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Foreword

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

The present document has been developed in collaboration with 3GPP SA5 and RAN3; GSMA has given also valuable suggestions and contributions. Moreover, the present document is developed jointly with ITU-T SG5 Q17/5.

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Introduction

In the absence of direct measurements, a radio access network's energy consumption can be estimated using a simple random sample of base station sites from the mobile network. There are two estimation methods described in the present document which can be used for this purpose: the basic estimation method, and the stratified estimation method.

In the basic estimation method, the sample is created with no consideration for the constitution of the mobile network. This method is well-suited for mobile networks generally characterized as homogenous, with normal statistical distributions of energy-influencing site characteristics across the network (e.g.base stations per site, radios per site).

In the stratified estimation method, the sample is created while taking the constitution of the mobile network into account. This method is well-suited to mobile networks generally characterized as heterogeneous, or mobile networks with non-normal statistical distributions of energy-influencing site characteristics.

An example of application of these two methods is given for better readability and ease of use in annex A.

1 Scope

The present document is aimed to define an estimation method for anticipating the total energy consumption of a radio access network based on measuring energy consumption of a few randomly chosen sites. The present document is used when measuring energy consumption of the whole network is either impossible or costly to an operator. Two different methods have been presented in the present document , one based on Basic Estimation Method and another based on stratified Estimation Method.

The present document deals with any type of radio access network such as homogeneous and heterogeneous network and technologies such as GSM, UMTS and LTE.

The estimation of energy consumption User Equipment (UE) is not within the scope of the present document.

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.

Not applicable.

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

Base Station (BS): network component which serves one or more cells and interfaces the user terminal (through air interface) and a radio access network infrastructure

Energy Efficiency (EE): relation between the useful output and energy consumption

Mobile Network (MN): set of equipment from the radio access network or sub-network that are relevant for the assessment of energy efficiency

power consumption: power consumed by a device to achieve an intended application performance

Radio Access Network (RAN): telecommunications network in which the access to the network (connection between user terminal and network) is implemented without the use of wires and that is part of GERAN, UTRAN or E-UTRA networks defined by 3GPP

Radio Access Network Energy Consumption (RANEC): overall energy consumption of equipment included in the RAN under investigation

Telecommunication Network (TN): network operated under a license granted by a national telecommunications authority, which provides telecommunications between Network Termination Points (NTPs)

3.2 Abbreviations

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

3GPP	3G (mobile) Partnership Project
BS	Base Station
CL	Confidence of Level
EC	Energy Consumption
E-UTRA	Evolved UMTS Terrestrial Radio Access Network
GERAN	GSM/EDGE Radio Access Network
GSM	Global System for Mobile communication
GSMA	GSM Association
ICT	Information Communications Technology
ITU	International Telecommunications Union
ITU-T	International Telecommunications Union - Telecommunication
LTE	Long Term Evolution
MN	Mobile Network
PDF	Probability Distribution Function
RAN	Radio Access Network
RF	Radio Frequency
T	Period of Time over the estimate is made
TLAF	Transmission Loss Adjustment Factor
UMTS	Universal Mobile Telecommunication Service
UTRAN	UMTS Terrestrial Radio Access Network

4 RAN Energy Consumption Estimation Method

4.1 General description

A simple random sample of radio access network energy consumption is supported by the following definitions:

- A RAN is a population consisting of "N" base station sites.
- A sample from the RAN population consists of "n" base station sites.
- All possible samples of "n" base station sites from the RAN population are equally likely to occur.
- Each sample of the RAN population has a mean site energy consumption of $\overline{x_i}$.
- The value of $\overline{x_i}$ serves as an estimate of the true mean site energy consumption for the entire RAN (denoted as μ).
- The size (n) of each RAN sample needs to be sufficiently large such that all possible values of mean site energy consumption ($\overline{x_i}$) form a normal (or near normal) sample distribution.
- The mean of the sample distribution ($\mu_{\bar{x}}$) is also the true mean of the site energy consumption (μ) for the entire RAN, as shown in figure 1.

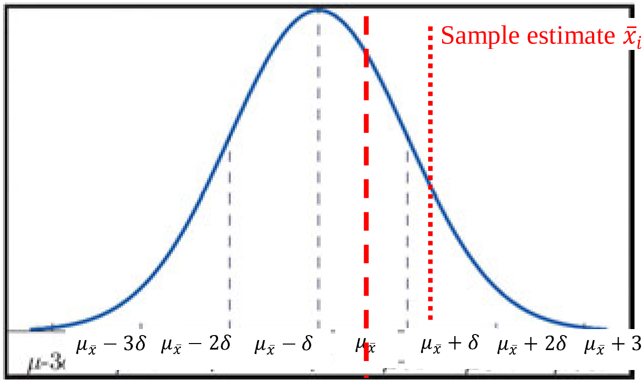


Figure 1: Normal Distribution of a Randomly Sampled Population

Using the above definitions, the radio access network's energy consumption is estimated by multiplying the sample estimate of the mean site energy consumption ($\bar{x}_i$) by the number of sites in the mobile network population (N).

$$EC_{RAN,\bar{x}} = N \cdot \bar{x}_i$$

The above estimate of RAN energy consumption also includes some indication of its accuracy relative to the true RAN energy consumption value. Therefore, energy consumption estimates are expressed as a confidence interval consisting of:

- The sample estimate of the RAN energy consumption ($EC_{RAN,\bar{x}}$), extrapolated from the sample mean ($\bar{x}_i$).
- The amount of time (T) covered by the energy consumption estimate.
- A margin of error expressing the maximum expected difference between the true energy consumption of the RAN and the sample estimate.
- The confidence level (CL) in the sampling method. Specifically, it reflects the percentage of sample estimates whose mean energy consumption and margin of error are expected to include the true mean site energy consumption.

Based on the above, a RAN energy consumption estimate is expressed in the following form:

$$\text{The CL \% confidence interval for the mobile network energy consumption over a period of T is } EC_{RAN,\bar{x}} \pm ME \text{ \% Watt} \cdot \text{Hours}$$

As an example, an estimate of a mobile network's energy consumption would be expressed as follows:

$$\text{The 95 \% confidence interval for the energy consumed by the mobile network over a one-month period is } 1{,}05 \times 10^{11} \pm 2{,}4 \text{ \% Watt} \cdot \text{Hours}$$

4.2 Basic Estimation Method

4.2.1 Select a Confidence Level

The confidence level reflects the confidence that one wants to have in the energy consumption estimate. It is an individual choice not specified by the present document, and it influences the size of the margin of error associated with the energy consumption estimate. It can be any percentage value up to 100 %, with 95 % being a common value. Note that choosing a confidence level of 100 % implies that every site in the network would have to be measured, thus defeating the purpose of the estimation method.

4.2.2 Specify the Sample Size "n"

In order to satisfy the requirements of the central limit theorem, the sample size (n) needs to be large enough to produce a normal sampling distribution. The less "normal" the shape of the network's underlying site energy consumption distribution, the larger the sample size needs to be in order for any estimate and associated margin of error to be valid.

Since the shape of the network is likely an unknown before any measurements take place, it is difficult to predict the sample size required to achieve a certain margin of error. Thus the sample size has to be chosen and measurements made first, with the associated margin of error calculated afterwards.

While the sample size is an individual choice, it is recommended that the sample measurement consist of:

- at least 50 of the network sites, representing at least 5 % of the network

A representative estimate and associated margin of error is more likely if both of these sample size requirements are satisfied.

4.2.3 Select the Random Sample of Base Station Sites

In order to be a truly random sample (n) of base station sites, the site selection needs be totally blind to such energy consumption influences as data traffic load, climate, site solution, site configuration, RF output power, and site capability. This can be achieved using the following site selection procedure:

- Itemize the population of mobile network base station sites in a vertical list consisting of "N" rows (i.e. one row for each base station site in the overall mobile network population). All information regarding the site configuration and environment should be excluded from the list in order to avoid the unconscious introduction of statistical bias.
- Using a random number generator, assign each entry in the site list a random number in the range of 0:1 to at least 6 decimal places. A spreadsheet's rand-function can be useful for this purpose.
- Sort the population site list based on the random number assignments, from the lowest random number to highest, as shown in figure 2.
- The first "n" base station sites in the sorted list (where "n" was determined in the previous step) should serve as the mobile network population sample. These "n" sites will have their energy consumptions directly measured.

Base Station Index	Base Station Name	Location	Random Number
1	BS0043A	MAIN ST	0.619291923
2	BS0043B	MAIN ST	0.627324076
3	BS0044A	MAIN ST W	0.125105478
4	BS0059E	HIGH PARK	0.647086334
5	BS0059F	HIGH PARK	0.752819185
6	BS0069B	REGENT HILLS	0.333481496
7	BS0069C	REGENT HILLS	0.446685252
8	BS0069E	REGENT HILLS	0.808364331
9	BS0083A	KAYVILLE	0.314409428
10	BS0084A	KAYVILLE	0.018700376

Original Base Station List

Base Station Index	Base Station Name	Location	Random Number
10	BS0084A	KAYVILLE	0.018700376
4095	BS4591D	LOWERTOWN	0.018943492
18	BS3401A	BRIDGE ST	0.022231044
10980	BS0321D	UPLANDS	0.023648181
1354	BS3311A	CEDAR HILL	0.027021437
3243	BS7920F	GRASSLAND	0.028293819
459	BS3310A	REDWATER	0.038400109
2944	BS0989A	VALLEY DRIVE	0.039000214
231	BS0943A	GREY ROCK	0.049812901
11231	BS6510B	MAPLE CREEK	0.049843129

Re-Ordered List Using Random Numbering

Use first "n" base station sites in re-ordered mobile network site list population sample

Figure 2: Creating the Random Site Sample

4.2.4 Choose a Measurement Period

The value of the measurement period (T) is an individual choice and is not specified by the present document. However, some consideration needs to be given to the fact that this value also determines the time period (T) over which the estimate applies. For example, if the energy consumption measurements are performed during a two-week period, the resulting estimate for the mobile network's energy consumption can only pertain to the **same** two-week period. The two-week measurement cannot be extrapolated to a year-long measurement, because other factors influencing energy consumption (such as yearly temperature fluctuations) would not be accounted for in the margin of error.

