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TECHNICAL REPORT

Environmental Engineering (EE);
Best practice to assess energy performance of
future Radio Access Network (RAN) deployment

Reference
DTR/EE-EEPS20

Keywords
5G, access, base station, energy efficiency, GSM, LTE, LTE-Advanced, mobile, network, NR, radio, site engineering, UMTS

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Environmental Engineering (EE).

Modal verbs terminology

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Introduction

Energy efficiency is one of the critical factors with substantial impact on environmental footprint and operational cost of the modern telecommunication systems. By 2016, **ICT** energy consumption is estimated to 7,8 % of Global Electricity and 4,4 % of Global total Energy Consumption. The **mobile systems** energy consumption is estimated to 1,8 % of the global electricity, equals 1 % of Global Total Energy Consumption. With introduction of new mobile system technologies to support the rapid traffic growth, while low efficiency legacy system still remains, the energy consumption may further increase. The increased energy consumption is a threat to the environment as well as the profitability of the industry as operator revenues may remain flat. The mobile industry is working hard to increase efficiency and reduce energy consumption of current and future RAN with focus on strategies to modernize RAN with new RAT's while reduce the total energy consumption of the RAN. Operators and vendors are running parallel studies on energy consumption of the future RAN, elaborating on different energy saving strategies. However, results are very different with low accuracy as methods are quite diverse with limited standard support for metrics and methods.

The aim of the present document is to collect best practices on future RAN energy performance assessment, list KPI's from available standards and define additional KPI's needed for a relevant assessment of future RAN deployment.

As RAN consumes 80 % of mobile systems energy consumption, the present document is focusing on RAN site and equipment, including Backhaul. Depending on technology, it is often referred to as BTS, NodeB, eNodeB, etc. and in the present document denoted as BS. Core and service networks are not considered. The power consumption of Radio Network Control nodes (RNC or BSC) are covered in ETSI ES 201 554 [i.35].

The measurements in testing laboratories of the efficiency of the Base Stations is the topic treated in ETSI ES 202 706 [i.18]. Field measurement energy performance is defined in ETSI ES 203 228 [i.19]. Energy metrics of those standards are preferred.

1 Scope

The aim of the present document is to find and describe methods and best practice to assess energy performance (Energy Consumption and Energy Efficiency) of a future RAN deployment. The results documented will include a summary of previous work, a collection of important preconditions as traffic aspects (growth, new traffic classes, potential disruption), collection of energy efficiency/saving solutions and strategies and energy issues in current networks. Network energy performance assessment method examples based on set of scenarios including different solutions. The assessment period is at least until 2020, optionally also including 5G impact. Energy consumption and efficiency definitions from ETSI ES 202 706 [i.18] and ETSI ES 203 228 [i.19] are preferred.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] CISCO®: "VNI Index".

NOTE: Available at http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html.

[i.2] CISCO®: "VNI® Global Mobile Data Traffic Forecast Update 2016-2021 White Paper".

NOTE: Available at http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html#~vniforecast.

[i.3] CISCO®: "VNI® complete forecast".

NOTE: Available at http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html#~completeforecast.

[i.4] Nokia®: "GWATT® Global What if Analyzer of neTwork energy consumpTion", Green Touch® Project, 2015.

NOTE: Available at http://alu-greentouch-dev.appspot.com/intro/.

[i.5] Ericsson®: "Traffic Exploration tool".

NOTE: Available at http://www.ericsson.com/TET/trafficView/loadBasicEditor.ericsson.

[i.6] Ericsson®: "Mobility report" Ericsson, Stockholm, 2016.

[i.7] "ICT EARTH® EU" May 2013.

[i.8] "EARTH® Publications" May 2013.

NOTE: Available https://cordis.europa.eu/project/rcn/94414_en.html.

[i.9] Ki Won Sung, Jens Zanderand R. Sibel Tombaz: "On metrics and models for energy-efficient design of wireless access networks", IEEE Wireless Communications Letters, vol. 3, no. 6, pp. 649-652, 2014.

[i.10] T. W. Slavisa Aleksic: "Holistic view on green network technologies: Wireless Access, wired core, data centers and end-user devices," in 5Green Summer School, Stockholm, 2014.

[i.11] "SMARTer2030® ICT solutions for 21st Century Challenges" GeSi™, 2015.

[i.12] Huawei® Technologies Sweden, Anders S.G. Andrae, Tomas Edler: "On Global Electricity Usage of Communication Technology: Trends to 2030", Challenges, vol. 6, pp. 117-157, 30 April 2015.

NOTE: Available http://www.mdpi.com/2078-1547/6/1/117.

[i.13] Ericsson®, Dr Pål Fenger: "From always on to always available. Energy Saving possibilities and potential" in 5Green Summer school, Stockholm, 2014.

NOTE: Available http://wireless.kth.se/5green/wp-content/uploads/sites/19/2014/08/2014-08-27-P%C3%A5l-Frenger-5green-summer-school-Part-1-From-always-on-to-always-available-final.pdf.

[i.14] Ericsson®, Dr Pål Frenger: "From always available to always optimized," in 5Green Summer School, Stockholm, 2014.

NOTE: Available at http://wireless.kth.se/5green/wp-content/uploads/sites/19/2014/08/2014-08-27-P%C3%A5l-Frenger-5green-summer-school-Part-2-From-always-available-to-always-optimized-final.pdf

[i.15] Deutche Telecom®, Christoph Lange, Dirk Kosiankowski, Rainer Weidmann and Andreas Gladisch: "Energy Consumption of Telecommunication Networks and Related Improvement Options", vol. 17, pp. 285-295, April 2011.

[i.16] IEEE paper WCNC14 track 3: "Assessment of the Energy Efficiency Enhancement of Future Mobile Networks," TNO®, Delft University of Technology, Remco Litjens, Yohan Toh and Haibin Zhang:, Mobile and wireless networks, Istanbul, 2014.

[i.17] IEEE communications Magazine Ericsson®:"The global footprint of mobile communications: The ecological and economic perspective" TUD, Albrecht Fehske Gerhard Fettweis, Jens Malmodin and Grgely Biczok, vol. 49, no. 8, pp. 55-62, 11 August 2011.

[i.18] ETSI ES 202 706: "Environmental Engineering (EE); Measurement method for power consumption and energy efficiency of wireless access network equipment".

[i.19] ETSI ES 203 228: "Environmental Engineering (EE); Assessment of mobile network energy efficiency".

[i.20] Recommendation ITU-T L.1310: "Energy efficiency metrics and measurement methods for telecommunication equipment".

[i.21] IEEE™ Wireless Communications: "How much energy is needed to run a wireless network?".

NOTE: Available at https://ieeexplore.ieee.org/document/6056691/.

[i.22] GreenTouch™ White Paper: "Green Meter Research Study".

NOTE: Available at https://s3-us-west-2.amazonaws.com/belllabs-microsite-greentouch/uploads/documents/GreenTouch_Green_Meter_Research_Study_26_June_2013.pdf.

[i.23] Energy Performance Evaluation Revisited: "Methodology, Models and Results".

NOTE: Available at https://ieeexplore.ieee.org/document/7763182/.

[i.24] A case study on estimating future radio network energy consumption and CO2 emissions".

NOTE: Available at https://ieeexplore.ieee.org/document/6707825/.

