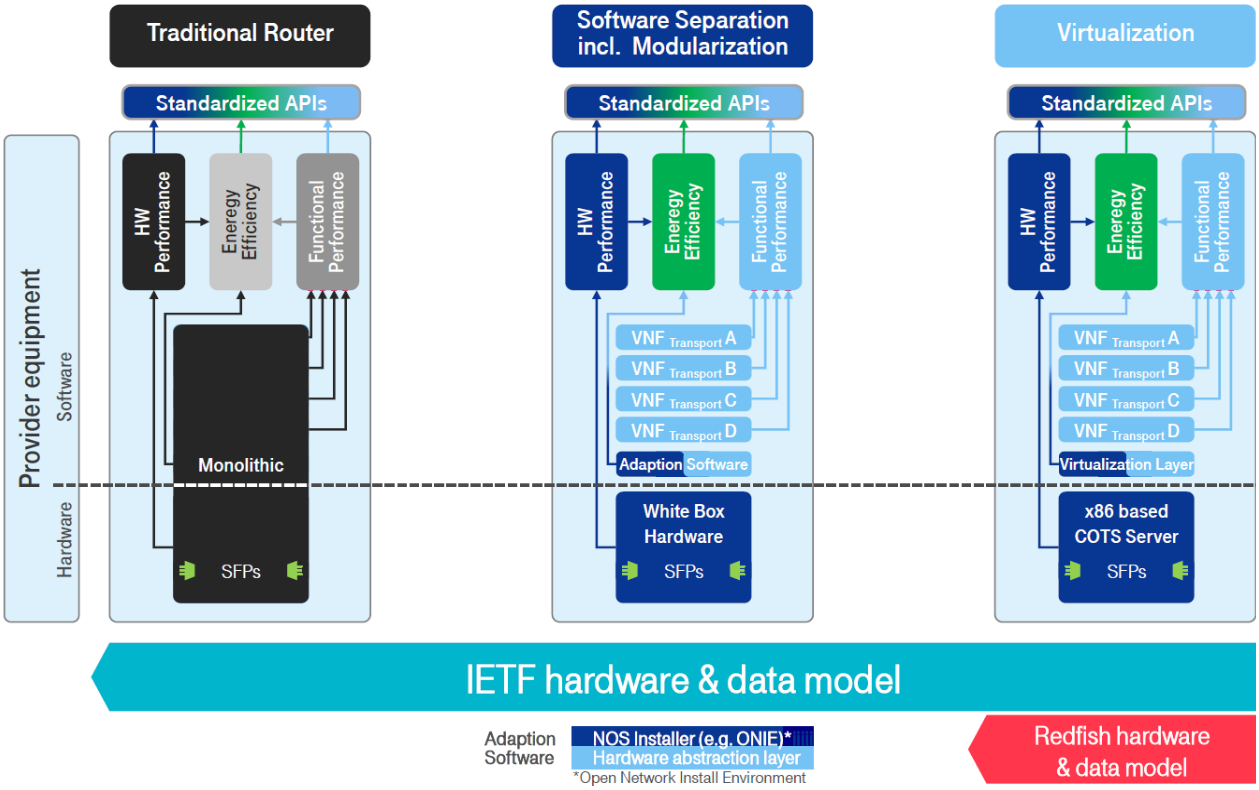

Figure 9: Hardware families, standardised APIs and hardware/data models

3.3.1 Hardware & data models

Collecting data from sensors across all platform implementation options as shown in Figure 9, i.e. “Monolithic”, “White Box based hardware (incl. Software Separation”) and “Virtualised (x86 based COTS server)”, platforms require a harmonised approach across the following specifications or SDO activities:

- IETF has started activities (see chapter 3.1.1) towards the development of a standardised hardware model with unambiguous relations to (energy) sensors and hardware related performance data.
- DMTF's **Redfish®** for example is a widely supported industry standard in x86 COTS servers for hardware management and hardware data model. Due to the upcoming virtualisation in MNO’s RAN networks, COTS servers will be deployed on RAN sites and can be used for virtualised transport functions based on x86 COTS hardware as well.

Harmonised data models including standardised APIs for telemetry information from hardware sensors are the basis to enable collection of consistent and comprehensive energy measurements across these different systems. A major requirement of operators is that the IETF hardware model and related sensor data allows a co-existence of the underlaying HW options and is as close as possible to the HW & data model to make operations for operators as easy as possible.

3.3.2 Energy consumption & energy efficiency

The challenge of deriving energy consumption from different infrastructures is best illustrated by Figure 6 and Figure 7. The three-step approach of data collection, harmonisation, and unified analytics plays an essential role here.

I. Collecting and harmonising data from these different platforms, ensuring consistency despite variations in data formats and measurement techniques.

  - This integration of all kinds of hardware can be best fulfilled by deploying equipment with standardised APIs.
  - In cases where no standardised APIs are

available, a normalisation of data has to be done by the controller (off-box), supporting a continuously developed mapping table.

II. Consolidating and calculating EC data in a unified and comprehensive manner.

- Breaking-down hardware usage and energy consumption to (virtualised-) transport functions become a ready-to-use solution in virtualised/containerised environments (e.g. Kepler [16], etc.). For transport equipment on "Monolithic" & "White Box" hardware basis, such functionality is a supplier-specific implementation, e.g. based on computational models and inbuilt APIs ("White Box").
- The break-down of hardware usage and energy consumption per (virtualised-) transport function is in best case implemented "on-box" to gain the best possible accuracy based on high sampling rates allowing to reduce load on performance data interfaces.

III. Deriving EE data in a unified and comprehensive manner.

- In cases where deriving energy efficiency based on normalised energy consumption and functional performance data is done by the controller (off-box), it can be computed based on best practice models or on defined standards. The results can then be exposed by a standardised API for energy efficiency.
- The computation of energy efficiency per (virtualised-) transport function is in the best case implemented "on-box" (see above) and metrics provided by standardised API.

Once various energy efficiency values on the device level are derived, the energy efficiency of a transport network and related network functions can be derived and further optimised (see chapter 5).

3.4 EC & EE IN SHARED-USE EQUIPMENT FOR VIRTUALISED RADIO AND TRANSPORT FUNCTIONS

The approach of "virtualisation" allows to share commodity x86 hardware for different types of network functions. By sharing HW resources for RAN and transport network functions, the amount of different HW deployed on RAN sites can be reduced.