4.2.5 Measure the Energy Consumption of the Base Station Site Sample

The energy consumption measured at each base station site in the mobile network population sample, for measurement period (T), is denoted as:

$$EC_{site,i}$$

These sample energy consumption site values can be obtained from either:

- direct on-site measurements; or
- energy consumption metering information supplied by the electrical utility.

Electrical utility metering is only used for the sample provided the following conditions are met:

- The utility supplies a site energy consumption value in units of Watt-Hours or similar.
- The site energy consumption value is representative of the site only, and only includes equipment which fulfils the site function.
- Any transmission loss adjustment factors (TLAF) applied by the utility are fully quantified and understood.
- TLAFs are removed from the site energy consumption values provided by the electrical utility, since direct energy consumption measurements at the site would not capture the transmission loss effect.
- The energy billing information (i.e. the financial cost of the electricity) is not used to derive a site's energy consumption value.

Having met the above criteria, site energy consumption values based on metering information is calculated as:

$$EC_{site,i} = \frac{EC_{site\ i,TLAF}}{TLAF_{utility}}$$

Where:

$EC_{site\ i,TLAF}$	The site energy consumption value supplied by the electrical utility which includes a transmission loss adjustment factor (TLAF)
$TLAF_{utility}$	The transmission loss adjustment factor applied by the electrical utility

4.2.6 Estimate the Radio Access Network Energy Consumption

The RAN energy consumption sample estimate ($EC_{RAN,\bar{x}}$) is based on the mean energy consumption ($\bar{x}$) of the sites in the base station sample calculated as:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} EC_{site\ i}$$

Where:

$\bar{x}$	Sample estimate of the RAN's mean site energy consumption
n	Number of sites in the mobile network sample
$EC_{site\ i}$	Energy consumption of a site within the sample

The mean site energy consumption ($\bar{x}$) for the sample is then multiplied by the number of sites in the mobile network population (N) to determine the sample estimate for the mobile network energy consumption ($EC_{RAN,\bar{x}}$):

$$EC_{RAN,\bar{x}} = N \cdot \bar{x}$$

Where:

$EC_{site\ i}$	Energy consumption of a site within the sample
$EC_{RAN,\bar{x}}$	Sample estimate of the RAN's total energy consumption
n	Number of sites in the mobile network sample
$\bar{x}$	Sample estimate of the RAN's mean site energy consumption
N	Total number of base station sites in the mobile network

4.2.7 Calculate the Margin of Error of the Mobile Network Estimate

The margin of error is the maximum difference between the sample estimate and the true value of the radio access network's energy consumption. The confidence in this maximum is described by the confidence level chosen in clause 4.2.1.

As a numerical value, the margin of error is calculated as follows:

$$Margin\ of\ Error_{Num} = N \cdot t_{n-1} \cdot \frac{s}{\sqrt{n}} \cdot \sqrt{\frac{N-n}{N-1}}$$

As a percentage, the margin of error is calculated as follows:

$$Margin\ of\ Error_{\%} = \frac{Margin\ of\ Error_{Num}}{N \cdot \bar{x}} \cdot 100$$

Where:

t_{n-1}	T-score for a sample of size n, determined from an online t-score calculator applying $(n-1)$ degrees of freedom, and a cumulative probability (CP) calculated as: $$CP = 1 - \frac{100 - CL\ \%}{200}$$ Where (CL) is the confidence level (in %) chosen in clause 4.2.1.
s	Standard deviation of the site energy consumptions of the mobile network sample

In the above equations, a t-score (rather than a z-score) is used since the standard deviation of the mobile network population is unknown. In addition, the $\sqrt{\frac{N-n}{N-1}}$ term is the finite population correction formula, and is included since the mobile network site population is finite and is being sampled without replacement. Finally, the $\frac{s}{\sqrt{n}}$ term represents the standard error of the sample mean, with the standard deviation (s) of the sample calculated as:

$$s = \sqrt{\frac{\sum_{i=0}^{n}(EC_{site\ i} - \bar{x})^2}{n-1}}$$

4.2.8 State the Radio Access Network Energy Consumption Estimate

The resulting radio access network energy consumption estimate includes the chosen confidence level, the measurement period, the estimated mobile network energy consumption, and the associated margin of error. The estimate is expressed in the following form:

The $\mathrm{CL}\ \%$ confidence interval for the radio access network energy consumption, over a period of T is $\mathrm{EC_{RAN,\bar{x}}} \pm \mathrm{ME}\ \%\ \mathrm{Watt} \cdot \mathrm{Hours}$

Where:

CL	Confidence level: the expression of confidence in the simple random sampling method
T	Period of time over which the estimate is made
$EC_{RAN,\bar{x}}$	Sample estimate of the radio access network's energy consumption
ME	Margin of error associated with the sample estimate

4.3 Stratified Estimation Method

4.3.1 General description

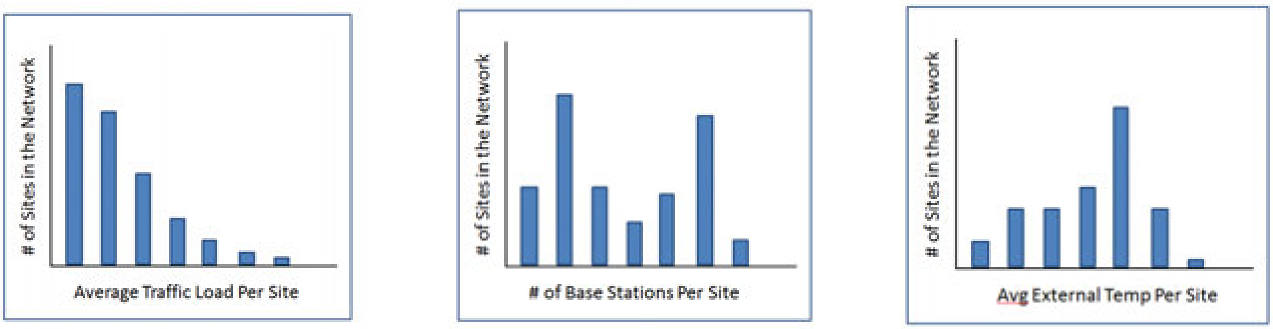
A stratified sampling method can be used to provide greater precision to the energy consumption estimation, by ensuring that all portions of the mobile network's site energy consumption distribution are adequately represented in the sample. Stratified sampling is especially effective when the network's energy consumption distribution is suspected of being non-normal (e.g. left-skewed, right-skewed, or multi-mode).

Non-normal energy consumption distributions can occur when two conditions are present in the network:

1) A site characteristic, known to have a **significant** influence on site energy consumption in the network of interest, is not uniformly present at all base station sites. Examples of such characteristics include:

   - The total number of base stations at each site.
   - The type of base station at each site (macro vs micro, as in a heterogeneous network).
   - The total number of radios at each site.
   - The average traffic load at each site.
   - The climate in which each site resides.

2) The identified site characteristic has a non-normal distribution across the network of interest, as exemplified in figure 3.



Left-Skew Distribution **Multi-Mode Distribution** **Right-Skew Distribution**

Figure 3

The following clauses provide a step-by-step description of the stratified estimation method. Each subheading pertains to an individual step in the stratified sampling procedure.

4.3.2 Define the Mobile Network Strata

The stratified method requires dividing the mobile network sites into "bins" or "strata". The strata definition is an individual choice and is not defined by the present document. However, in order to maximize the effectiveness of this sampling method, the strata definition should be based on a single site characteristic which:

- has a non-normal and non-uniform distribution across the network, **AND**
- **significantly** influences the **site's** energy consumption

Once the strata site characteristic is chosen, the range of each individual stratum need to be specified. These individual range definitions are also individual choices and are therefore not defined by the present document. Table 1 provides examples of site characteristics which could be used to define the site strata, along with some sample ranges.

Table 1: Examples of Strata Definitions for Stratified Sampling

Possible Strata Definitions	Resulting Stratum Ranges (Examples Only)
Number of base stations at the site	Stratum 1: $1 \leq \#\ \text{base stations on site} < 2$ Stratum 2: $2 \leq \#\ \text{base stations on site} < 3$ Stratum 3: $3 \leq \#\ \text{base stations on site} < 5$ Stratum 4: $5 \leq \#\ \text{base stations on site}$
Number of radios at the site	Stratum 1: $1 \leq \#\ \text{radios on site} < 4{,}5$ Stratum 2: $4{,}5 \leq \#\ \text{radios on site} < 6{,}5$ Stratum 3: $6{,}5 \leq \#\ \text{radios on site} < 8{,}5$ Stratum 4: $8{,}5 \leq \#\ \text{radios on site} < 11{,}5$ Stratum 5: $11{,}5 \leq \#\ \text{radios on site}$
Average external temperature of the site	Stratum 1: $10\ ℃ \leq \text{external site temperature} < 16\ ℃$ Stratum 2: $16\ ℃ \leq \text{external site temperature} < 22\ ℃$ Stratum 3: $22\ ℃ \leq \text{external site temperature} < 28\ ℃$ Stratum 4: $28\ ℃ \leq \text{external site temperature}$
Average RF loading of the site	Stratum 1: $0 < \text{RF loading} < 15\ \%$ Stratum 2: $15\ \% \leq \text{RF loading} < 30\ \%$ Stratum 3: $30\ \% \leq \text{RF loading} < 45\ \%$ Stratum 4: $45\ \% \leq \text{RF loading}$
Base station types	Stratum 1: Micro Base Station Sites Stratum 2: $0 \leq \#\ \text{macro base stations on site} < 2$ Stratum 3: $2 \leq \#\ \text{macro base stations on site}$

While several examples are shown, it is strongly recommended to choose only one site characteristic to define the mobile network strata. Combining several site characteristics in a single strata (e.g. heavily loaded sites with 12 or more radios, and located in warm climates) defeats the purpose of the random sample method, risks the introduction of bias into the random sample, and unnecessarily complicates the estimation procedure.

