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Foreword

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

Introduction

The need for a fair comparison of RBSs from different manufactures, in terms of energy efficiency (EE), has been an important issue for both operators and vendors. ETSI started a work item in 2008 to standardize a measurement method to measure the energy efficiency of Macro RBSs. The first standard (TS 102 706 [i.2]) was published in August 2009 and provided a static EE measurement method for RBSs. Two years later ETSI published the second version of the standard (TS 102 706 [i.1]) which includes both static and dynamic EE measurement methods.

The results from the energy efficiency measurements are intended for use by operators for comparison purposes, enabling the selection of the most energy efficient RBS for installation in a live network. In order to have reliable measurement results and valid RBS comparisons, the RBS should be tested under conditions which resemble a typical usage environment.

The present document has highlighted a number of practical issues in the existing released standard and also a number of items that can evolve the existing approved TS 102 706 [i.1] standard. The result of the present document will be used as an input when specifying the scope of a possible new work item for Release 3 of TS 102 706 [i.1].

1 Scope

The present document discusses the current energy efficiency measurement method specified in TS 102 706 [i.1]. Practical results obtained by following the specified measurement method as well as the potential need for clarification of the method are presented. Furthermore, the present document identifies the benefits of methodology enhancements such as fast fading, interference/noise, energy efficiency measurements related to temperature variances both inside and outside the RBS, energy efficiency measurements related to signal quality, multi carrier test setup for WCDMA and dynamic measurement methods for GSM.

The present document may be used as the basis of a possible revision of the TS 102 706 [i.1].

2 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 reference document (including any amendments) applies.

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2.1 Normative references

The following referenced documents are necessary for the application of the present document.

Not applicable.

2.2 Informative references

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] ETSI TS 102 706 (V1.2.1): "Environmental Engineering (EE); Measurement Method for Energy Efficiency of Wireless Access Network Equipment".

[i.2] ETSI TS 102 706 (V1.1.1): "Environmental Engineering (EE) Energy Efficiency of Wireless Access Network Equipment".

3 Abbreviations

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

ACLR	Adjacent Channel Leakage power Ratio
ATIS	Alliance for Telecommunications Industry Solutions
BTS	Base Transceiver Station
CCN	Cellular Coaxial Network
DL	Down Link
DPD	Digital Pre-Distortion
EVM	Error Vector Magnitude
GMSK	Gaussian Minimum Shift Keying
GSM	Global System for Mobile Communications
IM	Inter Modulation
IPERF	Internet Performance Working Group
LTE-A	Long Term Evolution - Advanced

MOCN	Multi Operator Core Network
OFDMA	Orthogonal Frequency-Division Multiple Access
PA	Power Amplifier
PLMNID	Public Land Mobile Network ID
QAM	Quadrature Amplitude Modulation
RAN	Radio Access Network
RBS	Radio Base Station
RF	Radio Frequency
RX	Receiver
SVN	Switched Virtual Network
TX	Transceiver
UDP	User Data Protocol
UE	User Equipment
UL	Up Link
UMTS	Universal Mobile Telecommunication System
USB	Universal Serial Bus
UTRAN	UMTS Terrestrial Radio Access Network
WCDMA	Wideband Code Division Multiple Access

4 Practical experiences with TS 102 706 V1.2.1

4.1 Introduction

The static energy efficiency measurement method specified in TS 102 706 [i.1] measures the energy consumption of an RBS under static load conditions, and is defined for GSM, WCDMA, LTE and WiMax radio access technologies. With the static measurement method, no traffic model is defined. Instead the RBS is loaded with different loads corresponding to low, medium and busy hour traffic. The input power and transmitted RF power of the RBS are measured at each of these load conditions.

The dynamic energy efficiency measurement method specified in the second release of TS 102 706 [i.1] measures the energy consumption of an RBS while delivering generated data traffic (based on the UDP protocol) to UEs distributed in the cell. Four UE groups are defined with only one UE present in each group. The UE groups are distributed in the cell such that Group 1 is closest to the antenna and Group 4 is furthest away (i.e. closest to the cell border).

The simplest way to measure energy consumption of an RBS (and generate an energy efficiency metric) is to follow the static method. However the static method is insufficient since there is no RBS in a live network that operates in static mode. For the measurement results to provide true value the RBS should be tested in an environment that more closely resembles realistic use conditions. The dynamic measurement method in TS 102 706 [i.1] is the first step to this approach.

4.2 General consideration

After comments received from different group members in the working group we have concluded that the standard needs to be enhanced by adding more description and rephrasing some text. Some additional explanations may also be needed.

The current TS 102 706 [i.1] is focusing on Macro base station. There might be a need for further specification to address other types of base stations.

Energy efficiency measurement methods for both WCDMA and LTE have been tested by two vendors. The results of these tests are provided in the following clauses.

Efficiency tests carried out according to the static measurement method in TS 102 706 [i.1] were relatively simple and left little room for different interpretations. However, RF power efficiency is not a suitable efficiency measurement for radio base stations. The relevant measure is the provided service (delivered bits within the RBS's range) and not the RBS's transmitted RF power. A more detailed description why RF power alone is insufficient can be found in annex A.

4.3 Practical test results from a WCDMA RBS product

4.3.1 Measurement test setup

A number of energy efficiency measurement tests were performed by vendor 1 to assess the effectiveness of the energy efficiency method when applied to a WCDMA RBS product. The test setup was based on the TS 102 706 [i.1].

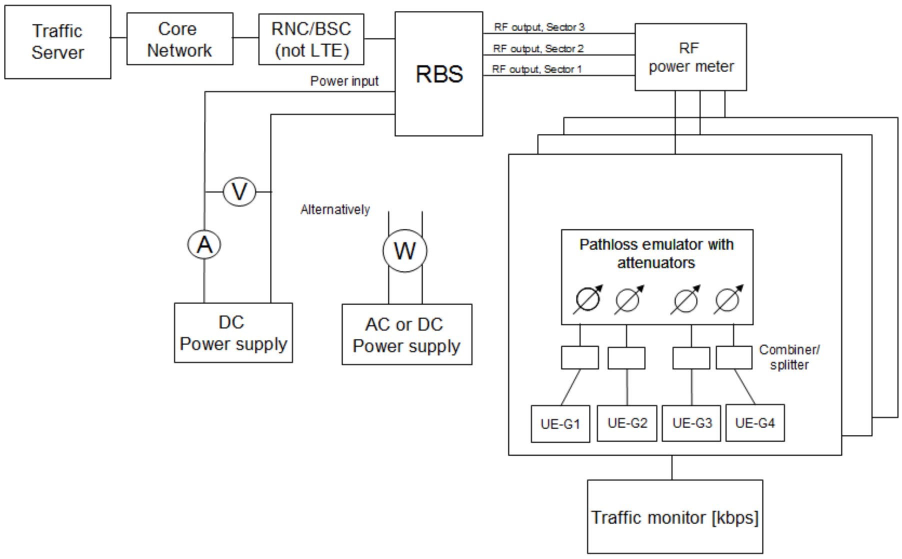

Figure 1: Test setup for dynamic measurement with UEs (example for three sectors)

The distribution of the UEs was based on the received signal strength according to TS 102 706 [i.1] (shown in Table 1).