[i.25] ETSI ES 202 706-1: "Environmental Engineering (EE); Metrics and measurement method for Energy Efficiency of wireless access network equipment; Part 1: Power Consumption - Static Measurement Method".

[i.26] ETSI TS 136 300 (V14.2.0): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2 (ETSI TS 36.300 version 14.2.0 Release 14)".

[i.27] ETSI TS 134 121: "Universal Mobile Telecommunications System (UMTS); User Equipment (UE) conformance specification; Radio transmission and reception (FDD); Part 1: Conformance specification (3GPP TS 34.121-1)".

[i.28] ETSI TS 136 104 (V11.2.0): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception (3GPP TS 36.104 V11.2.0 Release 11)".

[i.29] ETSI TR 136 913 (V14.0.0): "LTE; Requirements for further advancements for Evolved Universal Terrestrial Radio Access (E-UTRA) (LTE-Advanced) (3GPP TR 36.913 version 14.0.0 Release 14)".

[i.30] Draft New Report ITU-R M (IMT-2020.TECH PERF REQ) (5G NR).

[i.31] ETSI TS 145 005 (V8.0.0): "Digital cellular telecommunications system (Phase 2+); Radio transmission and reception (3GPP TS 45.005 version 8.8.0 Release 8)".

[i.32] Yuehong Gao, Xin Zhang, Yuming Jiang and Jeong-woo Cho: "System Spectral Efficiency and Stability of 3G Networks: A Comparative Study". Wireless Theories and Technologies (WT&T) Lab. Beijing University of Posts and Telecommunications (BUPT), 100876 Beijing, China; Centre for Quantifiable Quality of Service in Communication Systems (Q2S) Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway.

NOTE: Available at https://people.kth.se/~jwcho/data/icc2009study3g.pdf.

[i.33] IMEC BS Energy consumption model - online.

NOTE: Available at https://www.imec-int.com/powermodel.

[i.34] Micallef, G. (2013): "Energy Efficient Evolution of Mobile Broadband Networks", Department of Electronic Systems, Aalborg University.

NOTE: Available at http://vbn.aau.dk/files/77916735/Gilbert_Micallef_PhD_Thesis_Final_2_.pdf.

[i.35] ETSI ES 201 554: "Environmental Engineering (EE); Measurement method for Energy efficiency of Mobile Core network and Radio Access Control equipment".

3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AC Alternating Current
AirCon Air Condition
BS Base Station
CA Carrier Aggregation
cf cooling factor
CC Common Channels
COP Coefficient Of Performance.

NOTE: Efficiency KPI for climate equipment.

DBS Distributed Base Station
DC Direct Current
DL DownLink
EC Energy Consumption
EU European Union
FD-MIMO Full Dimension MIMO
FP7 UE Frame Program 7
GHG Green House Gas
GSM Global System for Mobile communication

GWATT® Global What

NOTE: If Analyser of network energy consumption.

ICT Information and Communication Technology
IoT Internet of Things

NOTE: Including M2M, D2D, V2X, etc.

IP Internet Protocol
ITU-T International Telecommunication Union - Telecommunication Standardization Sector
KPI Key Performance Indicator
KTH Royal Institute of Technology, Stockholm

NOTE: In Swedish: Kungliga Tekniska Högskolan.

LAA Large Antenna Arrays
LiU Linköping University
LSA Large Scale Antennas
LuU Lund University
METIS EU FP7 cofunded research project on telecommunication at 2020 and beyond.
MIMO Massive Input Massive Output
NB Narrow Band
PA Power Amplifier
PC Personal Computers
QoS Quality of Service
RAN Radio Access Network
RAT Radio Access Technology

NOTE: E.g. GSM, 3G, 4G, 5G.

RATS Radio Access Technologies
SC Small Cell
SE Spectral Efficiency
SEE Site Energy Efficiency
sf site factor

NOTE: I.e. total site energy consumption/BS equipment energy consumption.

sps shelter power share

NOTE: I.e. the dissipation in shelter versus DC energy consumption.

TBC To Be Confirmed
TCO Total Cost of Ownership
URL Uniform Resource Locator

NOTE: I.e. web address.

VNI Visual Networking Index

NOTE: CISCO® tool providing ICT traffic data.

WI Work Item
RNC Radio Network Control

4 Assessment of Energy Performance of future RAN

4.1 Assessment steps

The basic steps for the analysis are:

- Definition of Network.
- Definition of Baseline.
- Evolution Scenarios.
- Evolution Deployment steps.
- Result.

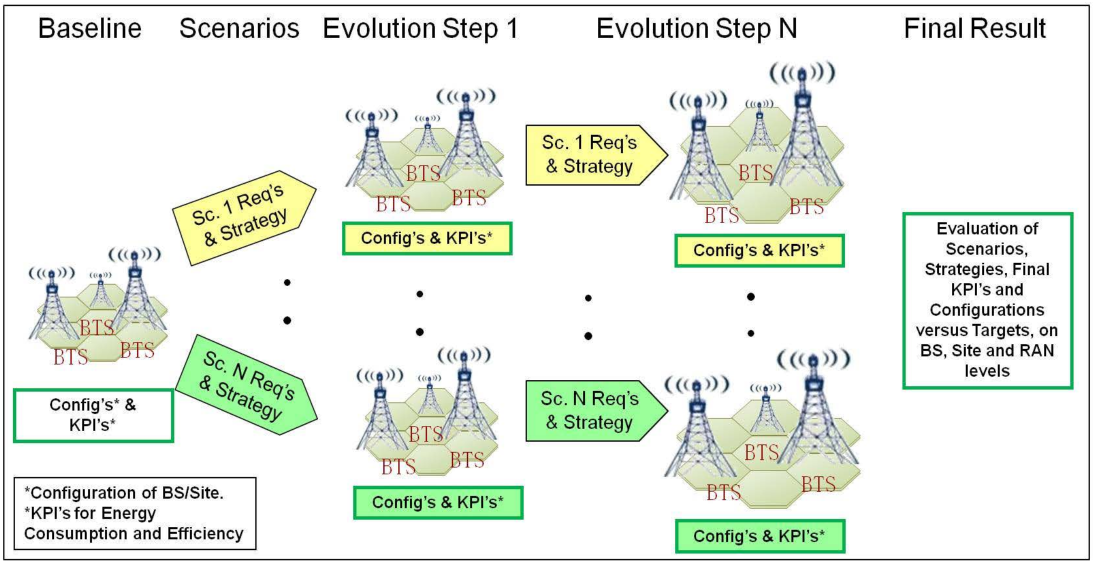

Figure 1: High level view of the assessment process of selected RAN

Depending on depth of the study, the following structure, or a subset, could be used:

- Definition of network to analyse. If the network to assess is large, a partial representation of the network may be chosen for analysis. Parameters of ETSI ES 203 228 [i.19], clause 4.2 "test parameter categorization" should be considered when selecting the Partial RAN sites.
- Definition of Baseline (field audit based or theoretical model based):
  - Starting date.
  - Focus on Incumbent (green field may be option for later version).
  - Configuration of Network, Backhaul, site and base station (including RAT).
  - Energy consumption and efficiency. Values and metrics.
  - Traffic, average and dynamic (subscriber and devices, including IoT), distribution over areas.
  - Equipment Utilization.
  - Features.
- Evolution Scenarios:
  - Traffic evolution assumptions (daily and weekly profiles including busy hour levels distribution over Rat's, subscribers, services, devices, IoT).
  - Requirements on QoS, Utilization margins.
  - Strategies for Coverage, Roll out of RAT's, Spectrum, BS types and configurations.
  - Refresh strategy, BS equipment and site infrastructure.
  - Site "clean up" of unused equipment.