It is also recommended to choose ranges which will result in an adequate number of base stations per stratum (i.e. if the ranges are too small, a large number of stratum will result, thus diluting the number of base stations in each). It is not necessary for the individual stratum ranges to be uniformly sized, nor is there a requirement for a certain number of stratum.

4.3.3 Divide the Mobile Network into the Site Strata

Place each site of the mobile network into one (and only one) stratum.

4.3.4 Select a Confidence Level

A confidence level is to be chosen in the manner described in clause 4.2.1.

4.3.5 Specify the Sample Size "n"

The sample size (n) is chosen in the manner described in clause 4.2.2.

4.3.6 Determine each Stratum's Contribution to the Overall Sample

In the stratified estimation method, each stratum contributes one or more sites (n_h) to overall mobile network sample (n), such that:

$$n = \sum n_h$$

The mobile network sample size (n) is determined using the same method as described in clause 4.2.2.

The number of sites sampled from a particular stratum is determined by the overall size of the stratum relative to the overall size of the mobile network, such that:

$$n_h = \left(\frac{n}{N}\right) \cdot N_h$$

Where:

n_h	Sample size of the particular stratum
N_h	Total number of sites in the particular stratum

4.3.7 Select the Random Sample of Base Station Sites from Each Stratum

Using the procedure described in clause 4.2.3, randomly select the required number of base stations (n_h) from each stratum. Note that the random selection procedure is applied to each stratum individually and independently from the others.

4.3.8 Measure the Energy Consumption of each Stratum Sample

Measure the energy consumption of the base station sites selected from each stratum, as described in clause 4.2.4.

4.3.9 Estimate the Mobile Network Energy Consumption

In the stratified estimation method, the mobile network energy consumption estimate is a weighted-mean of the individual stratum energy consumptions. This is accomplished using the following procedure:

1) Calculate the site energy consumption mean $(\bar{x}_h)$ for each stratum sample:

$$\bar{x}_h = \frac{1}{n_h} \sum_{i=1}^{n_h} EC_{site\ i}$$

Where:

$\bar{x}_h$	Sample estimate of the mean site energy consumption for the stratum

2) Weight each stratum mean, based on the ratio of the stratum site population to the site population of the whole mobile network. Sum these individual weighted means to determine the site energy consumption mean $(\bar{x})$ for the entire mobile network sample:

$$\bar{x} = \sum \left(\frac{N_h}{N} \cdot \bar{x}_h\right)$$

3) Calculate the sample estimate of the energy consumption for the entire mobile network:

$$EC_{network,\bar{x}} = N \cdot \bar{x}$$

4.3.10 Calculate the Margin of Error of the Mobile Network Energy Consumption Estimate

The margin of error for the mobile network energy consumption measurement can be calculated in one of two ways.

- If any of the individual stratum have sample sizes (n_h) of less than 6, it is suggested to use the procedure described in clause 4.2.7 (i.e. calculate the standard deviation of all measured sites as a single group).
- If all of the individual stratum have sample sizes (n_h) of at least 6, then the following calculation procedure is recommended:

1) Calculate the site energy consumption standard deviation (s_h) for each stratum sample, using the following formula:

$$s_h = \sqrt{\frac{\sum_{i=0}^{n_h}(EC_{site\ i} - \bar{x}_h)^2}{n_h - 1}}$$

Where:

s_h	Site energy consumption standard deviation for specific stratum sample

2) Calculate the standard deviation (s) for the overall mobile network energy consumption sample estimate, using the following formula:

$$s = \frac{1}{N} \cdot \sqrt{\sum \left[{N_h}^2 \cdot \left(1 - \frac{n_h}{N_h}\right) \cdot \left(\frac{{s_h}^2}{n_h}\right) \right]}$$

3) Calculate the margin of error for the mobile network energy consumption estimate. This is the numerical bound placed on the difference between the sample estimate of the mobile network and its true value. The confidence in this bound is described by the confidence level chosen in clause 4.3.4.

As a numerical value, the margin of error is calculated as follows:

$$Margin\ of\ Error_{Num} = N \cdot t_{n-1} \cdot s \cdot \sqrt{\frac{N-n}{N-1}}$$

As a percentage, the margin of error equation is expressed as follows:

$$Margin\ of\ Error_{\%} = \frac{Margin\ of\ Error_{Num}}{N \cdot \bar{x}} \cdot 100$$

In the above equation, a t-score (rather than a z-score) is used since the standard deviation of the mobile network population is unknown. In addition, the $\sqrt{\frac{N-n}{N-1}}$ term is the finite population correction formula, and is included since the mobile network site population is finite and is being sampled without replacement.

4.3.11 State the Mobile Network Energy Consumption Estimate

State the mobile network energy consumption estimates as described in clause 4.2.8.

5 Future Estimations and Network Upgrades

5.1 General description

Once the mobile network energy consumption has been estimated, the energy consumption measurement equipment can either be removed from the chosen sites or left in place to allow for future estimations to be made.

If the measurement equipment is left in place, care should be taken by the operator to ensure that decisions regarding future network upgrades are not influenced by the sites with energy consumption measurement capability. Targeting the previously-measured sites with new energy saving features will introduce a statistical bias and systemic error in future energy consumption estimates, thus negating the random nature of site selection and invalidating all future results.

5.2 Estimation Method as Path to Full-Network Measurements

A mobile network operator planning to equip all mobile network sites with energy consumption measurement capability may experience rollout delays due to time or budgetary constraints. In this scenario, the operator can deploy the full-measurement capability in phases, randomly choosing sites to receive measurement equipment in each phase.

For example, for a very large mobile network, assume the operator can only deploy full-measurement capability over a 5-year period (i.e. 20 % of the sites per year). It is possible for this operator to receive benefit from this phased deployment before it is complete, by ensuring a random selection of the 20 % of sites which will receive the next phase of measurement equipment. As described in the basic estimation method (clause 4.2), the mobile network estimate, and associated margin of error, can be updated as more sites receive measurement capability. Through this random deployment of measurement equipment, the operator can avoid introducing a statistical bias in the mobile network energy consumption estimation while getting an earlier return on investment.

Annex A: Implementation examples Implementation of Estimation Method Using Statistical Sampling

A.1 General description

This clause provides an example implementation of the statistical methods of estimating mobile network energy consumption. Both statistical methods, basic and stratified, are demonstrated.

To ease the explanation of these methods, a small mobile network of just 100 sites is used for this example. The site configuration information provided with the network includes the total number of base stations at each site, the total number of radios at each site, and the average external temperature measured at the site over a 24-hour period.

Site #	Ave External Temp (°C)	# of Base Stations on Site	# of Radios on Site
Site 1	23.901	4	12
Site 2	16.492	3	4
Site 3	20.001	2	6
Site 4	26.546	3	9
Site 5	18.767	3	9
Site 6	25.768	4	12
Site 7	22.599	3	9
Site 8	12.634	4	12
Site 9	21.771	4	12
Site 10	24.687	3	9
Site 11	11.867	3	9
Site 12	19.946	3	9
Site 13	19.794	3	9
Site 14	20.201	4	12
Site 15	17.629	3	9
Site 16	15.495	3	9
Site 17	17.008	2	6
Site 18	15.427	2	6
Site 19	15.133	2	6
Site 20	14.83	4	12
Site 21	16.486	3	7
Site 22	15.286	4	12
Site 23	19.015	3	9
Site 24	16.94	1	3
Site 25	13.334	3	9
Site 26	18.006	3	9
Site 27	12.12	2	6
Site 28	21.343	6	18
Site 29	22.234	2	6
Site 30	10.859	4	12
Site 31	20.269	3	9
Site 32	12.773	2	6
Site 33	16.785	4	12
Site 34	14.49	6	21
Site 35	12.252	5	15
Site 36	13.029	3	8
Site 37	21.746	4	12
Site 38	11.917	3	9
Site 39	11.587	4	11
Site 40	19.026	3	9
Site 41	14.86	3	9
Site 42	19.378	3	9
Site 43	17.736	5	15
Site 44	12.24	5	15
Site 45	28.156	4	12
Site 46	12.022	3	9
Site 47	12.386	5	15
Site 48	17.36	2	6
Site 49	16.289	3	8
Site 50	19.659	5	15
Site 51	11.327	3	9
Site 52	13.462	6	18
Site 53	13.172	4	12
Site 54	28.038	2	6
Site 55	12.307	4	12
Site 56	10.412	3	9
Site 57	18.048	3	7
Site 58	18.018	4	12
Site 59	16.663	3	9
Site 60	11.767	3	9
Site 61	11.684	4	12
Site 62	13.794	4	10
Site 63	12.195	5	15
Site 64	29.672	4	12
Site 65	11.13	2	6
Site 66	9.872	2	5
Site 67	11.603	1	2
Site 68	11.258	3	7
Site 69	11.705	3	8
Site 70	14.626	4	10
Site 71	13.973	5	15
Site 72	18.06	3	9
Site 73	13.085	2	6
Site 74	18.69	3	9
Site 75	20.078	2	6
Site 76	13.017	1	3
Site 77	11.144	2	6
Site 78	14.434	2	6
Site 79	14.199	3	9
Site 80	10.849	4	12
Site 81	10.439	4	12
Site 82	16.166	3	9
Site 83	11.859	2	6
Site 84	21.85	3	9
Site 85	10.349	5	15
Site 86	17.015	2	6
Site 87	11.707	4	10
Site 88	12.198	3	9
Site 89	19.478	3	9
Site 90	22.627	4	12
Site 91	17.969	4	12
Site 92	16.203	6	18
Site 93	16.118	3	9
Site 94	15.182	3	9
Site 95	19.898	3	9
Site 96	25.165	4	8
Site 97	12.77	4	12
Site 98	13.335	3	9
Site 99	15.646	2	6
Site 100	21.857	4	12

Figure A.1

A.2 Basic Estimation Method

A.2.1 Select a Confidence Level

The confidence level is an individual choice not defined by the present document. Since 95 % is a common confidence level used in sampling methodology, it is therefore chosen for this example as well.