Table 1: Received signal strength at different UE groups for WCDMA

	Received signal strength at UE group 1 [dBm]	Received signal strength at UE group 2 [dBm]	Received signal strength at UE group 3 [dBm]	Received signal strength at UE group 4 [dBm]
WCDMA/HSPA	-70	-85	-100	-115

Table 2: Transferring and silence times for each UE group for different activity levels

	Low traffic (10 %)		Medium traffic (40 %)		Busy hour traffic (70 %)	
	T_t[s]	T_s[s]	T_t[s]	T_s[s]	T_t[s]	T_s[s]
UE group 1	1	39	4	36	7	33
UE group 2	2	38	8	32	14	26
UE group 3	3	37	12	28	21	19
UE group 4	4	36	16	24	28	12

While performing the tests, it was noted that it was difficult to get stable results with UE group 4 (i.e. at the cell edge) as UE4 was frequently dropped from the cell. To get stable results, UE4 was removed from subsequent tests.

The generated data traffic was therefore based on the traffic model specified in TS 102 706 [i.1], with UE4 removed. Some modifications regarding the transferring and silence time for the UE groups were done as follows: the transferring and silence times setting for UE group 1, UE group 2 and UE group 3 of Table 3 is equal to the transferring and silence time for UE group 2, UE group 3 and UE group 4 of Table 2. The resulting transferring times and silence times applied to the remaining three UE groups are shown at Table 3.

Table 3: The modified transferring and silence time for each UE group for different activity levels set at test for WCDMA

	Low traffic (10 %)		Medium traffic (40 %)		Busy hour traffic (70 %)	
	T_t [s]	T_s [s]	T_t [s]	T_s [s]	T_t [s]	T_s [s]
UE group 1	2	38	8	32	14	26
UE group 2	3	37	12	28	21	19
UE group 3	4	36	16	24	28	12

Table 4: Test reference parameters

Parameter	Value	Unit
1. RBS configuration		
1.1 Number of sectors	1	
1.2 Number of Carriers per sector	1	
1.3 TX diversity	1 (TX path)	
1.4 RX diversity	1 (RX path)	
1.5 Type of RF signal combining		
1.6 Remote Radio Head (Yes/No)	Yes	
2. Frequency		
2.1 Downlink band	2 160	MHz
2.2 Uplink band	1 970	MHz
2.3 Channel bandwidth	5	MHz
3. Environment		
3.1 Temperature	26	°C
3.2 Type of air filter	N/A	

4.3.2 Measurement test results and analysis

For each activity level, the test time is n × 40 s where n = 10 (test time 400 s). Results for a single cycle (i.e. 40 seconds) are shown in Figures 2, 3 and 4 for traffic loads of 10 %, 40 % and 70 % respectively. The sampling time is 0,5 s. The red curve represents UE1 which is closest to the antenna, green to UE2, blue to UE3. UE4 is not active during the test.

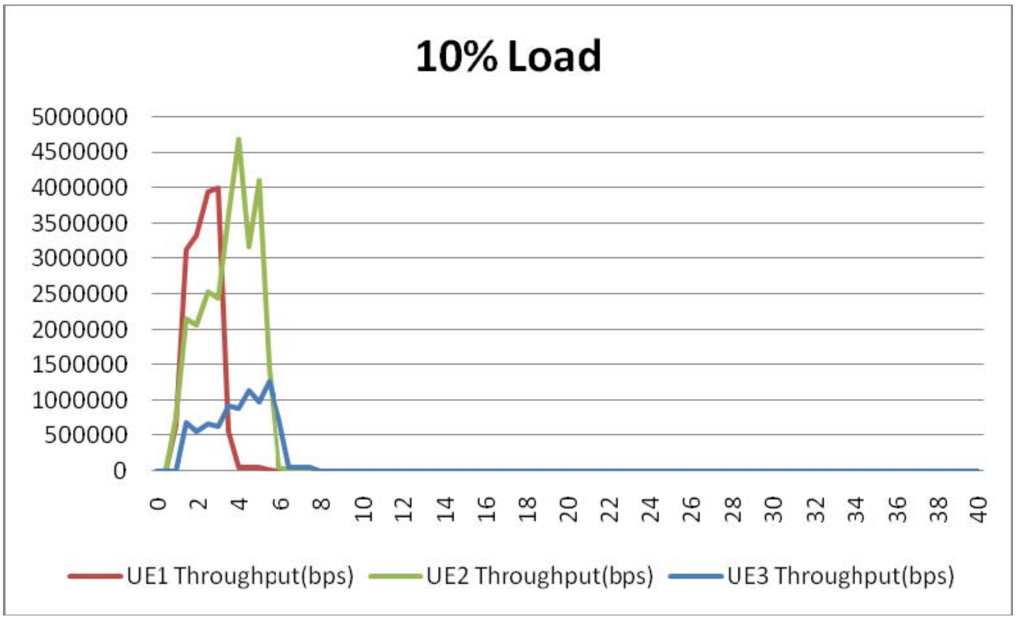

Figure 2: Test results under 10 % load for WCDMA (Y axis: Throughput (bps) vs. X axis: Time (sec))

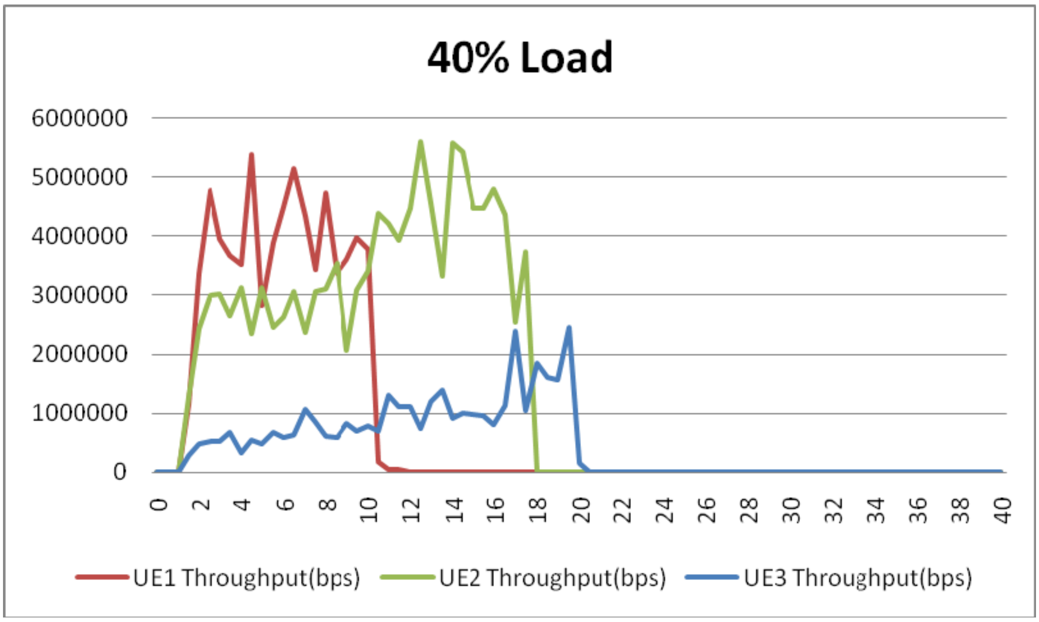

Figure 3: Test results under 40 % load for WCDMA (Y axis: Throughput (bps) vs. X axis: Time (sec))