  - Software and features strategy.
- Evolution deployment steps - per scenario:
  - Capacity KPI assumptions for RAN, Site and BS types and configurations.
  - Site and BS configurations - to comply to scenarios.
  - Site and BS Energy consumption models.
  - Energy consumption calculation.
- Result:
  - Transformation from analysed network to full network.
  - Alternative scenarios/solutions/strategies.
  - Final traffic (On device types, including IoT, traffic profiles, etc.).
  - Final configurations of equipment and sites.
  - Final site infrastructure.
  - Final utilization.
  - Final KPI's on performance: Capacity, Energy Efficiency, Energy Consumption, QoS.
  - Uncertainty and sensitivity analysis.
- Conclusion and interpretation of result.

4.2 Previous work: Tools, papers & reports

4.2.1 Tools

a) Cisco® VNI® Tool [i.1]: Traffic only, no energy aspects, but a versatile tool to extract many different traffic aspects. Sub-part for mobile networks [i.2] and for full IP network [i.3]. Useful for assessment of current and future traffic in ICT, with distribution over devices, traffic types/services, parts of network, etc. Energy consumption or efficiency is not in the scope of the present document.

b) Nokia® GWATT® : "An interactive application to Visualize the Green Touch Results" [i.4]. GWATT®is an online web tool developed by GreenTouch®to provide an end-to-end view of the GreenTouch® portfolio of technologies and solutions and to share the results and accomplishments in an easy-to-use and interactive application accessible to everyone. Thanks to the GWATT® interactive graphical user interface, the user can check in real time how individual technologies and combinations of technologies improve network energy performance and energy cost. Different network evolution scenarios can be simultaneously constructed and their energy performance compared. The GreenTouch® results are also displayed in comparison to the 2010 reference scenario and a 2020 business as-usual network evolution.

c) Ericsson® Traffic Exploration tool [i.5]: Traffic only, no energy aspects. (URL barcode in Ericsson® mobility report) [i.6]. The feature may be terminated (TBC).

4.2.2 Papers & Reports

a) Ericsson® "Mobility Report" [i.6]: Traffic, services, subscriptions and devices statistics over regions by 2016 and forecasts until 2022. One of the most used sources, in parallel with CISCO® VNI® tool.

b) EU FP7 EARTH® Project reports: Project has ended 2012 but homepage [i.7] and all reports [i.8] are still available. A useful holistic view on metrics, energy consumption of devices and equipment, impact of energy saving features and finally methods on how to estimate the cellular network energy efficiency. The estimation methods are still useful as input for assessment.

c) Update of EARTH-methods [i.23], published by Ericsson in 2016.

d) KTH Sibel Tombaz, Jens Zander [i.9]: "On metrics and models for energy-efficient design of wireless access networks".

e) Aleksic Slavisa: "A holistic view on green network technologies: Wireless Access, wired core, data centres and end-user devices" [i.10] Stockholm, 2014 evolution and metrics on energy consumption and efficiency. However, no methods provided on how the figures are calculated.

f) GeSi smarter 2030 report [i.11]: Energy consumption and abatement (saving in other sectors) of ICT usage 2015-2030. The report focuses on potential GHG emission reduction with the help of ICT solutions in various sectors. The key claim is that the GHG abatement potential from ICT solutions could reach 12 Gt in 2030 while the ICT related footprint is only 1,25 Gt, thus saving much more energy than its own consumption. Partners have left this organization, as results and methods are questioned.

g) Anders Andrae and Tomas Edler, Huawei®: "On Global Electricity Usage of Communication Technology: Trends to 2030" [i.12]: The work presents an estimate of the global electricity usage from ICT between 2010 and 2030 for three different scenarios. The document is based on a solid literature study and available sources for the current ICT energy consumption and uses a wide range of sources for the predicted development of ICT technologies and market trends. Three different scenarios are presented:

   1) Best case (lowest energy consumption assuming low traffic growth and high efficiency improvements).

   2) Expected case.

   3) Worst case (assuming high volume growth despite low efficiency improvements.

h) Pål Frenger, Ericsson: "From always available to always optimized" [i.14]: 5G/5Green Energy saving features and RAN energy saving evolution LTE => 5Green.

i) "A case study on estimating future radio network energy consumption and CO2 emissions" Joint study Ericsson/Vodafone on different LTE rollout/modernizing strategies [i.24].

j) Pål Frenger, Ericsson®: "From always on to always available" [i.13], including Vodafone case study on future RAN, 50 % saving 2006/2007 - 2020.

k) Earth EU FP7 project delivery D2.3. Energy efficiency analysis of the reference systems, areas of improvements and target break down [i.8].

l) The same research study is published 2011 in IEEE magazine paper as "How much energy is needed to run a wireless network" [i.21]. It was awarded "best IEEE ComSoc Magazine paper in 3 years".

m) IEEE, C Lange et al.: "Energy Consumption of Telecommunication Networks and Related Improvement Options" [i.15]: 2009 - 2017 Energy consumption evolution estimate. The report describes in details the impact of ICT in different sectors and countries. The ICT own emissions are estimated for three main ICT components: End-user devices (such as Smartphones, tablets, PCs, printers, etc.) creating ~47 % of the total ICT impact; Data centres with ~28 % of the total impact; Networks (fixed and mobile broadband, home networks, etc.) with 24 % of the total impact.
There is no detailed analysis on how these figures have been calculated and how the ICT impact could impacted with different technical solutions. Summary: the report gives a detailed overview of the impact of ICT solution on different industry sectors but it gives no guidance on how to minimize the direct impact from ICT systems and components. Impact on WI: low.

n) IEEE paper WCNC14: "Assessment of the Energy Efficiency Enhancement of Future Mobile Networks" [i.16], estimate of traffic and RAN energy consumption 2010 - 2020 under very benign conditions: The initial separate networks of two operators are later merged into a single shared network. Energy efficiency improvement results are extremely high - with no parallel in other Cellular Network studies.

o) Fehske, Malmodin: "The Global Footprint of Mobile Communications: The Ecological and Economic Perspective" [i.17].

p) GreenTouch® White Paper [i.22] describing methods and analysing results of the Green Touch project.