A.2.2 Specify the Sample Size "n"

It is recommended that the sample measurement consist of at least 50 of the network sites, representing at least 5 % of the network, especially if the energy consumption of the network has a "non-normal" distribution. Since the energy consumption distribution is unknown, the number of radios per site are plotted in a histogram instead (as the number of radios would be a significant influence of the overall site energy consumption).

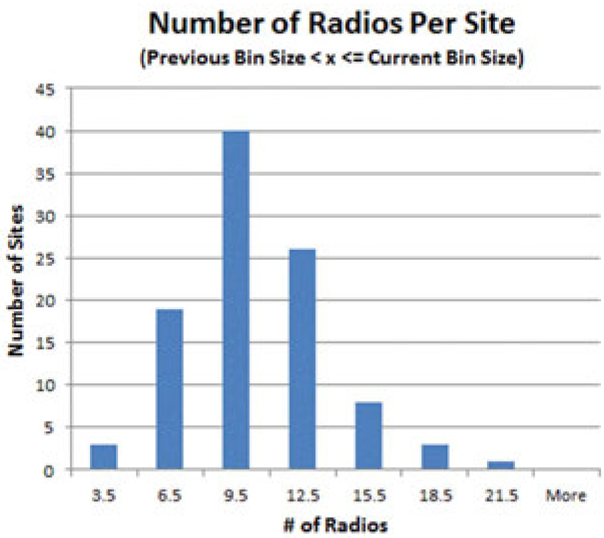


Figure A.2

The above histogram shows a left-skewed distribution of "radios per site", thus the minimum "50 site-5 percent" guideline should be applied. 50 sites of the 100-site network under investigation represents 50 % of the total, and is therefore a valid choice for the sample size.

A.2.3 Select the Random Sample of Base Station Sites

A built-in random-number function as added to each entry of the network site list. The list is then sorted from lowest-to-highest, based on the random number value. The first 50 sites in the newly-sorted list are the ones which will be measured for the sample, built into the spreadsheet, fifth column is added to the network site list.

BEFORE SORT

Site #	Ave External Temp (°C)	# of Base Stations on Site	# of Radios on Site	Rand #
Site 1	23.901	4	12	0.926639003
Site 2	16.492	3	4	0.392396688
Site 3	20.001	2	6	0.909633127
Site 4	26.546	3	9	0.509864594
Site 5	18.767	3	9	0.298939883
Site 6	25.768	4	12	0.377082479
Site 7	22.599	3	9	0.927158254
Site 8	12.634	4	12	0.484177956
Site 9	21.771	4	12	0.189682011
Site 10	24.687	3	9	0.718925391
Site 11	11.867	3	9	0.43196112
Site 12	19.946	3	9	0.212028855
Site 13	19.794	3	9	0.996214729
Site 14	20.201	4	12	0.616074228
Site 15	17.629	3	9	0.525451761
Site 16	15.495	3	9	0.768490511
Site 17	17.008	2	6	0.108752286
Site 18	15.427	2	6	0.9219085
Site 19	15.133	2	6	0.652080603
Site 20	14.83	4	12	0.24106871
Site 21	16.486	3	7	0.007858406
Site 22	15.286	4	12	0.389290199
Site 23	19.015	3	9	0.769783204
Site 24	16.94	1	3	0.856121246
Site 25	13.334	3	9	0.285360055
Site 26	18.006	3	9	0.981366184
Site 27	12.12	2	6	0.012024089
Site 28	21.343	6	18	0.560690014
Site 29	22.234	2	6	0.735293032
Site 30	10.859	4	12	0.672551132
Site 31	20.269	3	9	0.951208414
Site 32	12.773	2	6	0.73511668
Site 33	16.785	4	12	0.061656376
Site 34	14.49	6	21	0.467962325
Site 35	12.252	5	15	0.351888257
Site 36	13.029	3	8	0.915300794
Site 37	21.746	4	12	0.926403221
Site 38	11.917	3	9	0.276076998
Site 39	11.587	4	11	0.578384253
Site 40	19.026	3	9	0.404684118
Site 41	14.86	3	9	0.924327353
Site 42	19.378	3	9	0.382179678
Site 43	17.736	5	15	0.73892717
Site 44	12.24	5	15	0.728545496
Site 45	28.156	4	12	0.739715554
Site 46	12.022	3	9	0.314541834
Site 47	12.386	5	15	0.883124311
Site 48	[illegible]	[illegible]	[illegible]	0.279317658
Site 49	[illegible]	[illegible]	[illegible]	0.609864415
Site 50	[illegible]	[illegible]	[illegible]	0.74710492
Site 51	11.327	3	9	0.206207227
Site 52	13.462	6	18	0.218683482
Site 53	13.172	4	12	0.042840889
Site 54	28.038	2	6	0.442694416
Site 55	12.307	4	12	0.797649691
Site 56	10.412	3	9	0.16665262
Site 57	18.048	3	7	0.255434993
Site 58	18.018	4	12	0.484364877
Site 59	16.663	3	9	0.794989796
Site 60	11.767	3	9	0.068172921
Site 61	11.684	4	12	0.076460356
Site 62	13.794	4	10	0.34599142
Site 63	12.195	5	15	0.58043298
Site 64	29.672	4	12	0.570032554
Site 65	11.13	2	6	0.031109577
Site 66	9.872	2	5	0.710762365
Site 67	11.603	1	2	0.158719325
Site 68	11.258	3	7	0.073035969
Site 69	11.705	3	8	0.991645269
Site 70	14.626	4	10	0.797559531
Site 71	13.973	5	15	0.288782675
Site 72	18.06	3	9	0.681422003
Site 73	13.085	2	6	0.135038895
Site 74	18.69	3	9	0.042356597
Site 75	20.078	2	6	0.583171749
Site 76	13.017	1	3	0.809698876
Site 77	11.144	2	6	0.554618343
Site 78	14.434	2	6	0.906765434
Site 79	14.199	3	9	0.730941638
Site 80	10.849	4	12	0.370882883
Site 81	10.439	4	12	0.515261041
Site 82	16.166	3	9	0.009233601
Site 83	11.859	2	6	0.387059722
Site 84	21.85	3	9	0.075944451
Site 85	10.349	5	15	0.779209576
Site 86	17.015	2	6	0.392551885
Site 87	11.707	4	10	0.197873477
Site 88	12.198	3	9	0.6846965
Site 89	19.478	3	9	0.834894381
Site 90	22.627	4	12	0.804082831
Site 91	17.969	4	12	0.545430952
Site 92	16.203	6	18	0.184150913
Site 93	16.118	3	9	0.199653209
Site 94	15.182	3	9	0.529813002
Site 95	19.898	3	9	0.638183881
Site 96	25.165	4	8	0.414649482
Site 97	12.77	4	12	0.094841746
Site 98	13.335	3	9	0.349300886
Site 99	15.646	2	6	0.780448939
Site 100	21.857	4	12	0.840174074