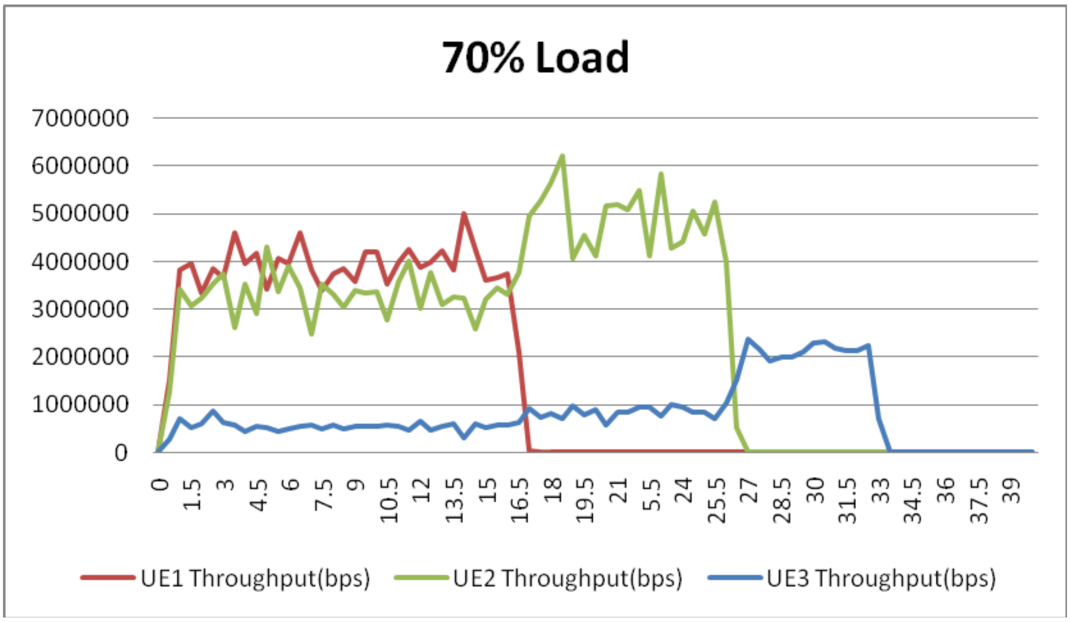

Figure 4: Test results under 70 % load for WCDMA (Y axis: Throughput (bps) vs. X axis: Time(sec))

Measured data from the WCDMA tests is given in Table 5. The energy efficiency is calculated for the different load levels according to the specified formula $EE = \frac{AverageThroughput}{Power} (\frac{kbps}{W})$

where $\text{Average Throughput} = \frac{\text{Gathered data rate kbit for all Three UEs}}{\text{Whole Test Period}}$

Table 5: Measured data for WCDMA

Load Level	Average Throughput(kbps) = (Gathered data rate (kbits) for all three UEs)/400 s	Power Consumption(W)	EE(kbps/W)
10 %	707,72	210,00	3,37
40 %	2 924,73	223,50	13,09
70 %	4 749,62	237,00	20,04

4.3.3 Observation

- With the attenuation value -115 dBm (required for UE4 with WCDMA), the test could not be finished as UE4 always dropped from the cell.
- Without UE4, all other three UEs work well with the test.
- Even without fading and interference, some variation at received data rate has been observed for each UE possibly due to the interference at environment (subject to further investigation).
- The loads of different UEs were not equal as originally intended (subject to further investigation).

4.4 Practical test results from an LTE RBS product

4.4.1 Basic measurement test setup

UEs were distributed according to TS 102 706 [i.1], shown in Table 6.

Table 6: Received signal strength at different UE groups for LTE

	Received signal strength at UE group 1 [dBm]	Received signal strength at UE group 2 [dBm]	Received signal strength at UE group 3 [dBm]	Received signal strength at UE group 4 [dBm]
LTE	-70	-85	-100	-115

The generated data traffic is based on the traffic model specified in TS 102 706 [i.1] shown below.

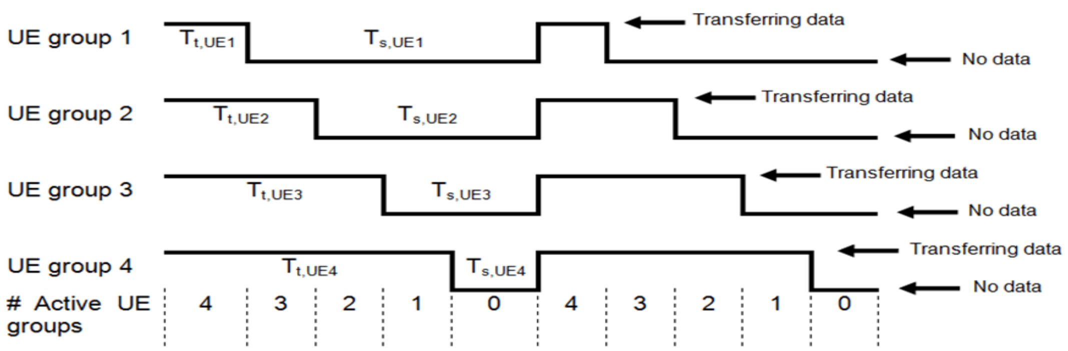

Figure 4a

The load is based on TS 102 706 [i.1] i.e. 10 %, 40 % and 70 % activity loads with transferring time and silence time stated in Table 7.

Table 7: Transferring and silence time for each UE group for different activity levels

	Low traffic (10 %)		Medium traffic (40 %)		Busy hour traffic (70 %)	
	T_t[s]	T_s[s]	T_t[s]	T_s[s]	T_t[s]	T_s[s]
UE group 1	1	39	4	36	7	33
UE group 2	2	38	8	32	14	26
UE group 3	3	37	12	28	21	19
UE group 4	4	36	16	24	28	12

4.4.2 Measurement test results from vendor 1

Table 8: Test reference parameters

Parameter	Value	Unit
1. RBS configuration		
1.1 Number of sectors	1	
1.2 Number of Carriers per sector	1	
1.3 TX diversity	2 (TX path)	
1.4 RX diversity	2 (RX path)	
1.5 Type of RF signal combining	N/A	
1.6 Remote Radio Head (Yes/No)	No	
2. Frequency		
2.1 Downlink band	1 842,5	MHz
2.2 Uplink band	1 747,5	MHz
2.3 Chanel bandwidth	20	MHz
3. Environment		
3.1 Temperature	26	°C
3.2 Type of air filter	N/A	

For each activity level, the test time is n × 40 s where n = 10 s (test period 400 s). The results from a single test cycle (i.e. 40 seconds) is shown in Figure 6 and Figure 7 for traffic loads of 10 %, 40 % and 70 % respectively. The sampling time is 0,5 s. The blue curve represents UE1 which is closest to the antenna, green represents UE2, purple represents UE3 and red represents UE4.