As an example, virtualised routers find their sweet spot as virtualised Cell Site Routers (vCSR) for O-RAN deployments in low-port-density or small cell sites, where cost efficiency, flexibility, and ease of scaling are prioritised over raw performance. Their ability to run on standard server hardware makes them ideal for distributed deployments, particularly in cloud-based and edge computing environments (see Figure 11).

3.4.1 Shared hardware - Deployment options

Virtualised Cell Site Routers (vCSR) may support virtualised Fronthaul Gateway (vFHG) functions or virtualised Cell Site Gateway (vCSG) functions or both functions.

The number of sectors, of used frequency bands, the use of single/twin/triple RUs, and the selected O-RAN split at the F1 interface, as well as the implementation of radio VNFs on- or off-site, leads to many possible configurations of base station (BS) sites. There is no one-fits-all-solution for virtualised transport equipment at BS sites. Figure 10 and Figure 11show two out of many possible configurations:

- High port and higher order O-RAN split with DU and CU on site, demanding eCPRI protocol use at the F1 interface and more than 3 RUs (see Figure 10) and
- Low port and lower order O-RAN split with DU and CU on site without necessity to implement eCPRI and at most 3 RUs (see Figure 11).

Today's limiting factors for a one-fits-all-solution in terms of hardware reuse are the number of physical ports on NICs, the CPU capacity of instantaneous use for transport & radio VNFs and the complexity of HW andSW server configurations.

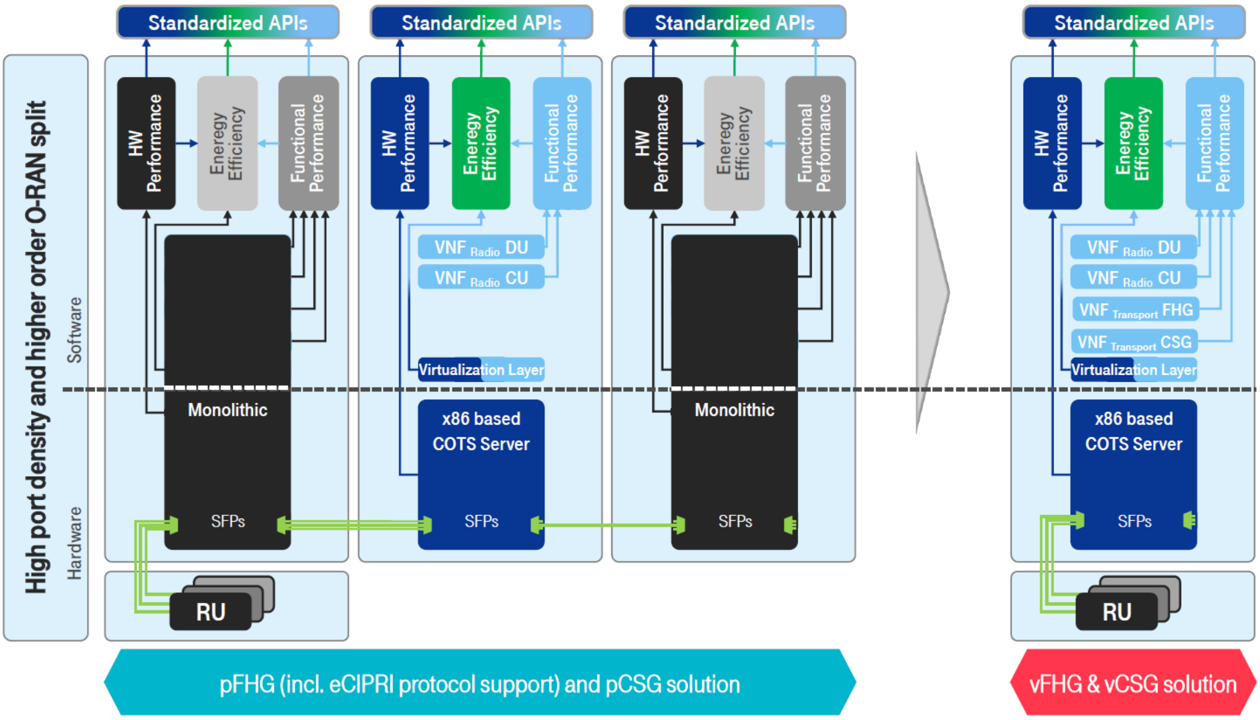

Figure 10: Exemplary migration path from a "PNF based site solution for connectivity" to a "shared resource solution" (high port and higher order O-RAN split site deployment)