AFTER SORT

Site #	Ave External Temp (°C)	# of Base Stations on Site	# of Radios on Site	Rand #
Site 26	18.006	3	9	0.005193361
Site 8	12.634	4	12	0.00638762
Site 7	22.599	3	9	0.026455039
Site 20	14.83	4	12	0.027143634
Site 70	14.626	4	10	0.033646149
Site 28	21.343	6	18	0.039478677
Site 9	21.771	4	12	0.051222724
Site 30	10.859	4	12	0.071365236
Site 25	13.334	3	9	0.073801706
Site 96	25.165	4	8	0.073811804
Site 38	11.917	3	9	0.076617544
Site 24	16.94	1	3	0.116427429
Site 76	13.017	1	3	0.120684238
Site 65	11.13	2	6	0.131928902
Site 84	21.85	3	9	0.136161267
Site 63	12.195	5	15	0.148315897
Site 80	10.849	4	12	0.161793201
Site 17	17.008	2	6	0.178878003
Site 67	11.603	1	2	0.18240394
Site 19	15.133	2	6	0.194461353
Site 86	17.015	2	6	0.195272875
Site 12	19.946	3	9	0.25300635
Site 50	19.659	5	15	0.256755364
Site 95	19.898	3	9	0.262255339
Site 45	28.156	4	12	0.285512266
Site 40	19.026	3	9	0.289060986
Site 23	19.015	3	9	0.298186025
Site 73	13.085	2	6	0.306143432
Site 54	28.038	2	6	0.306313989
Site 55	12.307	4	12	0.316356371
Site 48	17.36	2	6	0.322615271
Site 81	10.439	4	12	0.334876048
Site 64	29.672	4	12	0.348269603
Site 56	10.412	3	9	0.354748182
Site 74	18.69	3	9	0.365455232
Site 3	20.001	2	6	0.368454211
Site 43	17.736	5	15	0.370798534
Site 79	14.199	3	9	0.374398178
Site 5	18.767	3	9	0.381436853
Site 44	12.24	5	15	0.399319617
Site 47	12.386	5	15	0.406334214
Site 93	16.118	3	9	0.406711155
Site 60	11.767	3	9	0.409162356
Site 22	15.286	4	12	0.411566837
Site 92	16.203	6	18	0.417054188
Site 42	19.378	3	9	0.435806479
Site 18	15.427	2	6	0.453804847
Site 69	[illegible]	[illegible]	[illegible]	0.473153226
Site 29	[illegible]	[illegible]	[illegible]	0.491062377
Site 41	[illegible]	[illegible]	[illegible]	0.496158115
Site 66	9.872	2	5	0.503932408
Site 35	12.252	5	15	0.510667555
Site 21	16.486	3	7	0.521097957
Site 72	18.06	3	9	0.552751012
Site 61	11.684	4	12	0.563978614
Site 98	13.335	3	9	0.56841011
Site 46	12.022	3	9	0.574734662
Site 91	17.969	4	12	0.581672654
Site 77	11.144	2	6	0.588802238
Site 99	15.646	2	6	0.595051186
Site 89	19.478	3	9	0.615313617
Site 2	16.492	3	4	0.620656217
Site 31	20.269	3	9	0.628747755
Site 49	16.289	3	8	0.629084837
Site 39	11.587	4	11	0.631288786
Site 87	11.707	4	10	0.635286678
Site 71	13.973	5	15	0.644805296
Site 33	16.785	4	12	0.655930725
Site 15	17.629	3	9	0.659559871
Site 57	18.048	3	7	0.66318653
Site 58	18.018	4	12	0.670647604
Site 62	13.794	4	10	0.701823093
Site 4	26.546	3	9	0.702626385
Site 53	13.172	4	12	0.703716993
Site 83	11.859	2	6	0.719421436
Site 59	16.663	3	9	0.732257582
Site 36	13.029	3	8	0.742296605
Site 27	12.12	2	6	0.743012352
Site 78	14.434	2	6	0.752651922
Site 88	12.198	3	9	0.756138209
Site 1	23.901	4	12	0.757632789
Site 75	20.078	2	6	0.793318215
Site 52	13.462	6	18	0.7935808
Site 85	10.349	5	15	0.794325858
Site 37	21.746	4	12	0.806298238
Site 94	15.182	3	9	0.811571447
Site 14	20.201	4	12	0.815902575
Site 6	25.768	4	12	0.817891566
Site 100	21.857	4	12	0.846742994
Site 68	11.258	3	7	0.856506761
Site 90	22.627	4	12	0.880640396
Site 11	11.867	3	9	0.89223085
Site 82	16.166	3	9	0.897809989
Site 10	24.687	3	9	0.909303649
Site 51	11.327	3	9	0.909550948
Site 97	12.77	4	12	0.911191174
Site 16	15.495	3	9	0.933074388
Site 34	14.49	6	21	0.949263066
Site 32	12.773	2	6	0.963508263
Site 13	19.794	3	9	0.99183032

With sample size of 50, the first 50 sites in the sorted list will be directly measured

Figure A.3

A.2.4 Choose the Measurement Period

This is an individual choice, and for the purpose of this example a measurement period of 24 hours is chosen.

A.2.5 Measure the Energy Consumption of the Base Station Site Sample

For this example, the 50 sites were directly measured and yielded the following energy consumption values after the 24-hour measurement period.

24 Hr Pwr (kWh)	Site #	Avg External Temp (°C)	# of Base Stations on Site	# of Radios on Site	Rand #
59.984	Site 26	18.006	3	9	0.005193361
72.013	Site 8	12.634	4	12	0.00638762
87.079	Site 7	22.599	3	9	0.026455039
131.85	Site 20	14.83	4	12	0.027143634
68.98	Site 70	14.626	4	10	0.033646149
70.113	Site 28	21.343	6	18	0.039478677
95.864	Site 9	21.771	4	12	0.051222724
131.464	Site 30	10.859	4	12	0.071365236
112.393	Site 25	13.334	3	9	0.073801706
73.183	Site 96	25.165	4	8	0.073811804
22.293	Site 38	11.917	3	9	0.076617544
50.682	Site 24	16.94	1	3	0.116427429
44.09	Site 76	13.017	1	3	0.120684238
68.18	Site 65	11.13	2	6	0.131928902
87.174	Site 84	21.85	3	9	0.136161267
97.071	Site 63	12.195	5	15	0.148315897
180.153	Site 80	10.849	4	12	0.161793201
41.889	Site 17	17.008	2	6	0.178878003
92.282	Site 67	11.603	1	2	0.18240394
41.89	Site 19	15.133	2	6	0.194461353
80.082	Site 86	17.015	2	6	0.195272875
75.48	Site 12	19.946	3	9	0.25300635
100.135	Site 50	19.659	5	15	0.256755364
69.579	Site 95	19.898	3	9	0.262255339
168.746	Site 45	28.156	4	12	0.285512266
64.378	Site 40	19.026	3	9	0.289050986
62.2	Site 23	19.015	3	9	0.298186025
46.882	Site 73	13.085	2	6	0.306143432
124.659	Site 54	28.038	2	6	0.306313989
84.78	Site 55	12.307	4	12	0.316356371
49.587	Site 48	17.36	2	6	0.322615271
154.426	Site 81	10.439	4	12	0.334876048
187.229	Site 64	29.672	4	12	0.348269603
140.936	Site 56	10.412	3	9	0.354748182
51.783	Site 74	18.69	3	9	0.365455232
33.61	Site 3	20.001	2	6	0.368454211
97.034	Site 43	17.736	5	15	0.370798534
81.677	Site 79	14.199	3	9	0.374398178
85.169	Site 5	18.767	3	9	0.381436853
161.263	Site 44	12.24	5	15	0.399319617
90.81	Site 47	12.386	5	15	0.406334214
67.682	Site 93	16.118	3	9	0.406711155
126.054	Site 60	11.767	3	9	0.409162356
91.776	Site 22	15.286	4	12	0.411566837
125.071	Site 92	16.203	6	18	0.417054188
126.973	Site 42	19.378	3	9	0.435806479
44.284	Site 18	15.427	2	6	0.453804847
191.528	Site 69	11.705	3	8	0.473153226
91.356	Site 29	22.234	2	6	0.491062377
167.046	Site 41	14.86	3	9	0.496158115

Figure A.4

A.2.6 Estimate the Mobile Network Energy Consumption

The mobile network energy consumption sample estimate ($EC_{network,\bar{x}}$) is based on the mean energy consumption ($\bar{x}$) of the sites in the base station sample calculated as:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} EC_{site\ i}$$

$$\bar{x} = \frac{1}{50\ sites} \times 4\ 670{,}84\ kWh$$

$$\bar{x} = 93{,}42\ kWh\ per\ site$$

And the sample estimate for the mobile network energy consumption is:

$$EC_{RAN,\bar{x}} = N \cdot \bar{x}$$

$$EC_{RAN,\bar{x}} = 100\ sites \cdot 93{,}42\ kWh\ per\ site$$

$$EC_{RAN,\bar{x}} = 9\ 342\ kWh$$

A.2.7 Calculate the Margin of Error of the Mobile Network Estimate

The margin of error, as a numerical value, is calculated as follows:

$$Margin\ of\ Error_{Num} = N \cdot t_{n-1} \cdot \frac{s}{\sqrt{n}} \cdot \sqrt{\frac{N-n}{N-1}}$$

- The product of $(N \cdot \bar{x})$ was calculated in the previous step to be **9 342 kWh**.
- An online t-score calculator is used to determine the value of (t_{n-1}) to be: **2,010.** This calculation is based on the additional values of:
  - The cumulative probability (CP) associated with the 95 % confidence level chosen earlier:

$$CP = 1 - \frac{100 - CL\ \%}{200}$$

$$CP = 1 - \frac{100 - 95}{200}$$

$$CP = 0{,}975$$

  - The degrees of freedom (DoF) associated with the sample size (n):

$$DoF = (n - 1)$$

$$DoF = (50 - 1)$$

$$DoF = 49$$

- The standard deviation of the sample (s) is calculated using the built-in function of a spreadsheet. For this example, the standard deviation of the sample is: **41,77 kWh**.
- Replacing all calculated values into the margin of error formula gives:

$$Margin\ of\ Error_{Num} = N \cdot t_{n-1} \cdot \frac{s}{\sqrt{n}} \cdot \sqrt{\frac{N-n}{N-1}}$$

$$Margin\ of\ Error_{Num} = 100 \cdot 2{,}010 \cdot \frac{41{,}77}{\sqrt{50}} \cdot \sqrt{\frac{100-50}{100-1}}$$

$$Margin\ of\ Error_{Num} = 843{,}8\ kWh$$

As a percentage, the margin of error is calculated as follows:

$$Margin\ of\ Error_{\%} = \frac{Margin\ of\ Error_{Num}}{N \cdot \bar{x}} \cdot 100$$

$$Margin\ of\ Error_{\%} = \frac{843{,}8\ kWh}{9\ 342\ kWh} \cdot 100$$

$$Margin\ of\ Error_{\%} = 9{,}03\ \%$$

A.2.8 State the Mobile Network Energy Consumption Estimate

The resulting mobile network energy consumption estimate is stated as:

The 95 % confidence interval for the mobile network energy consumption,over a period of 24 hours is 9 342 ± 9,0 % kWh

A.3 Stratified Estimation Method

A.3.1 General description

This clause follows the step-by-step base estimation method described in clause 4.3.