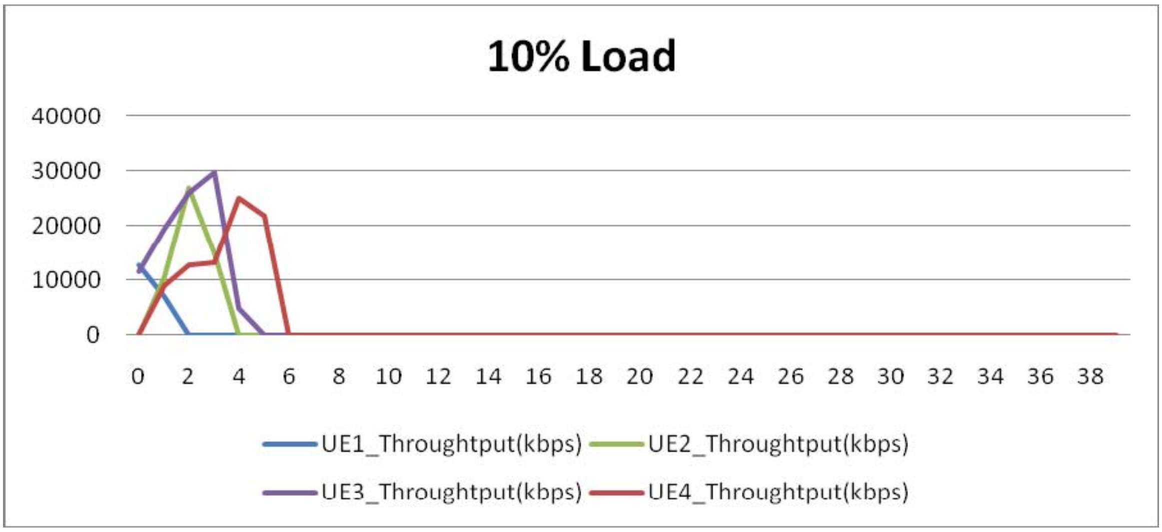

Figure 5: Test results under 10 % load for LTE (Y axis:Throughput (kbps) vs X axis:Time(sec))

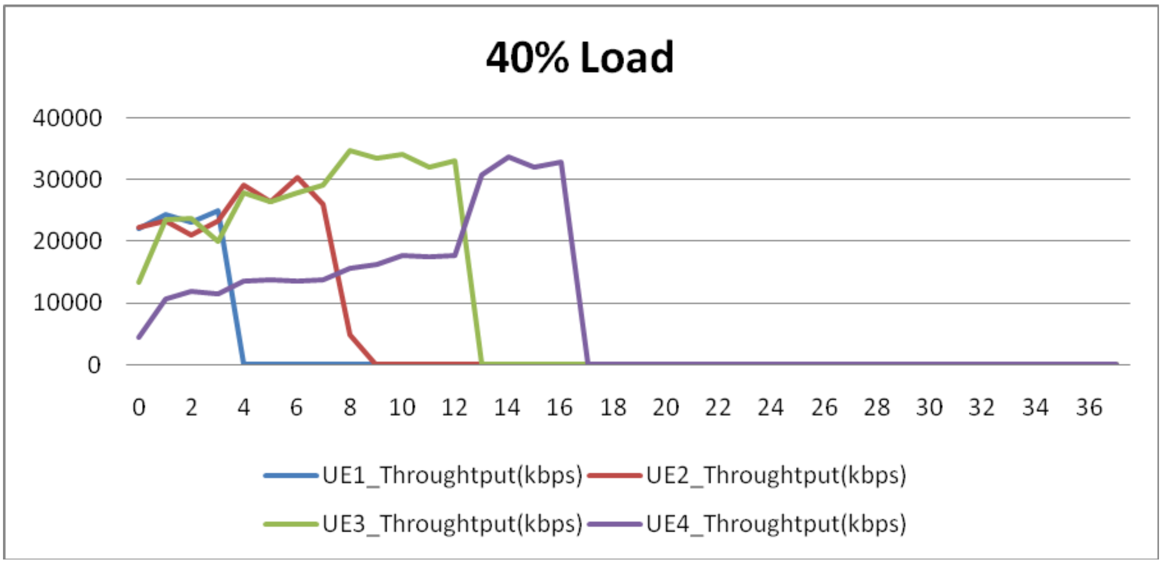

Figure 6: Test results under 40 % load for LTE (Y axis:Throughput (kbps) vs X axis:Time (sec))

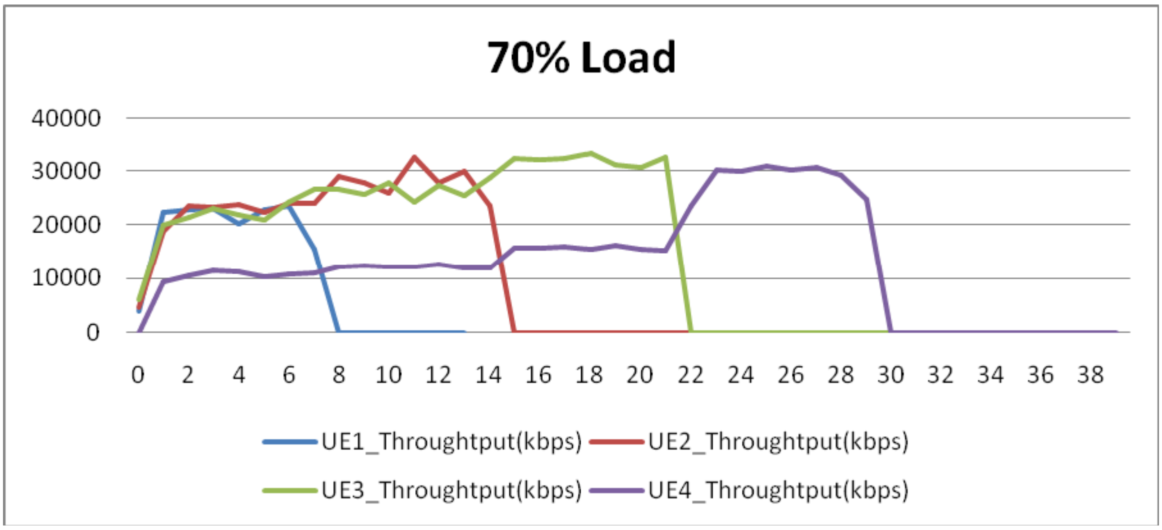

Figure 7: Test results under 70 % load for LTE (Y axis: Throughput(kbps) vs. X axis: Time (sec))

Measured data for LTE is given in Table 9. The energy efficiency is calculated for the different load levels according to the specified formula $EE = \frac{AverageThr\ oughput}{Power} (\frac{kbps}{W})$

where $\text{Average Throughput} = \frac{\text{Gathered data rate kbit for all four UEs}}{\text{Whole Test Period}}$

Table 9: Measured data for LTE

Load Level	Average Throughput(kbps)	Power Consumption(W)	EE(kbps/W)
10 %	6 671,31	270,00	24,71
40 %	23 302,88	312,00	74,69
70 %	39 410,71	350,00	112,60

4.4.3 Conclusion

The conclusion from the test is as follows:

- The test set up for LTE did not present the UE sensitivity problem observed with WCDMA test.
- For the entire test, it is observed that the receiving data time is larger than the transmission time set by Iperf. This is because of the data stored at buffer of RBS which continue transmitting to UE over the air even the Iperf stop transmitting data to UE.

5 Impact of physical parameters not covered in TS 102 706 V1.2.1

5.1 Radio channel challenges

Different conditions present in real radio environments are shown in Figure 8. These conditions impact the radio channel to a large extent and it is important they are included in an energy efficiency test environment. TS 102 706 [i.1] standard for radio equipment does not account for the impact of radio aspects (such as fading, interference and noise). The current test setup connects the radio base station to the UEs with coaxial cables, an "ideal" medium that is very different compared to transmission over the air.