4.2.3 Standards

a) ETSI ES 202 706 [i.18]: The document covers 2G, 3G and 4G. The first part - static measurements - only covers energy consumption. The second part - dynamic measurements - includes energy efficiency metrics. This standard will be split in two parts. ETSI ES 202 706-1 is already published but covers only static power consumption measurements. ETSI ES 202 706-2, dynamic testing, is under development and will include energy efficiency metrics.

b) ETSI ES 202 706-1 [i.25].

c) ETSI ES 203 228 [i.19]: Assessment of an existing field RAN deployment, including BS equipment and site infrastructure. This document is useful for the RAN Baseline definition phase and conversion between full network and analysed sub-network.

d) Recommendation ITU-T L.1310 [i.20]: Series L: Construction, installation and protection of cables and other elements of outside plant, Energy efficiency metrics and measurement methods for telecommunication equipment.

e) ETSI TS 134 121 [i.27]: table 6.2.1 provides 3G sensitivity figures that are used in the present document.

f) ETSI TS 145 005 [i.31].

g) ETSI TR 136 913 [i.29]: table 8.1 provides 4G cell average spectral efficiency figures used in the present document.

h) ETSI TS 136 104 [i.28]: clause 7.2 provides sensitivity figures used in the present document.

i) Draft New Report ITU-R M [i.30] (IMT-2020.TECH PERF REQ) (5G NR). Minimum requirements related to technical performance for IMT-2020 radio interface(s). Clause 4.5 provides 5G NR (New Radio) average spectral efficiency figures used in the present document.

5 Best Practice

5.1 Definition of network to analyse

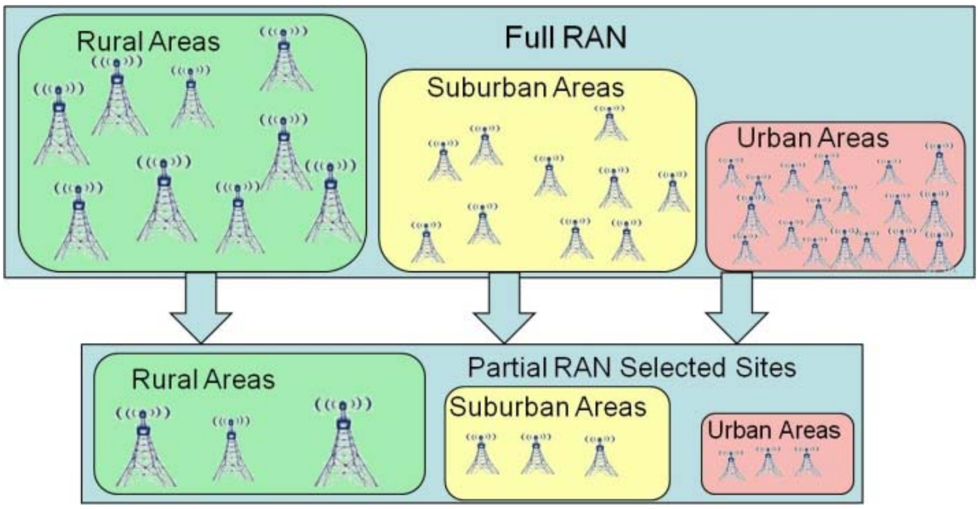

Figure 2: Selection of partial RAN sites for analysis

If the network is large, a partial representation of the network may be chosen that represents the different areas and types of BS sites within the full RAN. "Full RAN" means the total RAN under analysis that could be any size from limited area, city are, national RAN, regional RAN or global RAN. Configurations and Test Parameter Categorization of ETSI ES 203 228 [i.19], clause 4.2 should be considered for appropriate selection of partial RAN sites. The different categories are provided in table 1. [i.19] provides more detail on each category. Scaling factors should be defined for each site in the Partial RAN to enable re-scaling to the full RAN with correct values for number of sites, number of cells, RAN energy consumption, RAN total traffic and traffic per RAT.

Table 1: ETSI ES 203 228 [i.19] Test Parameter Categorization

Category	Parameter	Remarks
1	EC_{MN}	Measured network energy consumption
1	Capacity	As defined in clause 5.2
1	Coverage area	As defined in clause 6.2.3
2	Coverage ratio	As defined in clause 6.2.3
2	Demography	Population density as defined in clause 4.3.1
2	Topography	As defined in clause 4.3.2
2	Climate zones	As defined in clause 4.3.3
2	Informative classes	As defined in clause 4.3.4
2	CS/PS data ratio	Describes the fraction of CS traffic vs. PS traffic in the network

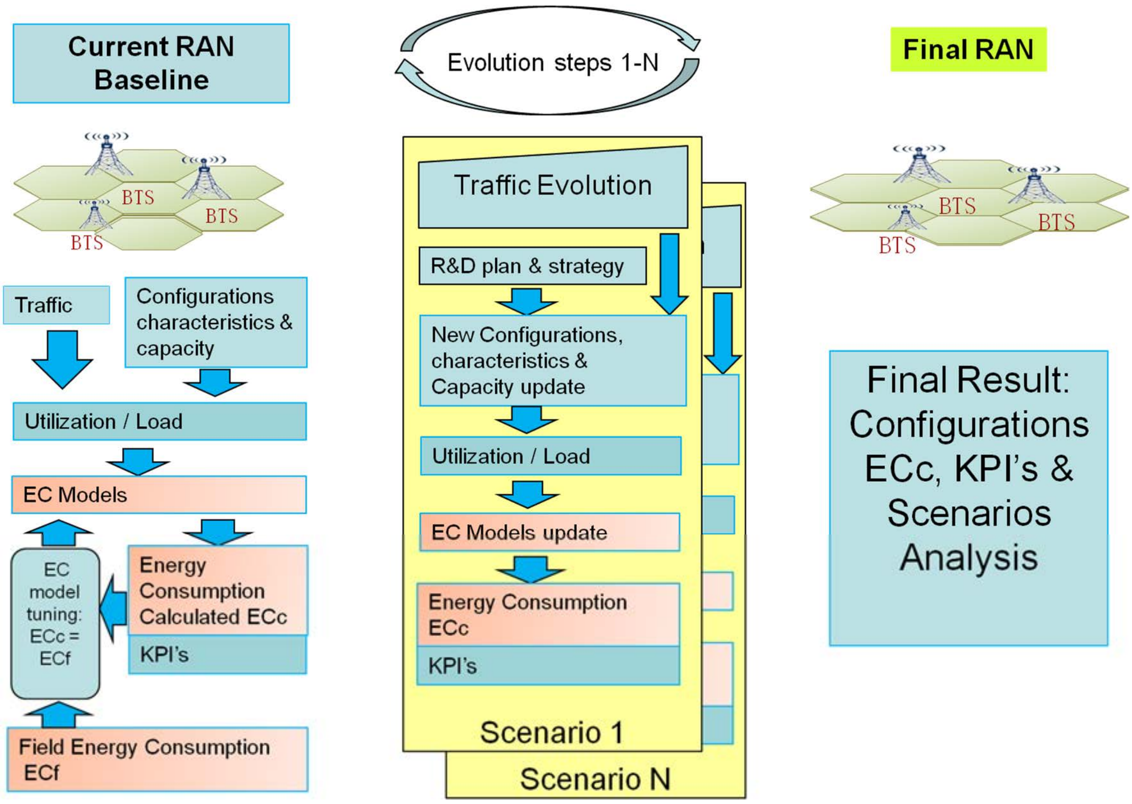

Figure 3: Assessment process phases of RAN to Analyse

5.2 Definition of baseline (audit or estimate based)

Focus on Incumbent Operator RAN.

5.2.1 Starting date

As traffic growth is quite steep, estimated ~ +47 % growth per year [i.1], the starting date is crucial for all baseline data, traffic as well as energy consumption. If data are collected over an extended period, i.e. > 2 months, all data should be adjusted to a nominal starting date considering measured or estimated traffic growth.

5.2.2 Configurations

Configurations of Network, Backhaul, site and base station (including RAT). Equipment year of manufacturing.