The 100-site network presented in this annex is a good candidate for the stratified estimation method because a single site characteristic has been identified which:

- has a non-normal and non-uniform distribution across the network; **AND**
- **significantly** influences the **site's** energy consumption.

Specifically, the number of radios at a site significantly influences the site's overall energy consumption. In addition, based on configuration information provided by the operator, this site characteristic is known to have a non-normal distribution in this particular network, as shown in figure A.5.

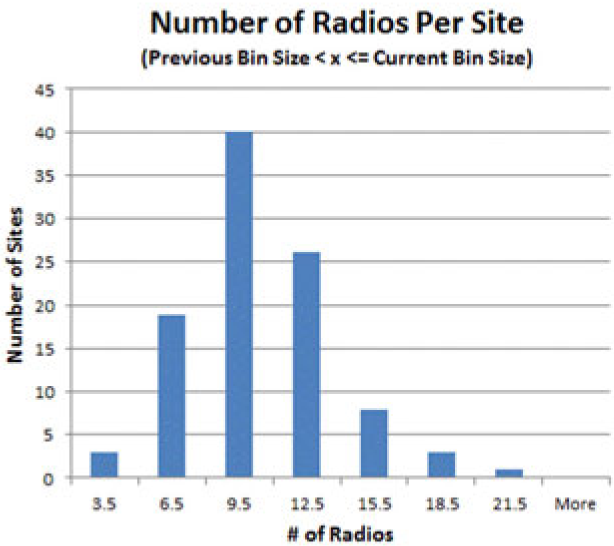


Figure A.5: Determining the Suitability of the Stratified Estimation Method

A.3.2 Define the Mobile Network Strata

As stated above, the stratums definition for this particular network will be based on the number of radios per site. The range of each stratum is chosen as follows.

Table A.1: Chosen Strata Definitions

Stratum #	Stratum Range
1	$0 \leq \text{Radios at the Site} < 3{,}5$
2	$3{,}5 \leq \text{Radios at the Site} < 6{,}5$
3	$6{,}5 \leq \text{Radios at the Site} < 9{,}5$
4	$9{,}5 \leq \text{Radios at the Site} < 12{,}5$
5	$12{,}5 \leq \text{Radios at the Site} < 15{,}5$
6	$15{,}5 \leq \text{Radios at the Site}$

A.3.3 Divide the Mobile Network into the Site Strata

The mobile network sites are divided into the site strata by sorting the site list based on the number of radios per site. Figure A.6 shows the resulting list, and the sites belonging to each stratum.

Stratum 1

Site #	Avg External Temp (°C)	# of Base Stations on Site	# of Radios on Site
Site 67	11.603		2
Site 24	16.94		3
Site 76	13.017		3

Stratum 2

Site #	Avg External Temp (°C)	# of Base Stations on Site	# of Radios on Site
Site 2	16.492	3	4
Site 66	9.872	2	5
Site 17	17.008	2	6
Site 18	15.427	2	6
Site 19	15.133	2	6
Site 27	12.12	2	6
Site 29	22.234	2	6
Site 3	20.001	2	6
Site 32	12.773		6
Site 48	17.36		6
Site 54	28.038	2	6
Site 65	11.13	2	6
Site 73	13.085	2	6
Site 75	20.078	2	6
Site 77	11.144	2	6
Site 78	14.434	2	6
Site 83	11.859	2	6
Site 86	17.015	2	6
Site 99	15.646	2	6

Stratum 3

Site #	Avg External Temp (°C)	# of Base Stations on Site	# of Radios on Site
Site 21	16.486	3	7
Site 57	18.048	3	7
Site 68	11.258	3	7
Site 36	13.029	3	8
Site 49	16.289	3	8
Site 69	11.705	3	8
Site 96	25.165	4	8
Site 10	24.687	3	9
Site 11	11.867	3	9
Site 12	19.946	3	9
Site 13	19.794	3	9
Site 15	17.629	3	9
Site 16	15.495	3	9
Site 23	19.015	3	9
Site 25	13.334	3	9
Site 26	18.006	3	9
Site 31	20.269	3	9
Site 38	11.917	3	9
Site 4	26.546	3	9
Site 40	19.026	3	9
Site 41	14.86		9
Site 42	19.378		9
Site 46	12.022	3	9
Site 5	18.767	3	9
Site 51	11.327	3	9
Site 56	10.412	3	9
Site 59	16.663	3	9
Site 60	11.767	3	9
Site 7	22.599	3	9
Site 72	18.06	3	9
Site 74	18.69	3	9
Site 79	14.199	3	9
Site 82	16.166	3	9
Site 84	21.85	3	9
Site 88	12.198	3	9
Site 89	19.478	3	9
Site 93	16.118	3	9
Site 94	15.182	3	9
Site 95	19.898	3	9
Site 98	13.335	3	9

Stratum 4

Site #	Avg External Temp (°C)	# of Base Stations on Site	# of Radios on Site
Site 62	13.794	4	10
Site 70	14.626	4	10
Site 87	11.707	4	10
Site 39	11.587	4	11
Site 1	23.901	4	12
Site 100	21.857	4	12
Site 14	20.201	4	12
Site 20	14.83	4	12
Site 22	15.286	4	12
Site 30	10.859	4	12
Site 33	16.785	4	12
Site 37	21.746		12
Site 45	28.156		12
Site 53	13.172	4	12
Site 55	12.307	4	12
Site 58	18.018	4	12
Site 6	25.768	4	12
Site 61	11.684	4	12
Site 64	29.672	4	12
Site 8	12.634	4	12
Site 80	10.849	4	12
Site 81	10.439	4	12
Site 9	21.771	4	12
Site 90	22.627	4	12
Site 91	17.969	4	12
Site 97	12.77	4	12

Stratum 5

Site #	Avg External Temp (°C)	# of Base Stations on Site	# of Radios on Site
Site 35	12.252	5	15
Site 43	17.736	5	15
Site 44	12.24	5	15
Site 47	12.386		15
Site 50	19.659		15
Site 63	12.195	5	15
Site 71	13.973	5	15
Site 85	10.349	5	15

Stratum 6

Site #	Avg External Temp (°C)	# of Base Stations on Site	# of Radios on Site
Site 28	21.343	6	18
Site 52	13.462		18
Site 92	16.203		18
Site 34	14.49	6	21

Figure A.6: Sites Placed in the Individual Stratum Definitions

A.3.4 Select a Confidence Level

The confidence level is an individual choice not defined by the present document. Since 95 % is a common confidence level used in sampling methodology, it is therefore chosen for this example as well.

A.3.5 Specify the Sample Size "n"

It is recommended that the sample measurement consist of at least 50 of the network sites, representing at least 5 % of the network, since the energy consumption of the network is suspected of having a non-normal distribution, as discussed in the introduction of this clause. 50 sites of the 100-site network under investigation represents 50 % of the total, and is therefore a valid choice for the sample size.

A.3.6 Determine each Stratum's Contribution to the Overall Sample

This step determines how many sites from each stratum (n_h) will contribute to the overall 50-site sample (n), such that:

$$n = \sum n_h$$

$$n_h = \frac{n \cdot N_h}{N}$$

Table A.2: Calculation of Each Stratum's Contribution to the Overall Sample

Stratum # (h)	Stratum Range	# of Sites in the Stratum (N_h)	Stratum Sites Contributing to the Sample $n_h = \frac{n \cdot N_h}{N}$	Adjusted Stratum Contributions $n = \sum n_h = 50$
1	$0 \leq \text{Radios at the Site} < 3{,}5$	3	$n_1 = \frac{n \cdot N_1}{N} = \frac{50 \cdot 3}{100} = 1{,}5$	1,5 adjusted to 2
2	$3{,}5 \leq \text{Radios at the Site} < 6{,}5$	19	$n_2 = \frac{n \cdot N_2}{N} = \frac{50 \cdot 19}{100} = 9{,}5$	9,5 adjusted to 9
3	$6{,}5 \leq \text{Radios at the Site} < 9{,}5$	40	$n_3 = \frac{n \cdot N_3}{N} = \frac{50 \cdot 40}{100} = 20$	20 (unchanged)
4	$9{,}5 \leq \text{Radios at the Site} < 12{,}5$	26	$n_4 = \frac{n \cdot N_4}{N} = \frac{50 \cdot 26}{100} = 13$	13 (unchanged)
5	$12{,}5 \leq \text{Radios at the Site} < 15{,}5$	8	$n_5 = \frac{n \cdot N_5}{N} = \frac{50 \cdot 8}{100} = 4$	4 (unchanged)
6	$15{,}5 \leq \text{Radios at the Site}$	4	$n_6 = \frac{n \cdot N_6}{N} = \frac{50 \cdot 4}{100} = 2$	2 (unchanged)

A.3.7 Select the Random Sample of Base Station Sites from Each Stratum

The sites within each stratum are then randomly sorted, separately from the other strata. The first (n_h) sites from each stratum in the resulting list are then measured. Figure A.7 shows the resulting list.