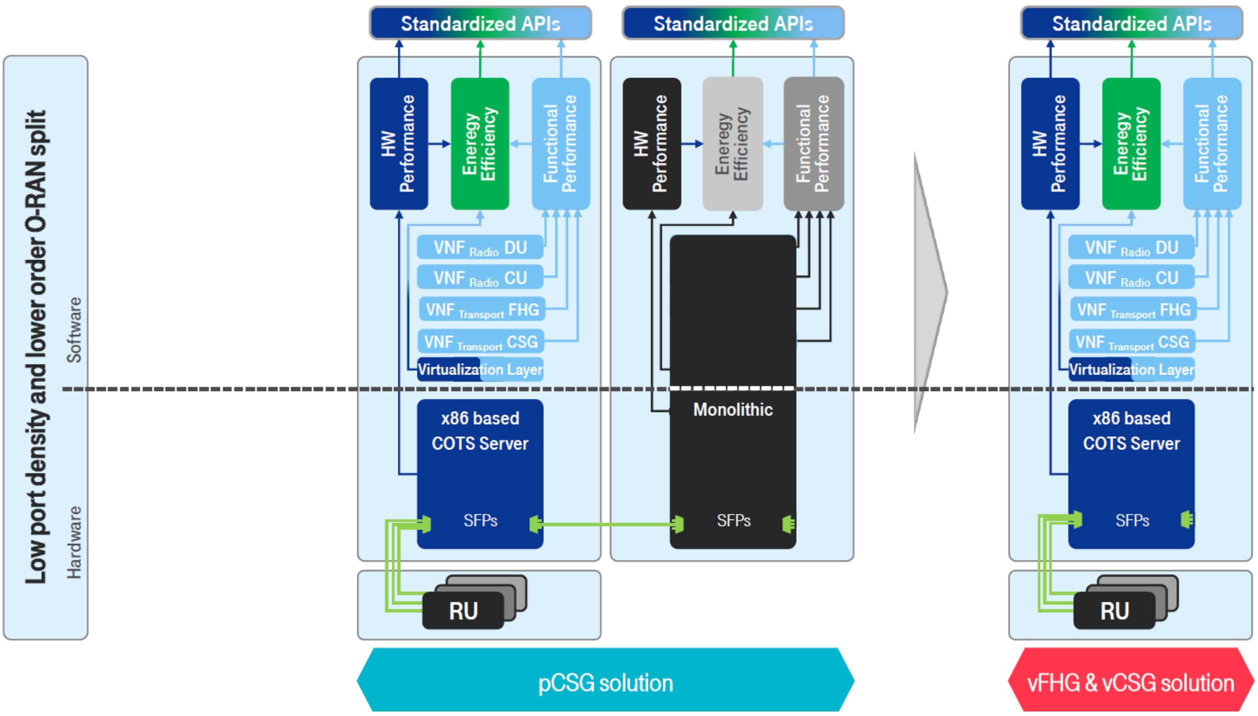

Figure 11: Exemplary migration path from a "PNF based site solution for connectivity" to a "shared resource solution" (low port density and lower order O-RAN split site deployment)

3.5 RECOMMENDATIONS TOWARDS SDOS

With the current situation of lack of standards defining the relevant metrics, there is a challenge for collection and generation of useful, comparable metrics and KPIs. As mentioned above this publication provides some recommendations to overcome this situation:

- Define a standardised and extendable hardware model with the capability to relate sensors with their capabilities (e.g. measured versus calculated measurements) to each hardware component. The related data models for hardware inventory and performance data enable operators to unambiguously map sensors and the measured or modelled data (i.e., including energy consumption, temperature, etc.) to the respective hardware (component).

- Standardisation of YANG modules for EC/EE monitoring and management is recommended.

- Each respective SDO is recommended to provide a common set of performance KPIs for monitoring purposes with a minimum and maximum or mandatory and optional set of parameters. The first step should be harmonising of data provided by the various physical interfaces to at least cover the TX/RX data volumes and rates per physical link (e.g. microwave frequency block, fibre port & fibre wavelength, etc.).

- It is recommended to define standardised APIs for functional performance data for functions operating on OSI layers 1-4.

- Additional recommendation is to define a layer specific and integrated KPI framework on equipment level (from bit to frame to packet to segment), that enables the mapping of energy consumption data on the bit-level to higher layer functions to determine energy consumption and energy efficiency of higher layer functions (details see 3.3.4).

- It is recommended to define standardised APIs for energy efficiency of key values for functions operating on OSI layers 1-4.

04 STANDARDISED COMPARISON OF EC IN VARIOUS RAN DEPLOYMENT SCENARIOS

In chapter 3 the principles of metering and monitoring of EC and EE for RAN transport equipment are described. O-RAN provides additional options for disaggregating BS equipment, and together with the upcoming virtualisation of transport functions a variety of deployment options becomes possible. Selecting the best-fit solution will become a challenge for MNO's solution design engineers.

If an operator is aiming for minimum energy consuming network deployments (e.g. of virtualised functions with shared resources - see chapter 3.4.1), a methodology for verifying or comparing EC of the selected deployment architectures and solution designs is needed.

Current RAN standards that assess and compare the energy consumption, are focusing on radio equipment or on complete base stations including transport equipment (cell site routing (CSR) functions). There is no explicit standard to define energy consumption or energy efficiency of transport equipment in access and aggregation networks.

The most objective methodology is a standardised comparison under laboratory conditions. As partial network wide testing is complex and costly, lab testing is focused on single equipment or - at most - dual equipment (link based) test cases.

ETSI has developed three standards to evaluate the energy consumption of complete base stations under static load and dynamic load situations in lab environments:

- ETSI ES 202 706-1 [17] for static load is applicable for radio access technologies (GSM, WCDMA, LTE and NR).
- ETSI TS 102 706-2 [18] for dynamic loads is applicable for LTE (4G).
- ETSI TS 103 786 [19] for dynamic loads is applicable for NR (5G).

The best substantiated results are achievable for un-split (g)NB solutions. A verification or comparison in lab environment for split (g)NB solutions has some limitations. It becomes too complex,

I. if a function like CU is hosted on centralised hardware (outside the BS-site) and additional transport equipment and hardware must be considered,
II. if the centralised CU function is providing resources for more than one DUs, or
III. if the centralised radio function itself is deployed over various servers to provide additional resilience.

Monitoring of EC and EE in heterogeneous networks is described in chapter 3.3. The metering methodology for virtualised functions is also applicable for implementations with shared resources, meaning that virtualised radio and transport functions are operated on x86 COTS based servers.

Figure 12, Figure 13 and Figure 14 show three different lab set-ups for CSR implementations (see also Figure 10 and Figure 11) and the related methodology for measuring the EC of BS- and transport equipment. In modern labs traffic generation, single radio and core modules can be emulated.

Once the system or function under test is selected, a representative site configuration (number of sectors and used frequencies, kind of RUs, etc.) and a related traffic profile (operator specific - if available - or the proposed standardised profile by ETSI) can be defined. The energy consumption of virtualised radio and transport functions is determined by the 3-step-approach described in chapter 3.3 (on-box or off-box; see Figure 6 and Figure 7). Various test-runs with different loads can be used to find optimum hard & software settings to optimise energy efficiency (see chapter 5).

The high accuracy power meters provide the overall energy consumption per physical node (RU, fronthaul switch, cell-site-gateway or x86 COTS server). A comparison between the measurements of the external high accuracy power meters with the aggregated measurements from the onboard meters ensure consistency of energy consumption measurements.

Note: The energy consumption is depending on the VNFs for radio and transport on the selected hardware (including configuration and settings) and the virtualisation layer (configuration & setting). The 5G standard is per-se designed to use the available bandwidth at the air-interface more efficiently than the LTE standard. Therefore, the recommended standards are not intended to compare the energy consumption and energy efficiency of LTE deployment designs with 5G deployment designs.