5.2.3 Energy consumption

Values and metrics of ETSI ES 203 228 [i.19] are recommended to be used.

Recommended metrics according to ETSI ES 203 228 [i.19]: Energy consumption according to clause 5.1, performance according to clause 5.2, energy efficiency is calculated according to clause 5.3.

5.2.4 Traffic measurement

Per site and per RAT PS, CS, according to ETSI ES 203 228 [i.19], clause 5.2. Average and/or Busy Hour values. If only Busy Hour values are available, average and total values can be calculated based on daily traffic profile.

Daily traffic profile (CS, PS and IoT), distribution over areas.

5.2.5 Calculation of capacity

Capacity should be calculated per band, RAT and cell or site. Capacity per cell/site is important for calculation of utilization and power consumption based on power consumption models.

The "raw" capacity is based on average spectral efficiency, sectorization and bandwidth. The figures are then reduced with a derating factor to consider burstiness of traffic and QoS requirements during busy hour.

Table 2: Spectral efficiency of UMTS, LTE and 5G Macro and 3G, 4G small cells

RAT	Config. DL	Config. UL	Case	Spectral Eff. DL	Spectral Eff UL	Source
UMTS	1T2R	-	Table 4, 16 users, HSDPA/HSUPA	0,786	0,104	[i.32]
LTE-A	2x2	1x2	Case 1	2,4	1,2	[i.29]
	4x2	2x4	Case 1	2,6	2,0	
	4x4	-	Case 1	3,7	-	
5G NR	-	-	Indoor Hotspot - eMBB	9	6,75	[i.30]
	-	-	Dense Urban - eMBB (see note)	7,8	5,4	
	-	-	Rural - eMBB	3,3	1,6	
3G, 4G small cells			Shared spectrum with macro, but LoS is dominating. Net LoS gain on SE: 2x Limited coverage loss of traffic × 0,8 Total gain factor vs. Macro: 1,6			
NOTE: This requirement applies to Macro TRxP layer of the Dense Urban -eMBB test environment as described in ITU report [i.30].						

Table 3: Spectral efficiency versus sectorizing "rule of thumb"

Number of sectors on site	Spectral efficiency factor per sector, versus 3 sector site	Site capacity factor versus 3 sector site
1	1	0,5
2	1	0,667
3	1	1
4	0,95	1,27
5	0,90	1,50
6	0,85	1,70

Capacity of band/sector = Spectral efficiency x sector factor x bandwidth x QoS derating factor.

5.2.6 Calculation or measurement of Utilization

Utilization may be measured or calculated. Utilization is the fraction of capacity used at Busy Hour. Utilization = Busy Hour traffic/Capacity at specified QoS.

5.2.7 Features

Energy saving of all features that contribute to energy saving, should be included with energy saving data for individual and combined features, if available. Preferably average % saving on Energy Consumption of equipment compared to features not activated.

5.2.8 Base station Energy Consumption models

For each type of base station and configuration, an energy consumption model is provided, usually by vendor, that is usually based on laboratory measurements. If Vendor energy consumption models are not available, public power consumption models could be used as IMEC online Base Station model [i.33] or Aaalborg University Base Station model [i.34] clause 3.3 with evolution figures 2013 - 2025 in clause 3.6. Power consumption of equipment:

$$P_{equipment} = \alpha + \beta \times L \text{ [W]}$$

$P_{equipment}$: average power consumption of equipment at a site

α: static power consumption of equipment at site

β: the consumption factor for variable part of load

L: Load. Value: 0 - 100 % of maximum load

5.2.9 Site Energy Consumption models

For each type of site infrastructure equipment, i.e. backhaul, cooling and power systems, an energy consumption model should be provided, usually by vendor, based on laboratory measurements.

Energy consumption of site is achieved by integration of power consumption over time. Power consumption of the site:

$$P_{site(AC)} = sf \times P_{equipment(DC)}$$

$$sf = \frac{1}{Eff_{rect}} + sps * (cf - 1)$$

sf: Site Factor. Same as "site_correction_factor" in [i.25]

Eff_{rect}: Rectifier Efficiency. Range: 82 to 98 %

sps (see note 1): Shelter Power Share. Dissipation in shelter versus equipment DC power consumption

cf (see note 2): Cooling factor

NOTE 1: sps: Shelter Power Share: Dissipation in shelter versus BS equipment DC power consumption. As rectifier losses are included in sps, the value can exceed 100 % for a traditional base station with all equipment within the climate shell, combined with low efficiency rectifiers.
For a DBS with high efficient rectifiers, sps is ~20 %.

NOTE 2: cf: Cooling factor. or $1 + \frac{1}{COP}$ (see note 3) of cooling equipment.

NOTE 3: COP: Coefficient Of Performance. Efficiency factor for cooling equipment. Common values: Air condition COP = 2 - 3 while cf is 1,4 - 2,0. Hybrid cooling cf is 1,1 - 1,2. (Facebook® Luleå claiming cf 1.07). Ventilation cf is ~1,05.

COP as Efficiency metric for heat pump:

- The equation is: $\boldsymbol{COP = \frac{Q}{W}}$

- Q is the useful heat transport (power or energy) provided by the climate system.
- W is the work (power or energy consumption) required by the climate system.
- The COP for heating and cooling are different.
- For cooling - the COP is the ratio of the power or energy transport versus the power or energy consumption of the climate system.
- For heating, the COP is the ratio of the heat power or energy transport *plus* the power/energy consumption of the climate system:

  $COP_{heating} = \frac{Qh}{W} = \frac{Qc+W}{W}$

  $COP_{cooling} = \frac{Qc}{W}$

  where:

  Q_c is the energy or power removed from the hot reservoir.

  Q_h is the energy or power supplied to the cold reservoir.

- For fans and heat exchangers, the hot reservoir is warmer then the cold reservoir.
- For heat-pumps, the "hot" reservoir is usually colder than the "cold" reservoir.

Most convenient is to use average values (daily or annually) of the factors that are used in the model. Average power is integrated over time to achieve the energy consumption.

ETSI ES 203 228 [i.19] SEE metric:

$$SEE = \frac{EC_{BSs}}{EC_{BSs}+EC_{SI}}\,; SEE = \frac{1}{sf}$$

5.2.10 Alignment of Base station and Site models versus measured field data

Base station alfa and beta and site parameters should be adapted to comply with measured field data.

5.3 Evolution Scenarios

Energy Performance and costs are highly dependent on traffic evolution, QoS and deployment strategies. Different scenarios are recommended based on following parameters:

a) Traffic evolution range assumptions (Daily and weekly profiles including busy hour levels distribution over Rat's, subscribers, services, devices, IoT).

b) Requirements on QoS, Utilization margins may increase, i.e. acceptable Utilization is a lower fraction of best effort available data rates.

c) Strategies for Coverage, Roll out of RAT's, Spectrum, BS types and configurations.

d) Refresh strategy, BS equipment and site infrastructure.

e) Site "clean up" of unused equipment. (it should be included in all scenarios).

f) Software and features strategy.

5.4 Evolution Steps

5.4.0 Evolution Granularity

Evolution is analysed with the wanted granularity, i.e. evolution steps. Usually 1-3 year steps. For evolution and migration details, 1 year steps are most suitable.