Site #	Avg External Temp (°C)	# of Base Stations on Site	# of Radios on Site	Rand #
Site 24	16.94	1	3	0.287565022
Site 67	11.603	1	2	0.542138672
Site 76	13.017	1	3	0.938054659
Site 17	17.008	2	6	0.072373621
Site 27	12.12	2	6	0.224269644
Site 3	[illegible]	[illegible]	6	0.229038463
Site 54	[illegible]	[illegible]	6	0.254084912
Site 48	[illegible]	[illegible]	6	0.25926663
Site 99	15.646	2	6	0.35517183
Site 32	12.773	2	6	0.364556283
Site 78	14.434	2	6	0.400111878
Site 86	17.015	2	6	0.420902745
Site 73	13.085	2	6	0.442320926
Site 75	20.078	2	6	0.535997197
Site 66	9.872	2	5	0.589399829
Site 77	11.144	2	6	0.613163411
Site 2	16.492	3	4	0.694244072
Site 65	11.13	2	6	0.755617446
Site 19	15.133	2	6	0.7608036
Site 29	22.234	2	6	0.889967456
Site 83	11.859	2	6	0.962780136
Site 18	15.427	2	6	0.995300221
Site 57	18.048	3	7	0.001081578
Site 89	19.478	3	9	0.027600266
Site 12	19.946	3	9	0.068300644
Site 74	18.69	3	9	0.073042434
Site 25	13.334	3	9	0.09319145
Site 4	26.546	3	9	0.129661833
Site 84	21.85	3	9	0.141352173
Site 26	18.006	3	9	0.167841019
Site 82	[illegible]	[illegible]	9	0.168663705
Site 56	[illegible]	[illegible]	9	0.171743947
Site 59	16.663	3	9	0.252720797
Site 46	12.022	3	9	0.294317775
Site 42	19.378	3	9	0.323668716
Site 72	18.06	3	9	0.380869761
Site 60	11.767	3	9	0.382329183
Site 36	13.029	3	8	0.383186453
Site 31	20.269	3	9	0.397168015
Site 49	16.289	3	8	0.41084486
Site 51	11.327	3	9	0.417552165
Site 96	25.165	4	8	0.47595332
Site 93	16.118	3	9	0.499115915
Site 94	15.182	3	9	0.541061569
Site 41	14.86	3	9	0.551021186
Site 15	17.629	3	9	0.55502852
Site 40	19.026	3	9	0.572694785
Site 68	11.258	3	7	0.586954712
Site 11	11.867	3	9	0.598471018
Site 21	16.486	3	7	0.611582765
Site 7	22.599	3	9	0.626263519
Site 38	11.917	3	9	0.653694485
Site 13	19.794	3	9	0.675971702
Site 88	12.198	3	9	0.789128798
Site 16	15.495	[illegible]	[illegible]	[illegible]98001164
Site 5	18.767	[illegible]	[illegible]	[illegible]41562041
Site 79	14.199	[illegible]	[illegible]	[illegible]70568757
Site 10	24.687	3	9	0.88673382
Site 23	19.015	3	9	0.909534971
Site 95	19.898	3	9	0.919489872
Site 69	11.705	3	8	0.971902788
Site 98	13.335	3	9	0.987366589

Site #	Avg External Temp (°C)	# of Base Stations on Site	# of Radios on Site	Rand #
Site 20	14.83	4	12	0.007842339
Site 61	11.684	4	12	0.091612935
Site 87	11.707	4	10	0.26985469
Site 81	10.439	4	12	0.276096034
Site 45	28.156	4	12	0.295432491
Site 64	[illegible]	[illegible]	12	0.340371159
Site 62	[illegible]	[illegible]	10	0.351096982
Site 90	22.627	4	12	0.386490068
Site 39	11.587	4	11	0.388078433
Site 30	10.859	4	12	0.388805981
Site 6	25.768	4	12	0.401133104
Site 33	16.785	4	12	0.502202896
Site 22	15.286	4	12	0.503921876
Site 91	17.969	4	12	0.505365954
Site 100	21.857	4	12	0.532758455
Site 14	20.201	4	12	0.57100531
Site 8	12.634	4	12	0.591624141
Site 97	12.77	4	12	0.605388475
Site 37	21.746	4	12	0.612951514
Site 70	14.626	4	10	0.670450541
Site 9	21.771	4	12	0.689548761
Site 58	18.018	4	12	0.793133376
Site 53	13.172	4	12	0.794376698
Site 55	12.307	4	12	0.835404337
Site 1	23.901	4	12	0.866330658
Site 80	10.849	4	12	0.944906576
Site 35	12.252	5	15	0.075466133
Site 43	[illegible]	[illegible]	15	0.263020382
Site 71	[illegible]	[illegible]	15	0.414866915
Site 63	12.195	5	15	0.505665701
Site 44	12.24	5	15	0.559758971
Site 50	19.659	5	15	0.571335679
Site 85	10.349	5	15	0.71659948
Site 47	12.386	5	15	0.962182511
Site 52	13.462	6	18	0.029400323
Site 34	14.49	6	21	0.434576765
Site 92	16.203	6	18	0.513706966
Site 28	21.343	6	18	0.682990844

Stratum 1: ($n_1 = 2$)

Stratum 2: ($n_2 = 9$)

Stratum 3: ($n_3 = 20$)

Stratum 4: ($n_4 = 13$)

Stratum 5: ($n_5 = 4$)

Stratum 6: ($n_6 = 2$)

Figure A.7: Sites Chosen From Each Stratum for the Overall Sample

A.3.8 Measure the Energy Consumption of each Stratum Sample

The base stations selected from each stratum are then directly measured. The results of these measurements are shown in figure A.8.

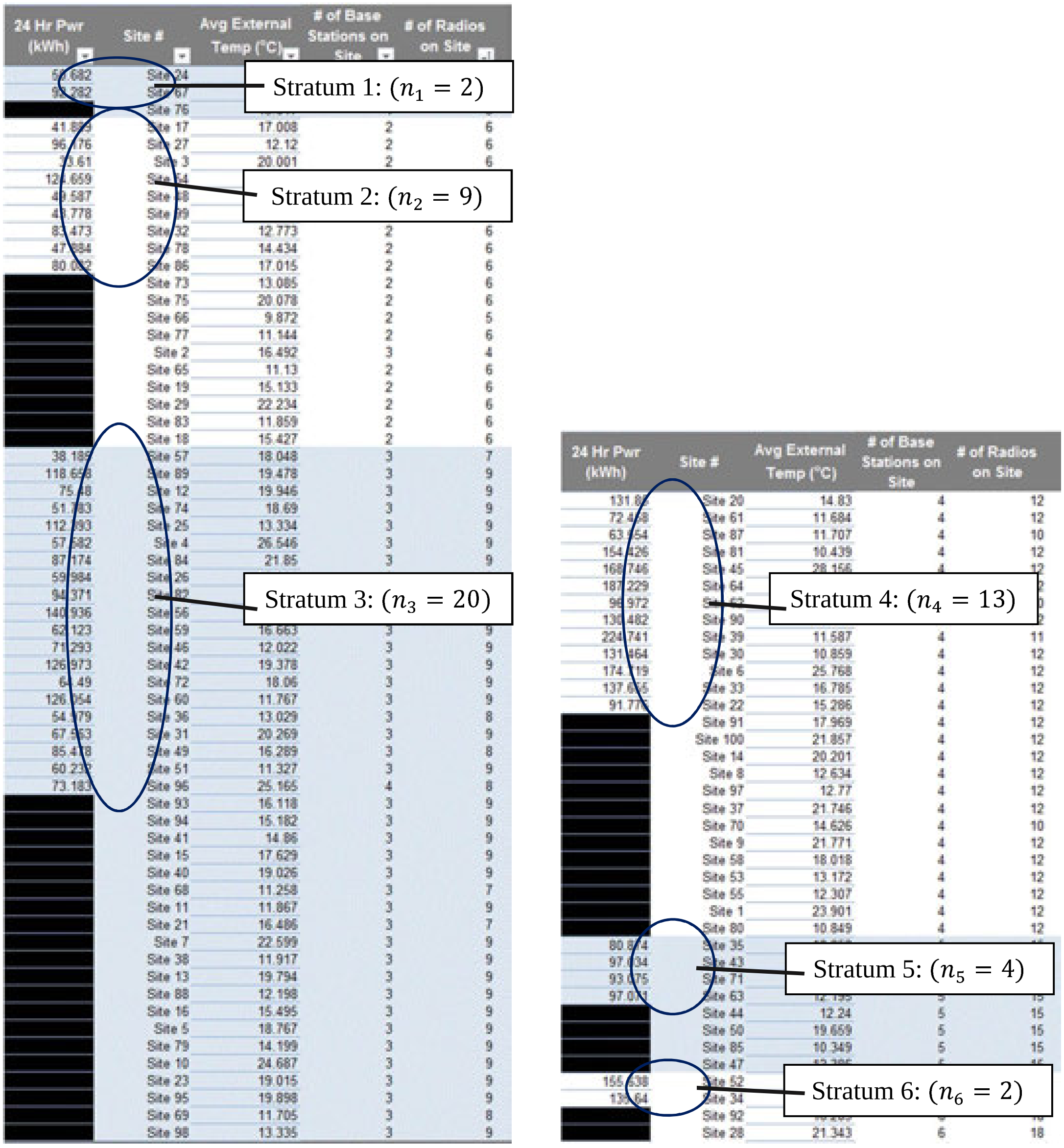


Figure A.8: Site Measurements Required from Each Stratum for the Overall Sample

A.3.9 Estimate the Mobile Network Energy Consumption

The energy consumption estimate for the mobile network requires two calculations:

- Each stratum's mean energy consumption (of the sites which were measured), using:

$$\bar{x}_h = \frac{1}{n_h}\sum_{i=1}^{n_h} EC_{site\ i}$$

- A weighted sum of each stratum's mean:

$$\bar{x} = \sum\left(\frac{N_h}{N}\cdot\bar{x}_h\right)$$

- An extrapolation of the site estimate to the entire mobile network:

$$EC_{RAN,\bar{x}} = N\cdot\bar{x}$$

Table A.3 summarizes the calculation of the mobile network energy consumption estimate.