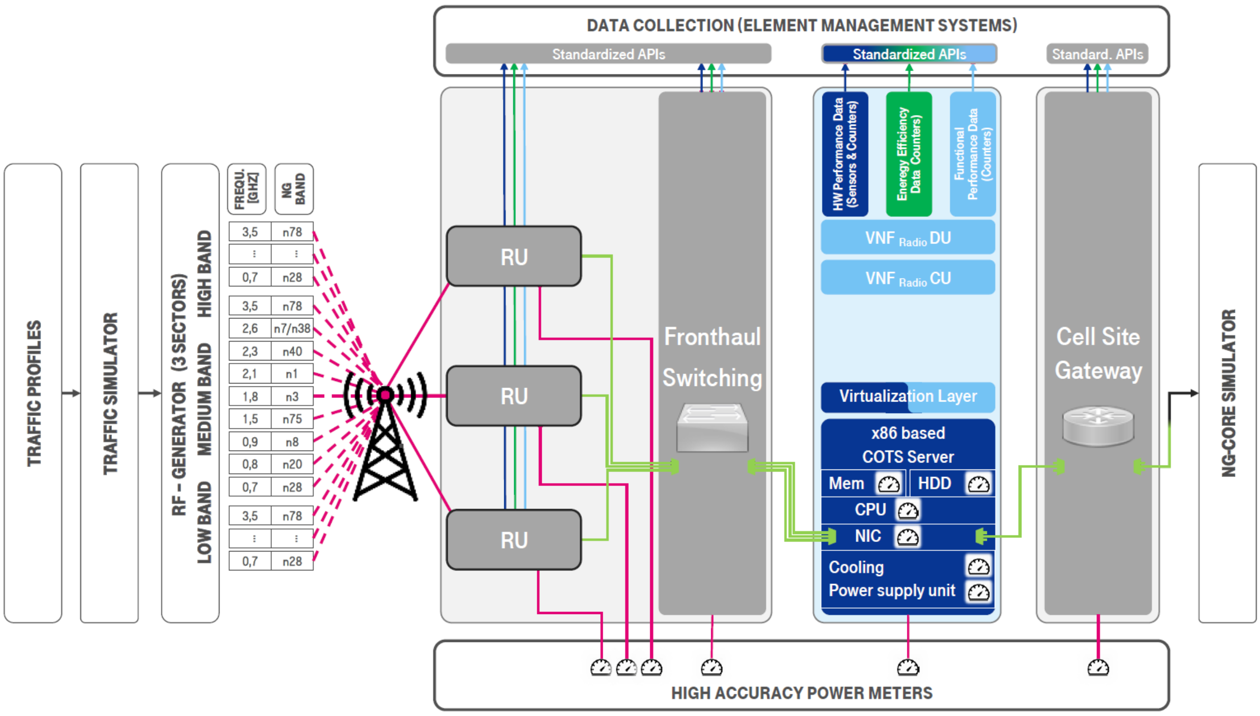

Figure 12: Transport functions (FHG and CSG) are based on physical transport equipment; radio functions (DU and CU) are virtualised and hosted on a x86COTS server.

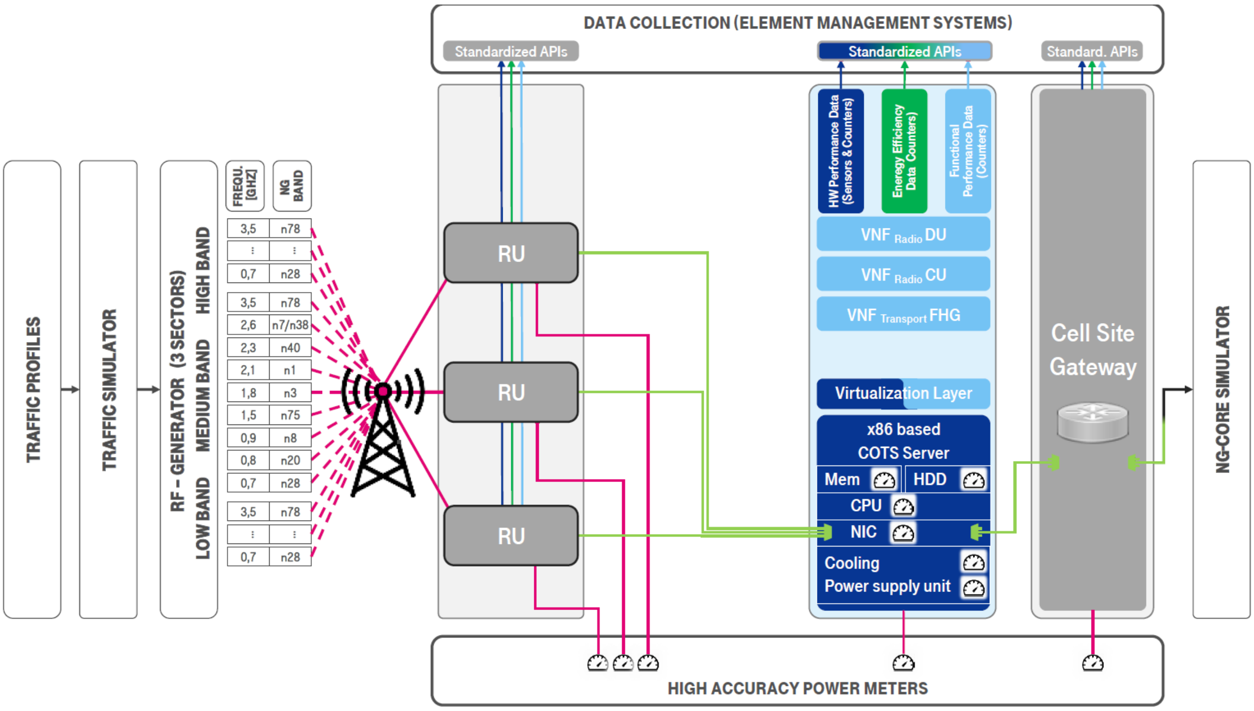

Figure 13: CSG function is realised by physical transport equipment; radio functions (DU and CU) and FHG function are virtualised and hosted on a shared x86 COTS server.