5.4.1 Traffic evolution

Traffic evolution is driven by traffic growth and evolution oftraffic profiles, subscribers, services anddevices.

Traffic Growth estimate is crucial for the evolution of equipment and energy consumption estimates. Besides operator own estimates, traffic growth estimates are provided by CISCO [i.2], Ericsson [i.6], Huawei [i.12] and EARTH® [i.8]. METIS® figure, 1 000 traffic growth, is vague as time interval is not provided. 2016, Global Mobile traffic grew 63 %. Future growth is estimated a bit lower.

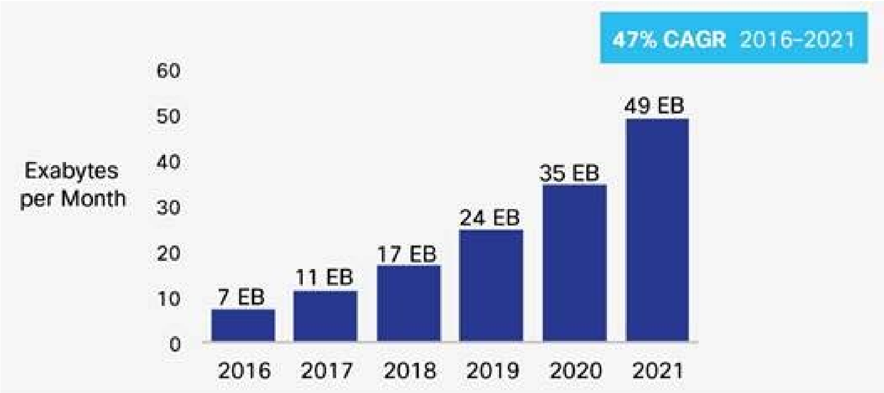

Figure 4: CISCO traffic growth prognoses [i.1] and [i.2]

Andrae Edler [i.5] assumes a slightly higher Global Mobile traffic CAGR than CISCO, arriving at 550 EB/Y (45,8 EB/Mo) by 2020 and 16 / 31 ZB for Best/Expected scenarios by 2030.

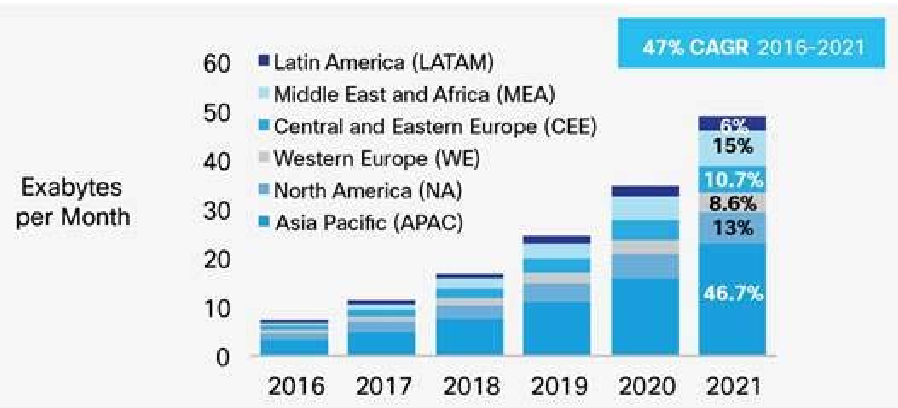

Figure 5: CISCO Global Mobile traffic growth distribution estimate [i.1] and [i.2]

a) Services: Video is today dominating, and will be even more in future. Surfing and gaming also increasing share. Voice traffic share will further reduce.

b) Daily traffic profile will "flatten" as voice share is reduced.

c) High difference between users. Traffic of sms/voice type of users will become insignificant compared to 4G and 5G heavy users.

RAT's and Devices. It is a "speed race" between devices and networks. New RAT's offering higher speeds will be best utilized by the new devices with high resolution screens and fast processors. A few heavy users may use all capacity of a cell. Smartphones and "phablets" will dominate over laptops and bit-rate hungry AR/VR devices will arrive on the market Device growth of 8 % CAGR is much slower than traffic growth, except for IoT (M2M) devices that explode in count - but not in data volumes. For non IoT devices - the device count CAGR is only 6 % [i.1].

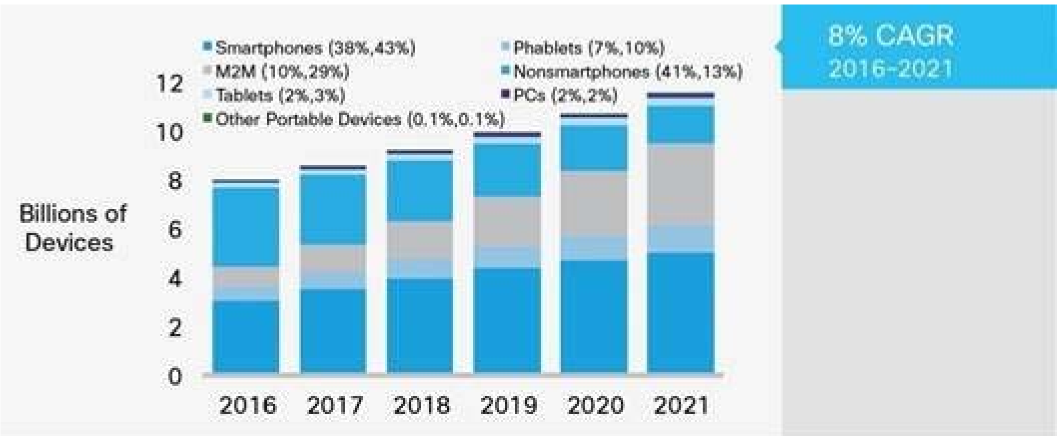

Figure 6: CISCO VNI Mobile devices evolution estimate [i.1] and [i.2]

5.4.2 IoT impact

Currently a majority of IOT and IoT devices are 2G. It will be costly to replace or promote replacement to transfer M2M traffic to 4G or 5G. The "small traffic" of IOT/IoT would need narrow band solutions for coverage and power limitations. 4G NB solutions with 1,4 MHz or 200 kHz bandwidth. 5G NB solutions under development, down to one subcarrier. If larger bandwidth is used, high processing/coding gain could be used for coverage. 8GPS 50 Hz data rate spread to 5 MHz and 20 MHz to gain link budget. A large amount of connected IOT/IoT devices may impact efficiency of Base Stations and RAN.

5.4.3 Equipment Utilization Evolution

The equipment utilization will change over time:

- If bands and RATS are added based only on the capacity need per site or sector, the energy efficiency will increase due to the higher utilization.
- If extra bands are added of competition reasons, beyond capacity needs, the energy efficiency will suffer.

5.4.4 Traffic calculation

Based on traffic evolution assumptions, traffic growth factors are defined for all RAN, differentiated over RAT's and optionally also over areas or sites. The growth factors are applied on each site to achieve evolution traffic levels on each cell/site.