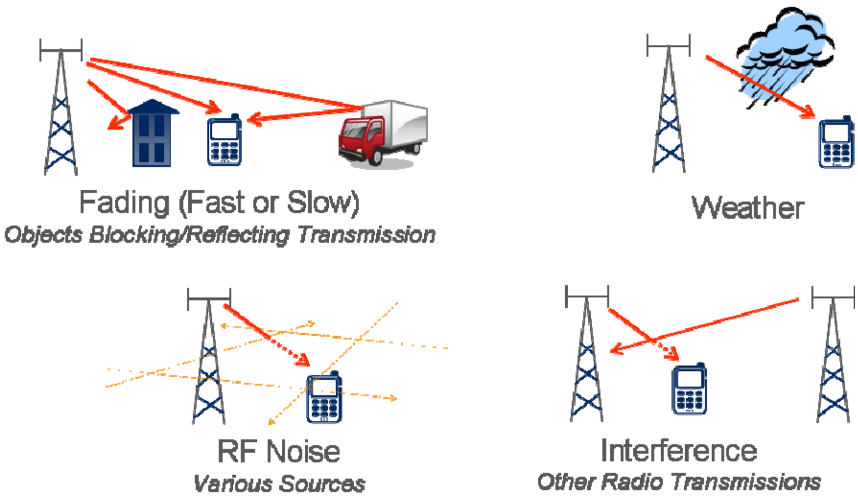

Figure 8: Radio channel challenges

It is well known by RBS design teams that the power amplifier (PA) in the RBS needs to be designed with high linearity in order to provide a high quality signal to the receiver in the UE. If the UE receiver has difficulties identifying the signal, the modulation may have to be reduced or retransmissions may be required because of higher bit errors. In either case, radio aspects impacting the radio channel between the RBS and the UE will result in lower throughput.

Since energy efficiency is most often defined as transferred bits per Watt of power consumed by the RBS, the EE measurement is very reliant on a radio link capable of high throughput and thus a realistic radio environment.

PA stages designed with better linearity are less power efficient. Thus, a PA exceeding the 3GPP linearity requirement (indicated by the ACLR value) is less power efficient than PA stages just fulfilling the 3GPP requirement of -45 dBc.

Further information about signal quality aspects is provided in annex A.

5.2 Fading

Fading is an important factor to consider when designing wireless communication systems. A number of factors could contribute to the total fading experienced by a radio channel, such as *slow fading* and *fast fading*. These fading types result from different types of transmitter and receiver movements and give rise to different fading behaviours of the channel.

5.2.1 Slow fading

Large-scale fading is caused by shadowing effects. If the propagation environment contains large prominent objects (e.g. hills, buildings or large vehicles) the received signal power can vary substantially causing relatively slow variations around the mean power (as determined by the path loss). This assumes that the receiver and/or the shadowing objects are moving relative to the transmitter (if the receiver and all shadowing object are still, the channel has no time dependent variations). This type of fading is referred to as shadow fading since it is easy to imagine the receiver as being shadowed by the object.

The effects of shadow fading and path loss are shown in Figure 9 (i.e. received signal power vs. logarithm of the distance between the transmitter and the receiver.)

The shadow fading model may be an irrelevant factor when it comes to energy efficiency measurements. However what may be important in energy efficiency measurements is the fast variations in the receive signal strength which often occur. The RBS which is fast enough to regulate its output power based on the variations of signal strength is the RBS which is most energy efficient. Shadow fading will not produce this effect and therefore could be neglected in the test setup for energy efficiency measurement method.

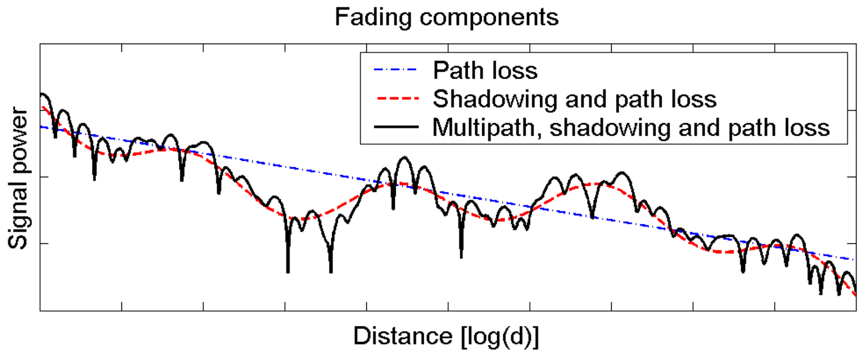

Figure 9: Fading components

5.2.2 Fast fading

Small variations in the receiver position give rise to more rapid fading behaviour. Due to the multipath propagation and fast variations in signal strength, a wireless communication system suffers from distortions referred to as fast fading. The received signal consists of a superposition of multiple signal components, all with different properties dependent on their respective propagation path. Movement through an environment with many obstacles (i.e. urban areas) leads to rapid changes in propagation paths between transmitter and receiver, even if the movement itself is small.

The distance between the transmitter and the receiver does not determine the amount of fast fading a receiver may be subjected to, nor does the distance between the transmitter and the receiver have to change in order for the effects of fast fading to be realized. A circular movement around an RBS or a stationary position in a changing environment both result in a constant distance to the transmitter yet the receiver would still experience fast fading. For these reasons the received channel power in Figure 10 is plotted against time rather than distance.

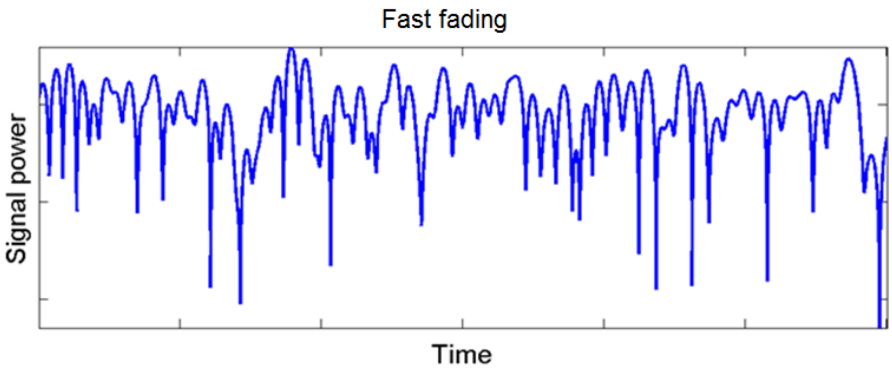

Figure 10: Fast fading channel

5.2.3 Dynamic energy efficiency measurement test (WCDMA) which includes a fading generator

A number of energy efficiency measurement tests have been performed by vendor 2 to show how RBS energy efficiency can be affected by introducing fading into the dynamic EE measurement test setup. The test procedure was based on the methodology described in TS 102 706 [i.1].

Test environment description:

- WCDMA RAN I&V test lab on vendor 2 premises.
- A macro RBS tested with only one cell activated.
- Four UEs used during the dynamic EE measurement.
- Attenuator used to emulate UE different positions.
- Power measurement tool used to measure the energy consumption.
- Auto Test instrument used in the lab to generate data traffic.
- Fading introduced into the channel using a fading generator.
- Note that distribution of the UEs according to the TS 102 706 [i.1] failed because of very low received signal strength at the cell border (i.e. -115 dBm). Therefore the UEs were distributed according to Table 10 in order to keep sufficient distance between the UE groups which was the choice of vendor 2.