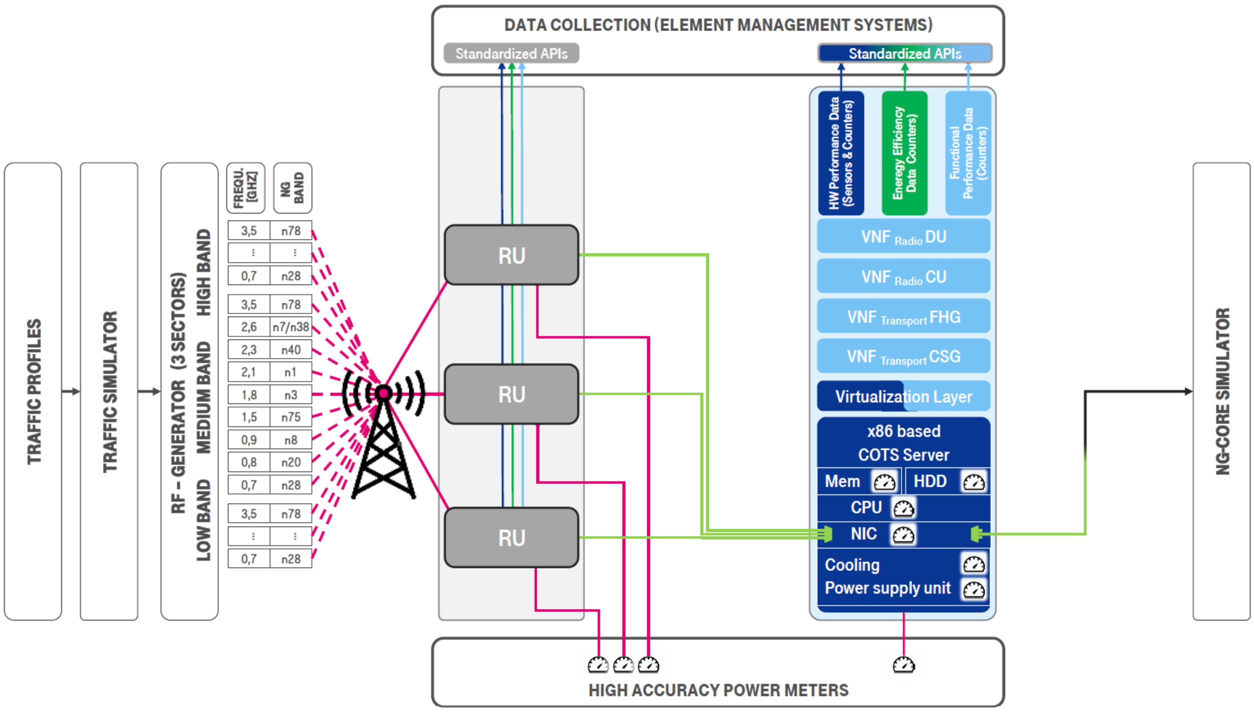

Figure 14: Transport functions (FHG and CSG) are virtualised, as well as the radio functions (DU and CU) ; all VNFs are hosted on a shared x86COTS server.

4.1 RECOMMENDATIONS TOWARDS SDOS

As the existing standards to evaluate the energy consumption of complete base stations under dynamic load situations in lab environments are updated and well harmonised, only minor recommendations are suggested:

- SDOs to consider definitions of metrics and measurement methods for energy efficiency of disaggregated mobile radio and transport network equipment. In particular, energy consumption measurement for disaggregated radio functions as well as transport functions on x86 COTS and White Box hardware need further consideration.

- Adopting test standards for 5G also to FDD (e.g. with 2 x 20 MHz bandwidth as available by ETSI for 4G LTE); e.g., applying dedicated download test scenarios for NR traffic profiles (i.e., for split NB and non-split gNB) should be considered.

05 FROM EE OBSERVABILITY TO EE MANAGEMENT (OPTIMISATION)

5.1 EE OBSERVABILITY

The International Telecommunication Union (ITU) has published several Recommendations to provide a better understanding of the energy efficiency of mobile networks [20], [21], [22], [23] and [24]. The focus of these ITU Recommendations is on the metrics and methods of assessing energy consumption and energy efficiency.

Following the ITU Recommendations Telco SDOs issued various standards:

- ETSI [17] [18] [19] specifications define static and dynamic methods to determine energy consumption and energy efficiency measurements on equipment level in lab environment

→ radio specific standard with focus on equipment at BS-sites (see chapter 4).

- ETSI EN 303 472 [25] defines and describes energy efficiency measurement methodologies on network level for capacity energy efficiency [Mbits / Wh] and coverage energy efficiency [km² / Wh]

→ radio specific standard with focus on equipment at BS sites.

- ETSI EN 203 228 [8] defines how to compute network wide KPIs for Mobile Network Data Energy Efficiency [bit / J], Mobile Network Coverage Energy Efficiency [m² / J] and Mobile Network Latency Energy Efficiency [s-1/ J]

→ including radio and transport equipment across the entire RAN architecture as described in [21].

- 3GPP TS 28.554 [26] describes a method to determine the energy consumption [J] and energy efficiency of a 5G slice [bit / J].

→ Including radio and core equipment but excluding transport equipment.

- ETSI EN 305 200 series [27], [28], [29], [30] defines a generic KPI framework for equipment specific energy consumption [Wh] not specifying energy efficiency

→ Including fixed network radio, transport and core equipment.

The above list of standards is not aimed to be a complete collection, but this brief overview shows very well that they all have their specific applications and there is no holistic approach to cover energy consumption and energy efficiency of a RAN transport network.

If an MNO is aiming for a holistic energy consumption of the transport network, two use cases are very often in focus:

- How to cover sections of transport networks where the MNO does not have direct access to the network elements (e.g. the MNO is a connectivity tenant – see chapter 5.1.1).
- How to determine energy consumption of the transport network for an overarching network service like a 5G slice (see chapter 5.1.2).

5.1.1 EC & EE observability concerning operational models (scope 2 & 3 issue)

Managing and improving energy efficiency of a transport function requires insights into the energy consumption of this transport function.

Along the radio, access and aggregation domain of a radio access network and its x-haul transport segments (see Figure 4), an MNO can have different roles regarding the ownership and operational responsibility of passive and active network infrastructure (see Figure 15).