5.4.5 Capacity expansion strategy

Adding new sites is avoided as being difficult and costly while operators want to expand the capacity of the current sites as first priority:

- Add new bands and RAT's as available. Equipment is added for the new bands. Physical sectors/lobes and coverage can be maintained. Energy consumption will increase, but also the efficiency as utilization may increase and the new RAT's added are more energy efficient than the legacy RAT's, according to table 2 in clause 5.2.
- 4.5G: CA and Massive MIMO:
  - 3GPP FD-MIMO, Release 13, with 5x spectral efficiency of 2x2 MIMO. Release 13 available late 2017.
- 5G solutions, start 2019:

  - CC (common channels) using existing bands. DL Massive MIMO used as CA - supplementary downlink. Specified in ETSI TS 136 300 [i.26]. The Uplink solutions are described in ETSI TR 136 714 [i.26].
  - Higher sectorization: Coverage will be increased with narrow lobes while spectral efficiency (SE) is reduced when exceeding 3 sectors due to interference.
    Rules of thumb: 4 sectors 5 % SE loss. 5 sectors 10 % SE loss. 6 sectors 15 % SE loss. The effect of expansion from 3 to 6 sectors is only +70 % capacity. If multi-band antennas are used, all bands need the same sectorization. If not - more antennas are needed. Add small cells (HetNet). High efficiency - if located at traffic hot spots. Low coverage. SC in Macro band not a good solution as spectral efficiency is impaired in common coverage areas. More efficient to use exclusive band, fex LAA (License Assisted Access) 4G DL on 5 GHz WiFi band. LAA field tests are done by Huawei, Qualcom and Ericsson. LSA available option for Europe/EU, 2,3 GHz to 2,4 GHz. LAA for other regions.
  - Cell split. Usually the least preferred option.
- "Old" RAT's are less efficient than the successors while RAT termination is important to avoid increased energy consumption. If 2G and 3G RAN remains when 5G is rolled out, RAN energy consumption will increase substantially. Strategies for termination of old RAT's are precious.
- For higher frequencies > 3 GHz and small cells, new sites are required.

5.4.6 Capacity Calculation

Capacity as calculated according to clause 5.2.5.

5.4.7 Utilization calculation & capacity adaptation

Utilization is calculated according to clause 5.2.6. If utilization is > 100 %, the configuration should be expanded and capacity and utilization recalculated.

5.4.8 Coverage strategy

Table 4: Path loss frequency dependency modelling

Path loss model	Okumura Hata	COST-HATA 231	Walfish-Bertoni	Ericsson 9999
Comment	First basic, based on measurements in Japan	Improved for higher frequency range	Valid for area with multiple buildings of similar height with BS antennas slightly higher than the buildings	For Rural, suburban and Urban areas
Frequency range [MHz]	150 - 1 000	1 000 - 2 000		< 2 000, adaptable > 2 000
Path loss diff, 2X frequency, suburban	5,7 dB	10 dB	6,3 dB	4,3 dB
Path loss diff, 2X frequency, Urban	7,7 dB	10 dB	6,3 dB	4,3 dB
Path loss diff, 2X frequency, Dense Urban	7,9 dB	10 dB	6,3 dB	4,3 dB
Average	7,1 dB	10 dB	6,3 dB	4,3 dB

The current path loss models deviate on frequency dependency. In the present document, 6 dB for doubling of frequency and 3 dB for 1,4x frequency are used as rule of thumb.

Table 5: Typical range of antenna gain in field deployment. Source Huawei

Area	Low band (see note)	High band (see note)	Comment
Urban - antenna size restrictions	10 - 12 dBi	10 - 12 dBi	High band 0 - 3 dB higher gain than low band Multi-band antennas covering all bands are preferred, but gain is max 18 dBi. High band has 0 - 3 dB higher gain than low band. Same gain most common - to achieve same lobe for both bands. In case frequency dependent path loss is not compensated with RF power, Hand-Over to low band provides coverage of distant UE's.
Urban - typical	15 - 17 dBi	15 - 17 dBi	
Suburban	15 - 17 dBi	15 - 17 dBi	
Rural	15 - 18 dBi	17 - 18 dBi	
Rural, extreme coverage	19 - 21 dBi	19 - 21 dBi	
NOTE: Low band < 1GHz, High band 1 - 3,5 GHz.			

Table 6: Sensitivity survey 2&-5G and corresponding PSD for equal coverage

Technology	GSM	UMTS	HSPA	LTE, LTE-A	5G NR
Channel BW [MHz]	0,2	3,8		20	20 (..100..)
Sensitivity dBm	-104,0	-103,7 -106,7	-103,7 -106,7	-101,6	-101,6
Ref	[i.32]	[i.27]	[i.27]	[i.28]	[i.30]
Power/carrier ratio for equal coverage	1	1	1	2 - 3	2 - 3
PSD, Power/5MHz for equal DL coverage		1	1	0,5 - 0,75	0,5 - 0,75
Device peak TX power	24 - 39 dBm (Class 2)	23 dBm	23 dBm	23 dBm	NA

Ideally, all RAT's and bands should have similar coverage area and lobe form to support carrier aggregation and smooth hand-over between cells. Table 6 shows indicative values on how to compensate for bandwidth and sensitivity at same frequency band. Table 4 indicates how to compensate RF power over frequency. Usually high band RF power cannot be increased with 6 dB, but up to 3 dB. Another 3 dB gain at high band versus low band is supported by some multi-band antennas with 15 to 18 dBi gain used in rural areas, while multiband antennas with same gain over bands are preferred on urban and suburban areas to get the same lobe-form though coverage range differs.

As lobe or coverage area is not identical over bands - band hand-over is needed for distant UE's.

5.4.9 Hardware strategy, equipment refresh

- Replace "concentrated" indoor BS with outdoor or "distributed" to reduce feeder losses and cooling energy consumption. PA power can be reduced with 50 % if radio units are located close to antenna, eliminating feeder losses.
- New generations of BS Hardware are more efficient. TCO of a swap should be investigated.
- Replacing GSM single carrier BS with combiners with multi carrier PA saves energy.
- For multi-standard bands, using multi standard baseband and radio units may save energy.
- AU, Active Antenna Unit alternative should be considered.

5.4.10 Site infrastructure saving

- Reduce cooling energy consumption.
- Renewal of rectifiers. A "low hanging fruit". Rectifiers in field may be of low efficiency, 82 % to 87 %, while latest generation rectifier provides up to 98 % efficiency. Reduction of rectifier losses has a double effect:
    - Firstly, the energy consumption is reduced because of reduced rectifier losses.
    - Secondly, there is less heat to cool, reducing load and energy consumption of cooling equipment.
    - It may also pave the way to use hybrid ventilation/HEX/Air condition systems that are more energy efficient, but need more space per cooling capacity.

- Liquid cooling could increase cooling efficiency.

- The saving is easy to estimate when load energy, energy to cool, and cooling COP is known, using site infrastructure energy consumption formulas.

- Reducing feeder and cooling losses by swapping standard indoor base stations to Remote Radio types, i.e. radio units with natural cooling, located outdoor close to antenna. In the climatized shelter only rectifier, transmission and a small "main unit" (Base Band and control) are hosted, thus reducing the heat load and energy consumption of the cooling equipment. As feeder losses are reduced a smaller power amplifier can be used.
  Saving can be estimated applying the site energy consumption formulas to known Base Station consumption distribution.

- Site "Clean up" saving.

Equipment that is removed from operation may still be connected to the mains - wasting power. There are field examples of networks where 20 % of equipment energy consumption was caused by such unused equipment. A thorough audit should be done on a number of pilot sites to estimate potential energy saving. The result can be extrapolated to get the potential of the full network.