Table 10: Modified received signal strength for WCDMA UEs at different positions in the cell

	Received signal strength at UE group 1 [dBm]	Received signal strength at UE group 2 [dBm]	Received signal strength at UE group 3 [dBm]	Received signal strength at UE group 4 [dBm]
WCDMA/HSPA	-56	-72	-88	-102

The generated data traffic is based on the traffic model specified in TS 102 706 [i.1] and only for 40 % and 70 % activity loads.

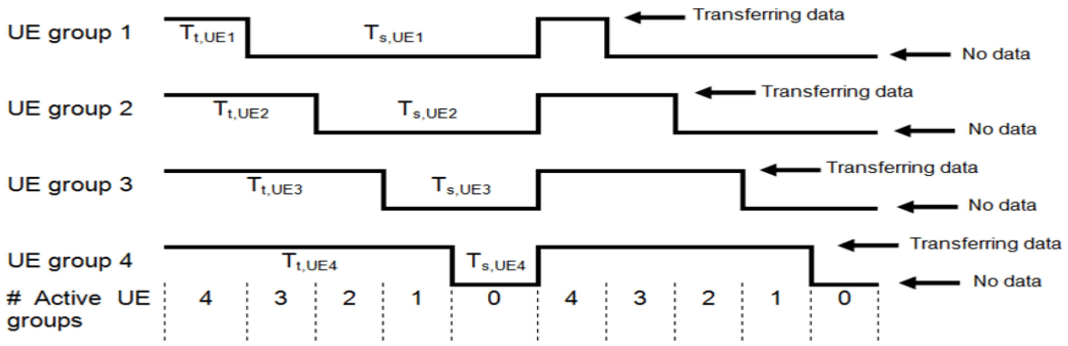

Figure 10a

Table 10a

	Low traffic (10%)		Medium traffic (40%)		Busy hour traffic (70%)	
	T_t [s]	T_s [s]	T_t [s]	T_s [s]	T_t [s]	T_s [s]
UE group 1	1	39	4	36	7	33
UE group 2	2	38	8	32	14	26
UE group 3	3	37	12	28	21	19
UE group 4	4	36	16	24	28	12

Results

Two different energy efficiency measurement tests were performed. One without any fading present in the radio channel and one with fading present in the channel.

Figure 11 shows results from the RBS loaded to 70 %, specifically the measured throughput to each UE placed in the cell according to Table 10, without any fading present in the channel (i.e. the radio channel is transmitted via a coaxial cable and is pure). The red plot in Figure 11 is related to UE1 (Group 1) which is closest to the antenna, green to UE2, blue to UE3 and finally pink to UE4 which is furthest away from the antenna.

The average received data rate (as received by the UEs) was 4 546 kbps and the average RBS energy consumption was 461,7 W. Taking these two values into the EE formula (i.e. $EE = \frac{kbps}{W}$) the resulting energy efficiency was 9,85 [kbps/W].

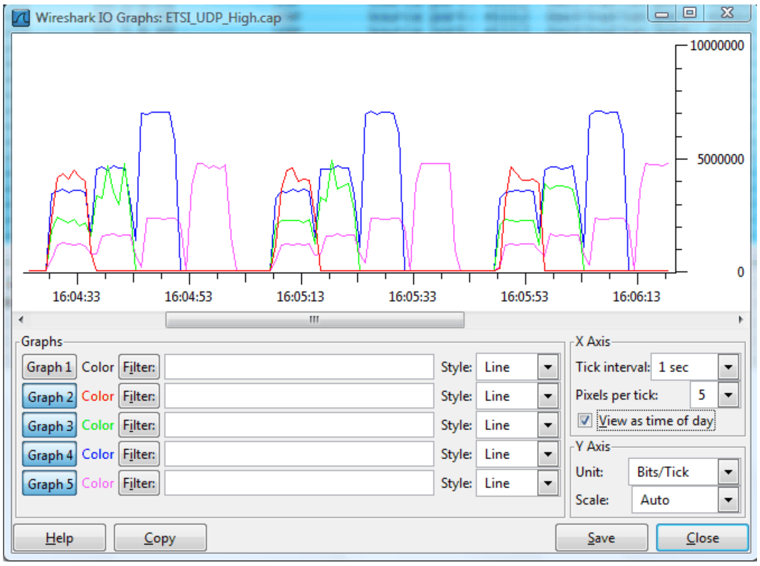

Figure 11: Measured received data rate at 4 UEs placed in different positions in the cell without any fading present in the channel

Figure 12 shows results from the RBS loaded to 70 %, specifically the measured throughput to each UE with the same configuration as above but in this case the radio channel includes fading.

The average received data rate (as received by all UEs) was 2 083 kbps, and average RBS energy consumption was 464,5 W. Taking these two values into the EE formula (i.e. $EE = \frac{kbps}{W}$) the resulting energy efficiency was 4,49 [kbps/W].

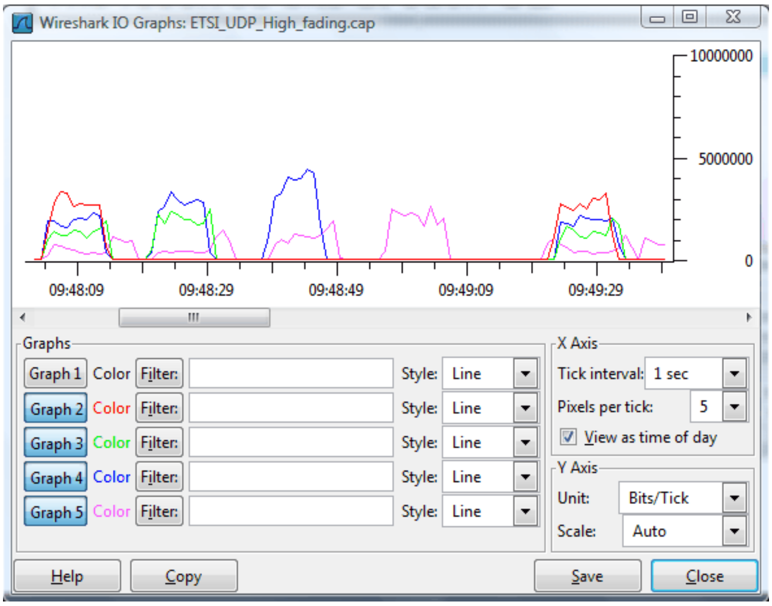

Figure 12: Measured received data rate at 4 UEs placed in different positions in the cell with fading present in the channel

5.2.4 Dynamic energy efficiency measurement test (LTE), which includes a fading generator

A number of energy efficiency measurement tests in LTE RAN have been done by Vendor 2 in order to verify the existing standard and also to show how fading affects the radio channel, the throughput performance and thus the energy efficiency. The tests with and without fading were based on TS 102 706 [i.1].

5.2.4.1 Test environment description

- Samsung 4G USB modems, model GT-B3730, Band7 (4 UEs)
- Network Protocol Analyser
  - Version 1.6.7 (SVN Rev 41973 from /trunk-1.6) on UE side
  - Version 1.3.0-SVN-29077 (SVN Rev 331) on Network side
- IPERF
- Fading Generator
- Fading Model
  - ITU Pedestrian A Speed 3 km/h (PA3)
- POWER Measurement Equipment

The UEs were distributed according to TS 102 706 [i.1] (stated in Table 11 and shown in Figure 13).