- Passive Infrastructure Provider
- Network Provider
- Service Provider

In case the MNO is holding the licences for mobile radio services, owning and operating the RAN equipment and transport infrastructure and providing the mobile communication services, the MNO is a so called “Vertical Provider”, meaning the MNO is taking over all aforementioned roles.

In case the MNO is leasing dark fibre, but operating the active transport equipment (routers), the MNO is reduced to the roles “Network Provider” and “Service Provider”.

The MNO can only collect energy consumption data of active hardware for monitoring purposes, if he is acting in the role of a network provider - assuming the operated equipment and the standardisation of APIs are enabling this.

In case the MNO is not acting as network provider in all 3 domains of all used technologies, there will be limitations on the ability to determine end-to-end energy consumption and energy efficiency.

To overcome these limitations, the hosting transport network provider would have to provide measurements for the data volume of the hosted MNO (e.g. tenant of transport resources) on the physical layer [bits] or on the network layer [packets] together with the energy consumption [Wh] or [J] based on a standardised or contractually agreed hardware usage and energy consumption break down.

Note: The break-down of energy usage of transport nodes running in idle mode to transport functions and/or service providers is not part of this publication.

	Radio network		Access network						Aggregation network			
	2G – 5G		micro - wave		passive optical network (PON)		active optical network (AON)		CWDM		DWDM	
Service Provider (SP)	voice, data	☑	connec-tivity	☑	connec-tivity	☒	connec-tivity	☑	connec-tivity	☑	connec-tivity	☑
Network Provider (NP)	nodeB	☑	ODU/IDU	☑	OLT/ONU	☒	router	☑	router	☑	router	☑
Passive Infrastructure Provider (PIP)	frequency (licence)	☑	frequency (licence)	☑	dark fiber	☒	dark fiber	☒	dark fiber	☒	dark fiber	☒

Figure 15: Typical roles of a MNO using various technologies in the radio access network (RAN), see also Figure 4

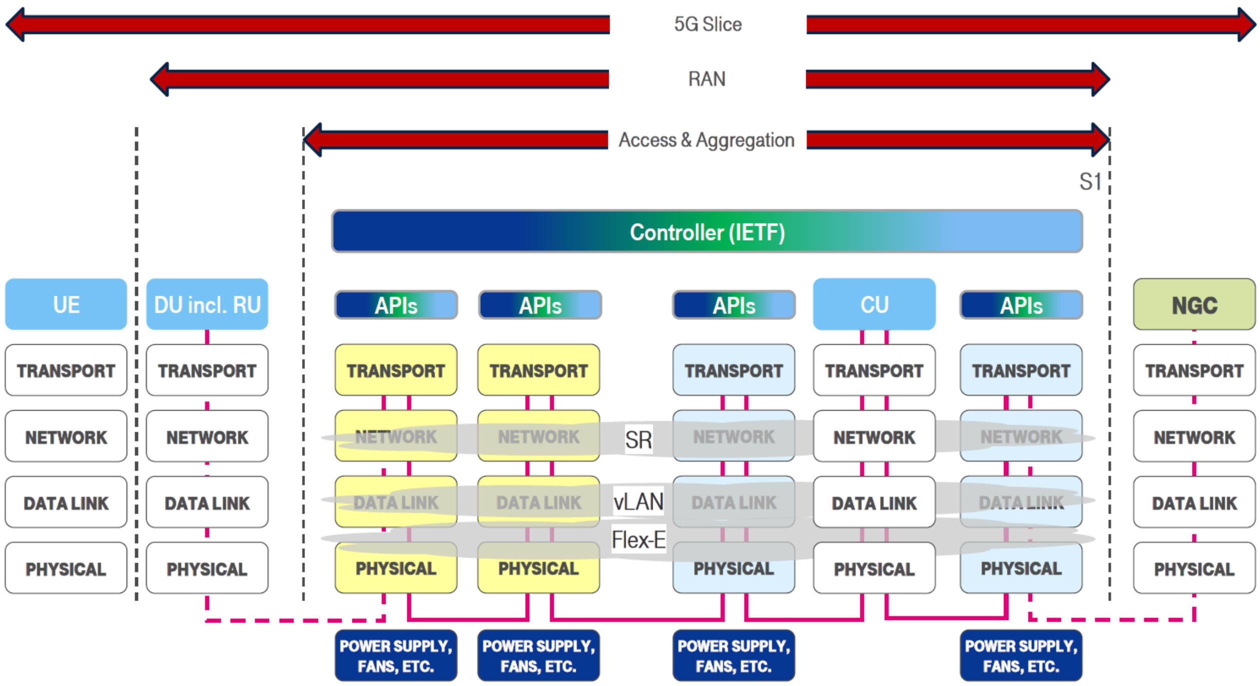

Figure 16: Exemplary transport overview in 5G networks

5.1.2 EC and EE observability in 5G slices

A slice starts in the Next Generation Core (NGC), passes radio nodes hosting CU and DU functions – using transmission capacity provided by transport nodes - and terminates at the UE (see Figure 4 and Figure 16). As access & aggregation networks are only a part of a 5G slice, determining energy consumption and managing the energy efficiency of a slice requires a clear knowledge of the utilisation of resources by different slices and a standardised definition of functional KPIs for the functions that realise the desired slicing functionality.

5G-slices can be implemented in transport networks by use of various features (e.g. vLAN, Segmented Routing (SR); Flex-E, etc.) on different layers (see Figure 16). A stringent observability and management demand operational effort. This makes it difficult to manage 5G-slices, especially temporarily implemented slices. IETF has started a working group [32] to coordinate the slicing activities inside IETF and to ensure consistent specifications.

As mentioned in chapter 3.2 and chapter 3.5, a standardised definition of the KPIs per function including a data model for exposing them is a prerequisite to define uniform and transparent Energy Efficiency KPIs through various layers. Especially when moving from the hardware/device level to a link/network layer (physical and logical). This becomes even more obvious, when the energy efficiency shall be determined on a 5G-slice or service level. With the existing framework of standardisation, the best achievable result for Energy Efficiency calculations is a breakdown of energy consumption for the whole device based on data transported per slice/service. The given standards define Energy Efficiency mainly as break-down of performance (data volume) divided by Energy usage of a device.