- How to calculate Site energy consumption: See clause 5.2.9.

5.4.11 Software and features

All available features should be listed and energy saving figures provided for individual features and combinations - for different BS types and traffic levels.

5.4.12 Spectrum strategy

Spectrum and RAT's could be added based on capacity need only, or additional bands/RAT's added for competition on coverage, capacity and or QoS.

5.5 Result

Transformation from analysed partial network to full network.

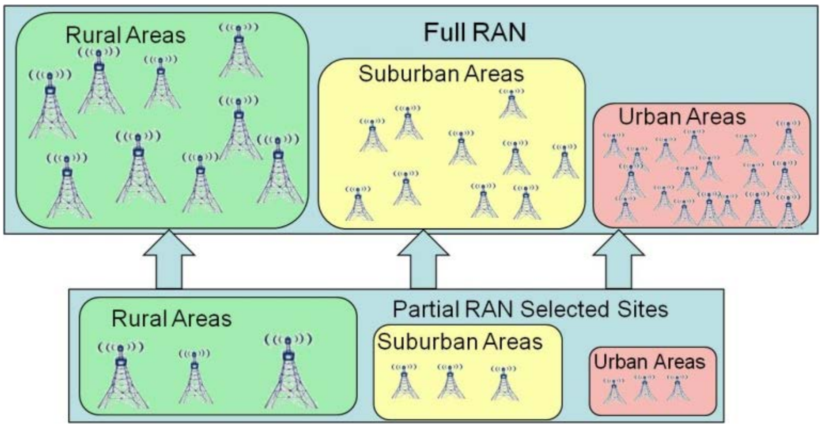

Figure 7: Transformation from analysed partial RAN to the full RAN

The Partial RAN data is re-scaled to Full RAN values, using scaling factors as described in clause 5.1, to achieve the number of sites, number of cells, energy consumption, total traffic and traffic per RAT - for the full RAN. The scaling factors can be modified any time during the analysis process.

- Alternative solutions/strategies.

- Final traffic (On Services, QoS, device types, including IoT, traffic profiles, etc.).

- Final configurations of equipment.
- Final Site infrastructure.
- Site Energy consumption calculation as of evolution part.
- Final Utilization.
- Final KPI's on performance: Capacity, Energy Efficiency, Energy Consumption, QoS, Coverage.
- Uncertainty and sensitivity analysis.
- Conclusion and interpretation of result.

Annex A: Previous work reviews

A.1 Tool Reviews

A.1.1 Review of GWATT Tool (GreenTouch® project)

A.1.1.1 Introduction

GWATT® is an interactive application to visualize the GreenTouch® results. The online web tool (http://alu-greentouch-dev.appspot.com/intro/1) developed by GreenTouch®, provides an end-to-end view of the GreenTouch portfolio of technologies and solution, and to share the results and accomplishments in an easy-to-use and interactive application accessible to everyone.

A.1.1.2 Breakthroughs

GreenTouch® has delivered a comprehensive portfolio of technologies, architectures, algorithms and protocols for dramatically improving network energy efficiency. Collectively the impact of all these solutions is captured in the Green Meter results for the respective network segments in mobile access, fixed access and core networks.

GWATT® is a single portal that provides access to all the technologies across the solutions portfolio and summarizes the GreenTouch Green Meter results. It has been designed to help ICT stakeholders visualize the energy impact of the technologies using dynamic scenarios and multiple metrics (including energy consumption, energy cost and equivalent carbon emissions). The user is able to identify the energy hotspots in the communication networks and through different "what if" scenarios understand the impact of the GreenTouch® technologies and solutions.

A.1.1.3 Results

GreenTouch® publicly launched GWATT® to share its dramatic findings with the ICT industry and any interested parties. The application is freely available at: http://alu-greentouch-dev.appspot.com/intro/1.

GWATT® incorporates the entire portfolio of GreenTouch® technologies from mobile access, fixed access and core networks based on the GreenTouch research projects, including those technologies and demonstrations being showcased at the GreenTouch® Final Event in New York.

Thanks to the GWATT® interactive graphical user interface, the user can check in real time how individual technologies and combinations of technologies improve network energy performance and energy cost.

Different network evolution scenarios can be simultaneously constructed and their energy performance compared. The GreenTouch® results are also displayed in comparison to the 2010 reference scenario and a 2020 business as-usual network evolution.

A.1.1.4 Demonstration

A live demonstration of GWATT® was provided during the event so visitors could experience the power of the application for themselves. The three GreenTouch® network domains (mobile access, fixed access and core networks) can be selected by the GWATT® user. Within these domains, a technology menu is offered and users can choose any technology or combination of technologies that they are interested in. GWATT® then provides a visualization of the energy efficiency gains, energy cost, energy consumption and CO2 savings.

A.2 Papers and Reports review

A.2.1 SMARTer 2030 (GeSI) report review

The report [i.11] describes the impact of ICT from an environmental, social and economic point of view. It is divided in four main chapters:

- Benefits from ICT on an environmental, social and economic level.
- Sectors which will profit most from applying ICT.
- Countries which can benefit from ICT solutions.
- Call to action - how to accelerate ICT adoption.

The report [i.11] focuses on potential GHG emission reduction with the help of ICT solutions in various sectors. The key claim is that the GHG abatement potential from ICT solutions could reach 12 Gt in 2030 while the ICT related footprint is only 1,25 Gt.

The report describes in details the impact of ICT in different sectors and countries. The ICT own emissions are estimated for three main ICT components:

- End-user devices (such as Smartphones, tablets, PCs, printers, etc.) creating ~47 % of the total ICT impact.
- Data centres with ~28 % of the total impact.
- Networks (fixed and mobile broadband, home networks, etc.) with 24 % of the total impact.

There is no detailed analysis how these figures have been calculated and how the ICT impact could impacted with different technical solutions.

Summary: The report gives a detailed overview of the impact of ICT solution on different industry sectors but it gives no guidance on how to minimize the direct impact from ICT systems and components. Impact on WI: low.

A.2.2 Review of "On Global Electricity usage of Communication Technology: Trends to 2030" (Anders Andrae, Tomas Edler)

[i.12] presents an estimate of the global electricity usage from ICT between 2010 and 2030. The future energy consumption estimate is calculated for three different scenarios.

The document is based on a solid literature study and available sources for the current ICT energy consumption and uses a wide range of sources for the predicted development of ICT technologies and market trends. Three different scenarios are presented:

- Best case (lowest energy consumption).
- Expected.
- Worst case (assuming high volume growth despite low efficiency improvements.

The document [i.12] presents detailed ICT energy consumption predictions for different three different scenarios. The scenarios are based on generic technology and market predictions. The report as such is very valuable as it presents the possible ICT energy consumption under different assumptions and clearly demonstrates the importance of ICT energy efficiency measures to limit ICT energy consumption. The report is a good justification for the WI but does not directly provide answers for how to optimize future networks. Impact on WI: medium.

Annex B: Bibliography

3GPP TR 36.714-05-01: "Evolved Universal Terrestrial Radio Access (E-UTRA); LTE Advanced inter-band Carrier Aggregation (CA) Rel-14 for 5 Down Link (DL) / 1 Up Link (UL)".

History

Document history		
V1.1.1	May 2018	Publication