Table 11: Received signal strength for LTE UEs at different positions in the cell

	Received signal strength at UE group 1 [dBm]	Received signal strength at UE group 2 [dBm]	Received signal strength at UE group 3 [dBm]	Received signal strength at UE group 4 [dBm]
LTE	-70	-85	-100	-115

Figure 13 shows the graphical view of UEs location in the cell by CCN (Cellular CoaxialNetwork).

NOTE 1: CCN is a proprietary tool to place the UEs in the cell with different attenuations and it is fully computerized.

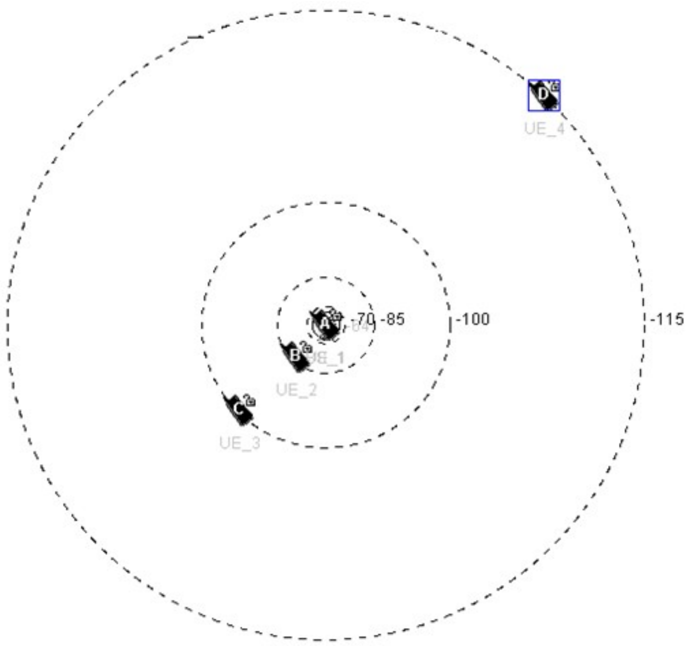

Figure 13: UEs distribution done by CCN

The generated data traffic is based on the traffic model specified in TS 102 706 [i.1].

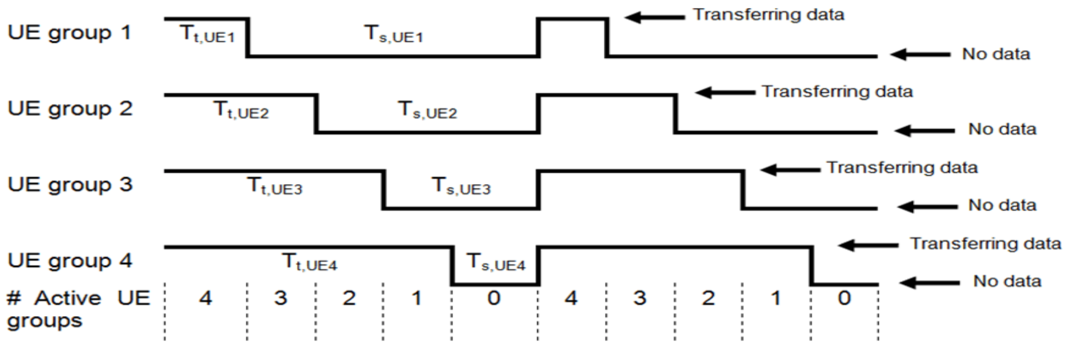

Figure 13

The load is also based on TS 102 706 [i.1] i.e. 10 %, 40 % and 70 % activity loads as stated table 11a.

Table 11a

	Low traffic (10%)		Medium traffic (40%)		Busy hour traffic (70%)	
	T_t [s]	T_s [s]	T_t [s]	T_s [s]	T_t [s]	T_s [s]
UE group 1	1	39	4	36	7	33
UE group 2	2	38	8	32	14	26
UE group 3	3	37	12	28	21	19
UE group 4	4	36	16	24	28	12

Measurement results and Observations

Two different configurations have been tested during the test period, one without and one with fading present in the radio channel.

No strange behaviour was observed during the tests especially when placing UE4 at the cell border according to Table 11. It has to be mentioned that in the EE measurement test with WCDMA, UE4 was unstable at the position stated by the existing standard i.e. a place with received signal strength -115 dBm. UE4 was therefore moved a bit closer to the cell centre (i.e. the received signal strength was -102 dBm, see clause 5.2.3.

Figure 14 to Figure 19 show the received data versus the time for each UE during one duty cycle i.e. 40 seconds. In the figures the plot with black colour is from UE1, red from UE2, green from UE3 and blue from UE4. UE1 is the closest UE to the antenna and UE4 is the closest to the cell border. This distribution has been shown in Figure 13 and is based on Table 11.

Figure 14 to Figure 16 show the received data when the channel is pure and no fading is added. The test confirmed the stability in the test setup and the test procedure of the specified measurement test in TS 102 706 [i.1].

Figure 17 to Figure 19 show the received data throughput when the channel includes fading.

The received average throughput, the average measured power consumption and the energy efficiency indicator are given in Table 12 when no fading is added and Table 13 when fading is added. The results indicate the effects that fading has on the resulting throughput and hence the energy efficiency value.

The EE indicator calculation is based on the definition in TS 102 706 [i.1]:

$$EE = \frac{\overline{Throughput}}{\overline{P}}\left[\frac{Mbps}{W}\right].$$

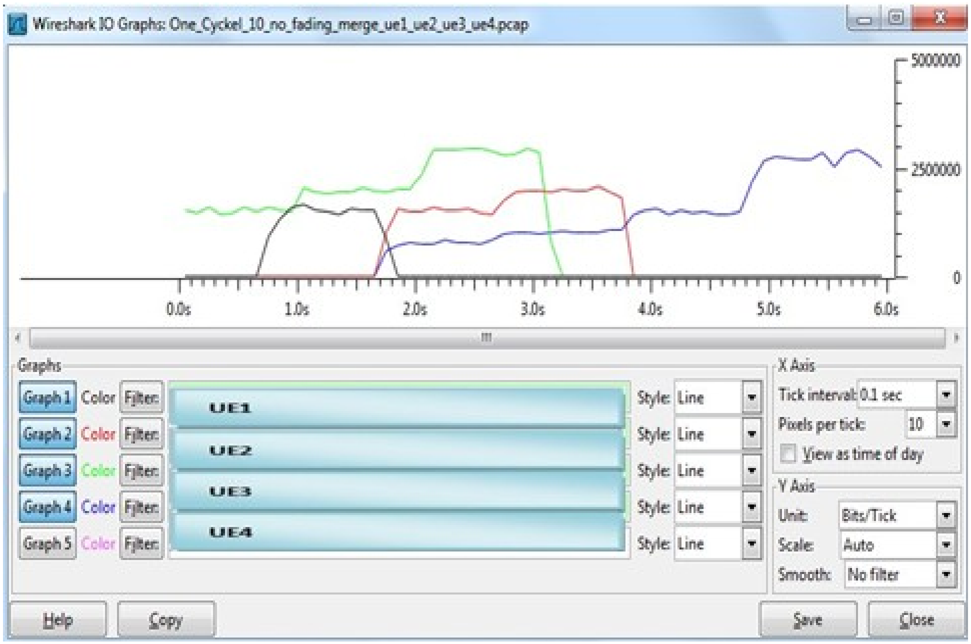

Figure 14: Received data at UEs with activity load 10 % and no fading

NOTE 2: The tick interval in Figure 14 is 0,1 second while for Figures 15 to 19 the tick interval is 1 second.