5.2 EE MANAGEMENT (OPTIMISATION)

Energy efficiency (EE) management can be implemented on equipment, link, transport network level, and on slice level (see Figure 16). Prerequisites for EE optimisations are monitoring of energy consumption at the infrastructure/platform layer and the physical layer, an accurate break down of hardware usage and energy consumption and standardised functional performance KPIs for all standardised transport functions at higher level layers functions (see 3.1 and 3.2). EE can then be determined and optimised on all layers of a transport network:

- **Infrastructure / Platform Layer:** EE on equipment level is strongly depending on the capability of hardware components (e.g. fans, rectifiers in PSUs, etc.) to adapt their energy usage to the traffic demands like routed packets and the requested routing functions (e.g. packet inspection, synchronisation, etc.).

→ To allow operators to optimise energy consumption, transport equipment often supports a selection of supplier specific configurations for different profiles, which allow to adapt to the specific hardware configuration and the customer specific use of the equipment.

- **Physical layer:** The EE is strongly depending on the technical design of the equipment, the physical transport media (e.g. loss over optical fibre-link distance, weather conditions on micro-wave links, etc.), and usage / load distribution.

→ The implementation of sleep modes in PONs and AONs, as well as frequency bandwidth reductions for micro-wave links are common features to reduce energy consumption and increase energy efficiency on equipment and link level.

→ The activation of sleep mode features is realised by pre-defined operator specific threshold settings or by logic based on artificial intelligence (AI) models considering trade-off analysis between energy savings and QoS (e.g. latency).

→ Flexible Ethernet (Flex-E) implements a flexible and refined management of interface resources by eliminating the one-to-one mapping between the MAC and PHY layers. It is designed to implement service isolation and network slicing. It is defined by Optical Interworking Forum (OIF).

- **Data Link layer:** Configuration of security, QoS scheduling, VLAN-functions etc. are implemented on the processing units of transport equipment and therefore strongly impacting the EC and EE. Setting the feature configurations is always fine tuning and a trade-off decision between functional performance and EE. Proper implementation of HW and energy usage break-down algorithms is a prerequisite to optimise energy consumption of functions at this layer.

→ A consequent implementation of the recommendations that were discussed in earlier chapters enables operators to monitor the changes of EC and EE when changing configuration settings of functions on this layer.

- **Network layer:** IP-routing performance (e.g. throughput) is strongly impacting the EC and consequently the EE on a transport network level.

→ Segment routing (SR) is a packet steering technology that offers a highly scalable approach for establishing predefined forwarding paths to meet specific constraints such as available bandwidth, latency, protection, physical diversity or minimum EC. Currently, SR considers EC information based on equipment data sheets. Dynamically re-routing based on EC measurements requires a realisation of the recommendations that were discussed in earlier chapters.

Note: The Flex-E Shim layer is neither part of the 4- or 5-layer Internet models nor the OSI-model. The integration of this additional layer into the requested KPI framework (see chapter 3.2) enabling break-down of hardware and energy usage for higher layer functions is not part of this publication.

5.2.1 Future developments impacting EE

Transport network equipment including x86 based COTS servers for virtualisation are still designed to handle peak loads, they often remain heavily underutilised during normal or low-traffic hours. Despite this underutilisation, energy consumption is barely related to the managed traffic. The energy consumption is up to nearly 100%, even when there is little or no traffic.

Therefore, increasing the energy efficiency of transport equipment is key. Three main focus areas of industry developments are listed below:

(i) Physical Layer:

> Silicon photonics is expected to enter the mainstream market for IP and optical transport networks within the next few years.

As advancements in photonic integration and manufacturing continue, the technology is becoming more viable for large-scale deployment. Its ability to reduce energy consumption, increase bandwidth, and simplify network architectures makes it an attractive solution for modern data centres and high-speed transport networks.

> Optimising architecture of optical - electrical transformation components to reduce heat production and energy consumption, enabling e.g. 400GbE, 800 GbE (OIF 400ZR/800ZR) and even higher transmission rates capable transport equipment.

(ii) Network Layer: Modern traffic steering methodologies, such as Segment Routing and Flex-Algo, enable more efficient energy use by dynamically adjusting network capacity based on actual demand. The goal is to reduce energy consumption during periods of low or no traffic.

The diagram below (see Figure 17) shows a simple fully meshed IP Transport Network. On the left hand, all nodes are being utilised according to standard routing protocol next hop decisions (for simplification routing hop locations have been named by IATA Airport codes). The right-hand diagram shows an energy efficiency optimised routing behaviour, where traffic is being redirected to an alternative path, with the consequence that networks links or even entire network nodes can be shut down / hibernated if the traffic load situation allows (indicated in % on each link before and after optimisation).

(iii) IP & Optical convergence: Silicon photonics is seen as a promising technology for that by integrating optical components onto silicon chips, it allows for faster data transfer with lower energy loss, significantly improving efficiency in data centres and high-performance computing environments. In addition, the introduction of ZR and ZR+ optics brings these two domains already closer together.

There is apparently not yet mature equipment or software, which start to adopt these new approaches. It is up to network operators to advocate and promote these novel idea and approaches, through industry forums such as IOWN (Innovative Optical and Wireless Network) [31] for example.

5.3 RECOMMENDATIONS TOWARDS SDOS

- Define an integrated KPI framework on the transport network level that enables the determination of energy consumption and energy efficiency of higher layer functions for link and network wide analysis.

- Define a KPI framework that is applicable for fixed and mobile transport networks and that also provides all roles of operating models (see Figure 15) with sufficient information about the energy consumption and energy efficiency of the transported data.

- Define an API that enables operators to expose and manage the capabilities of slices by a standardised API. This API shall include energy consumption and energy efficiency KPIs for each 5G-slice.