Table A.3: Example Calculation of the Mobile Network Energy Consumption Estimate From Stratum Measurements

Stratum Info			Stratum Energy Consumption Mean	Weighted Stratum Energy Consumption Mean
Stratum Number (h)	Stratum Sample Size (n_h)	Stratum Population Size (N_h)	$\bar{x}_h = \frac{1}{n_h}\sum_{i=1}^{n_h} EC_{site\ i}$	$\bar{x}_{h,weight} = \frac{N_h}{N} \cdot \bar{x}_h$
1	2	3	$\bar{x}_1 = \frac{1}{2}(142{,}96) = 71{,}48$	$n_1 = \frac{3}{100}(71{,}48) = 2{,}14$
2	9	19	$\bar{x}_2 = \frac{1}{9}(601{,}14) = 66{,}79$	$n_2 = \frac{19}{100}(66{,}79) = 12{,}69$
3	20	40	$\bar{x}_3 = \frac{1}{20}(1\ 628{,}91) = 81{,}45$	$n_3 = \frac{40}{100}(81{,}45) = 32{,}58$
4	13	26	$\bar{x}_4 = \frac{1}{13}(1\ 766{,}07) = 135{,}85$	$n_4 = \frac{26}{100}(135{,}85) = 35{,}32$
5	4	8	$\bar{x}_5 = \frac{1}{4}(368{,}05) = 92{,}01$	$n_5 = \frac{8}{100}(92{,}01) = 7{,}36$
6	2	4	$\bar{x}_6 = \frac{1}{2}(291{,}28) = 145{,}64$	$n_6 = \frac{4}{100}(145{,}64) = 5{,}83$
			Intermediate Calculation $\bar{x} = \sum\left(\frac{N_h}{N} \cdot \bar{x}_h\right)$	$\bar{x} = \sum\left(\frac{N_h}{N} \cdot \bar{x}_h\right) = 95{,}92\ kWh$
			Mobile Network Energy Consumption Estimate $EC_{network,\bar{x}} = N \cdot \bar{x}$	$EC_{network,\bar{x}} = N \cdot \bar{x}$ $EC_{network,\bar{x}} = 100 \cdot (95{,}92\ kWh)$ $EC_{network,\bar{x}} = 9\ 592\ kWh$

A.3.10 Calculate the Margin of Error of the Mobile Network Energy Consumption Estimate

Method 1: If some stratum have sample sizes (n_h) of less than 6

Since there are individual stratum which have sample sizes (n_h) of less than 6, the standard deviation of the measured sites should be calculated as if the sites had been randomly selected from the mobile network as a whole, rather than from individual stratums. From the individual site measurements across all stratum, a spreadsheet's standard deviation function is used to determine that:

$$s = 42{,}85\ kWh$$

Then the margin of error is calculated as:

$$Margin\ of\ Error_{Num} = N \cdot t_{n-1} \cdot \frac{s}{\sqrt{n}} \cdot \sqrt{\frac{N-n}{N-1}}$$

$$Margin\ of\ Error_{Num} = 100 \cdot (2{,}010) \cdot \frac{42{,}85}{\sqrt{50}} \cdot \sqrt{\frac{100-50}{100-1}}$$

$$Margin\ of\ Error_{Num} = 865{,}62\ kWh$$

As a percentage, the margin of error is calculated as follows:

$$Margin\ of\ Error_{\%} = \frac{Margin\ of\ Error_{Num}}{N \cdot \bar{x}} \cdot 100$$

$$Margin\ of\ Error_{\%} = \frac{865{,}62\ kWh}{9\ 592\ kWh} \cdot 100$$

$$Margin\ of\ Error_{\%} = 9{,}02\ \%$$

It is interesting to note that when the stratum sample sizes are very small, and Method 1 is used as a consequence, the margin of error value may not improve very much over the basic estimation method.

Method 2: If all stratum have sample sizes (n_h) of 6 or more

Purely as a demonstration however, the standard deviation of the measured sites, calculated on a per stratum basis and then combined, is shown below. In other words, if all of the individual stratum had sample sizes (n_h) of at least 6, then the following calculation procedure would be used:

1) Calculate the site energy consumption standard deviation (s_h) for each stratum sample, using the following formula or a spreadsheet's built-in formula for the standard deviation of a sample:

$$s_h = \sqrt{\frac{\sum_{i=0}^{n_h}(EC_{site\ i} - \bar{x}_h)^2}{n_h - 1}}$$

2) Calculate the standard deviation (s) for the overall mobile network energy consumption sample estimate:

$$s = \frac{1}{N} \cdot \sqrt{\sum \left[{N_h}^2 \cdot \left(1 - \frac{n_h}{N_h}\right) \cdot \left(\frac{{s_h}^2}{n_h}\right) \right]}$$

Table A.4 summarizes the application of the above equations.

Table A.4: Example Calculation of the Mobile Network Energy Consumption Standard Deviation From Stratum Measurements

Stratum Info			Standard Deviation of Stratum Sample $s_h = \sqrt{\frac{\sum_{i=0}^{n_h}(EC_{site\ i} - \bar{x}_h)^2}{n_h - 1}}$	Intermediate Calculation ${N_h}^2 \cdot \left(1 - \frac{n_h}{N_h}\right) \cdot \left(\frac{{s_h}^2}{n_h}\right)$
Stratum Number (h)	Stratum Sample Size (n_h)	Stratum Population Size (N_h)		
1	2	3	$s_1 = 29{,}42$	$3^2 \cdot \left(1 - \frac{2}{3}\right) \cdot \left(\frac{29{,}42^2}{2}\right) = 1\,298{,}3$
2	9	19	$s_2 = 30{,}76$	$19^2 \cdot \left(1 - \frac{9}{19}\right) \cdot \left(\frac{30{,}76^2}{9}\right) = 117{,}1$
3	20	40	$s_3 = 29{,}16$	$40^2 \cdot \left(1 - \frac{20}{40}\right) \cdot \left(\frac{29{,}16^2}{20}\right) = 34\,012{,}2$
4	13	26	$s_4 = 46{,}77$	$26^2 \cdot \left(1 - \frac{13}{26}\right) \cdot \left(\frac{46{,}77^2}{13}\right) = 56\,873{,}3$
5	4	8	$s_5 = 7{,}66$	$8^2 \cdot \left(1 - \frac{4}{8}\right) \cdot \left(\frac{7{,}66^2}{4}\right) = 469{,}4$
6	2	4	$s_6 = 14{,}14$	$4^2 \cdot \left(1 - \frac{2}{4}\right) \cdot \left(\frac{14{,}14^2}{2}\right) = 799{,}8$
		Mobile Network Energy Consumption Standard Deviation $s = \frac{1}{N} \cdot \sqrt{\sum \left[{N_h}^2 \cdot \left(1 - \frac{n_h}{N_h}\right) \cdot \left(\frac{{s_h}^2}{n_h}\right) \right]}$		$s = \frac{1}{100} \cdot \sqrt{9\,3570{,}1} = \mathbf{3{,}1}$

3) Calculate the margin of error for the mobile network energy consumption estimate:

$$Margin\ of\ Error_{Num} = N \cdot t_{n-1} \cdot s \cdot \sqrt{\frac{N-n}{N-1}}$$

$$Margin\ of\ Error_{Num} = 100 \cdot (2{,}010) \cdot (3{,}1) \cdot \sqrt{\frac{100-50}{100-1}}$$

$$Margin\ of\ Error_{Num} = 442{,}8\ kWh$$

As a percentage, the margin of error equation is expressed as follows:

$$Margin\ of\ Error_{\%} = \frac{Margin\ of\ Error_{Num}}{N \cdot \bar{x}} \cdot 100$$

$$Margin\ of\ Error_{\%} = \frac{442{,}8\ kWh}{100 \cdot (95{,}92)} \cdot 100$$

$$Margin\ of\ Error_{\%} = 4{,}6\ \%$$

A.3.11 State the Mobile Network Energy Consumption Estimate

The resulting mobile network energy consumption estimate is stated as:

The 95 % confidence interval for the mobile network energy consumption,
over a period of 24 hours is $9\ 592 \pm 4{,}6\ \%$ kWh

Annex B:
Bibliography

- ETSI TR 103 117: "Environmental Engineering (EE); Principles for Mobile Network level energy efficiency".
- ETSI ES 202 706: "Environmental Engineering (EE); Measurement method for power consumption and energy efficiency of wireless access network equipment".
- ETSI TS 125 104: "Universal Mobile Telecommunications System (UMTS); Base Station (BS) radio transmission and reception (FDD) (3GPP TS 25.104)".
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- ETSI TS 132 425 (V12.0.0): "LTE; Telecommunication management; Performance Management (PM); Performance measurements Evolved Universal Terrestrial Radio Access Network (E-UTRAN) (3GPP TS 32.425 version 12.0.0 Release 12)".
- ETSI TS 132 412 (V11.1.0): "Digital cellular telecommunications system (Phase 2+); Universal Mobile Telecommunications System (UMTS); LTE; Telecommunication management; Performance Management (PM) Integration Reference Point (IRP): Information Service (IS) (3GPP TS 32.412 version 11.1.0 Release 11)".
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- ETSI TS 136 314: "LTE; Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Layer 2 - Measurements (3GPP TS 36.314)".
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- ETSI TS 132 405 (V11.1.1): "Digital cellular telecommunications system (Phase 2+); Universal Mobile Telecommunications System (UMTS); LTE; Telecommunication management; Performance Management (PM); Performance measurements; Universal Terrestrial Radio Access Network (UTRAN) (3GPP TS 32.405 version 11.1.1 Release 11)".
- ETSI ES 202 336-12: "Environmental Engineering (EE); Monitoring and control interface for infrastructure equipment (power, cooling and building environment systems used in telecommunication networks); Part 12: ICT equipment power, energy and environmental parameters monitoring information model".
- ISO/IEC 17025 (2005): "General requirements for the competence of testing and calibration laboratories".

History

Document history		
V1.1.1	April 2018	Publication