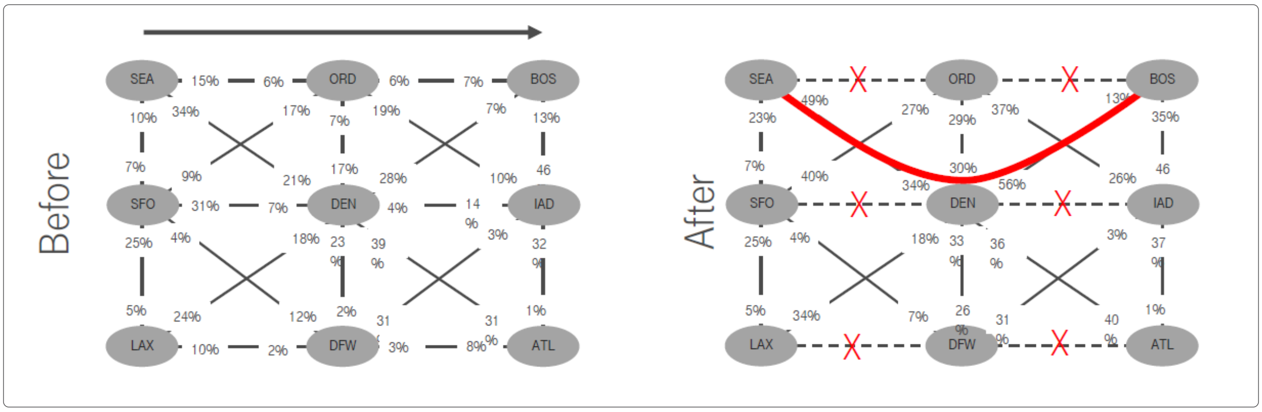

Figure 17: Energy efficient Traffic Steering - how it works (simplified)

06 CONCLUSION

Metering is the prerequisite for the monitoring of energy consumption and energy efficiency, which are basic indicators needed for network optimisation. In transport networks optimisations are not only impacting energy consumption and efficiency of single network devices but need to be evaluated on a network-level across all involved network devices.

The main findings and recommendations from this report are as follows:

FINDINGS:

- Transport network equipment is used in many industries – not just telecommunication services. Consequently, standardisation is distributed across several Standards Development Organisations (SDOs).
- Energy Metering is insufficiently covered in current standards.
- The lack of standardisation hinders operators' ability to collect and collate energy data and therefore their ability to optimally manage the energy footprint of their transport networks.

RECOMMENDATION:

- Further standardisation is needed – in particular in relation to defining data models and key performance values that enable energy efficiency to be derived at a network device / network function level.
- The industry should consider consolidating and further harmonising standards where possible.

Through these measures, the document aims to guide the industry toward a more sustainable and efficient future for mobile transport networks.

07 LIST OF ABBREVIATIONS

API	Application Programming Interface
ASIC	Application Specific Integrated Circuit
BBF	Broadband Forum
COTS	Commercial Off The Shelf
CSR	Cell Site Router
CWDM	Coarse Wavelength Division Multiplexing
DPDK	Data Plane Development Kit (reference: https://www.dpdk.org/)
DSL	Digital Subscriber Line
DWDM	Dense Wavelength Division Multiplexing
EC	Energy Consumption
EE	Energy Efficiency
eCPRI	enhanced Common Public Radio Interface
ETSI	European Telecommunications Standards Institute
GFN	Green Future Networks
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IP	Internet Protocol
ITU	International Telecommunications Union
MPPS	Million Packets Per Second
MEF	Metro Ethernet Forum
NIC	Network Interface Card
OSI	Open Systems Interconnection
PON	Passive Optical Network

pCSG	Physical Cell Site Gateway
pFHG	Physical Fronthall Gateway
Pt-2-Pt	Point to Point
PNF	Physical Network Function
RAN	Radio Access Network
RFC	Request For Comment (IETF specification)
SR	Segment Routing
SR-IOV	Single Root I/O Virtualisation
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
vCSR	Virtualised Cell Site Router
vFHG	Virtualised Fronthaul Gateway
vCSG	Virtualised Cell Site Gateway
YANG	Yet Another Next Generation (a form of data model)

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10 DEFINITIONS AND EXPLANATIONS OF KEY TERMS

5G SLICE

A 5G slice is a logical network that provides specific network capabilities and network characteristics, supporting various service properties for network slice customers.

MOBILE AGGREGATION SITE GATEWAY (MASG)

Node at the radio controller, MME or serving gateway site that presents the transport network interface to the mobile equipment, (as defined by BBF in TR-221 [6])

CELL SITE GATEWAY (CSG)

Node at the cell site that presents the transport network interface to the Base Station equipment, (as defined by BBF in TR-221 [6]).

CWDM / DWDM

In fibre-optic communications, wavelength-division multiplexing (WDM) is a technology which multiplexes a number of optical carrier signals onto a single optical fibre by using different wavelengths of laser light. For more details see [7]

ENERGY EFFICIENCY

relation between the useful output and energy consumption, as defined in ETSI ES 203 228 [8]

FLEX-E

Flexible Ethernet is defined by Optical Interworking Forum (OIF). It implements a flexible and refined management of interface resources by eliminating the one-to-one mapping between the MAC and PHY layers.

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NEXT GENERATION MOBILE NETWORKS ALLIANCE

NGMN – the Next Generation Mobile Networks Alliance – is a global, operator-driven organisation, established by leading international mobile network operators (MNOs). As a global alliance of nearly 70 companies and organisations – including operators, vendors, and academia – NGMN provides industry guidance to enable innovative, sustainable and affordable next-generation mobile network infrastructure.

NGMN drives global alignment of technology standards, fosters collaboration with industry organisations and ensures efficient, project-driven processes to address the evolving demands of the telecommunications ecosystem.

VISION

The vision of NGMN is to provide impactful industry guidance to achieve innovative, sustainable and affordable mobile telecommunication services to meet the requirements of operators and address the demands and expectations of end users. Key focus areas include Mastering the Route to Disaggregation, Green Future Networks and 6G, while supporting the full implementation of 5G.

MISSION

The mission of NGMN is:

- To evaluate and drive technology evolution towards the three **Strategic Focus Topics:**
  - **Mastering to the Route to Disaggregation**
    Leading in the development of open, disaggregated, virtualised and cloud native solutions
  - **Green Future Networks**
    Developing sustainable and environmentally conscious solutions
  - **6G**
    Providing guidance and key requirements for design considerations and network architecture evolution
- To define precise functional and non-functional requirements for the next generation of mobile networks
- To provide guidance to equipment developers, standardisation bodies, and collaborative partners, leading to the implementation of a cost-effective network evolution
- To serve as a platform for information exchange within the industry, addressing urgent concerns, sharing experiences, and learning from technological challenges
- To identify and eliminate obstacles hindering the successful implementation of appealing mobile services.