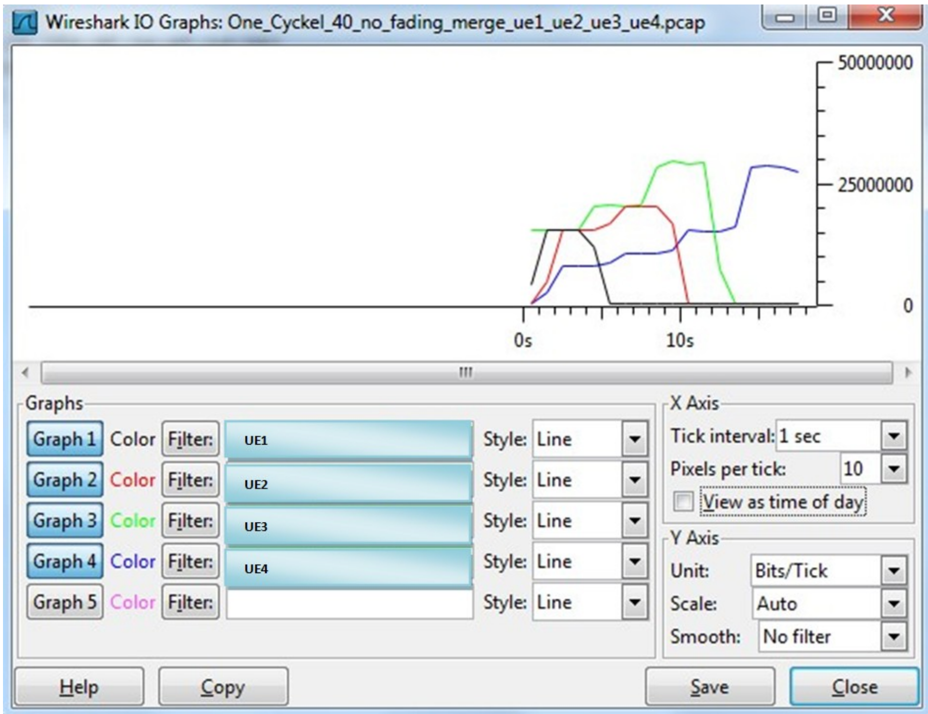

Figure 15: Received data at UEs with activity load 40 % and no fading

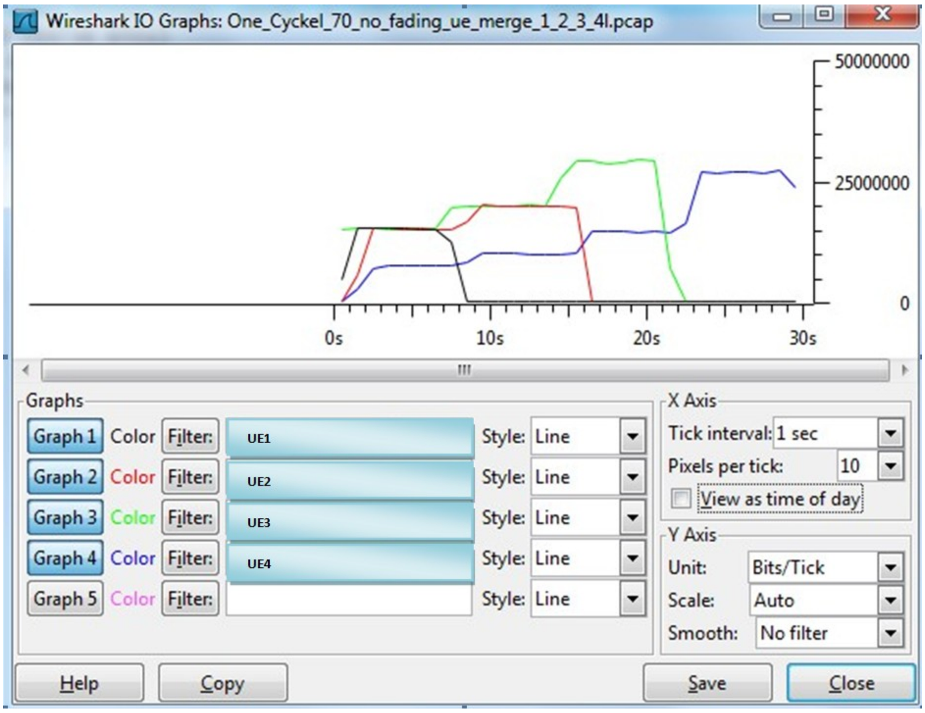

Figure 16: Received data at UEs with activity load 70 % and no fading

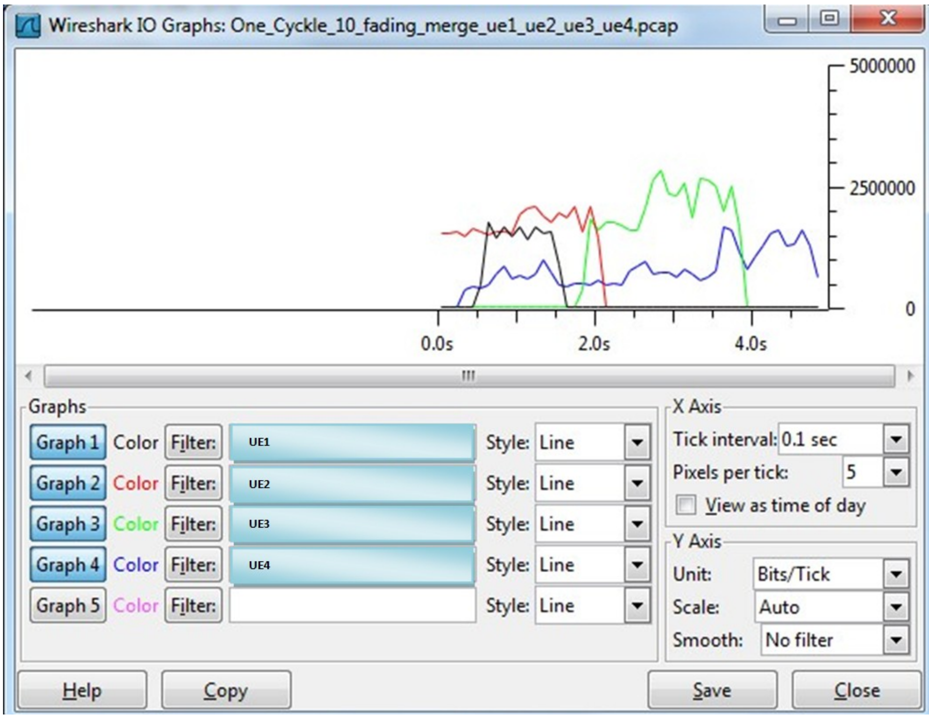

Figure 17: Received data at UEs with activity load 10 % and fading

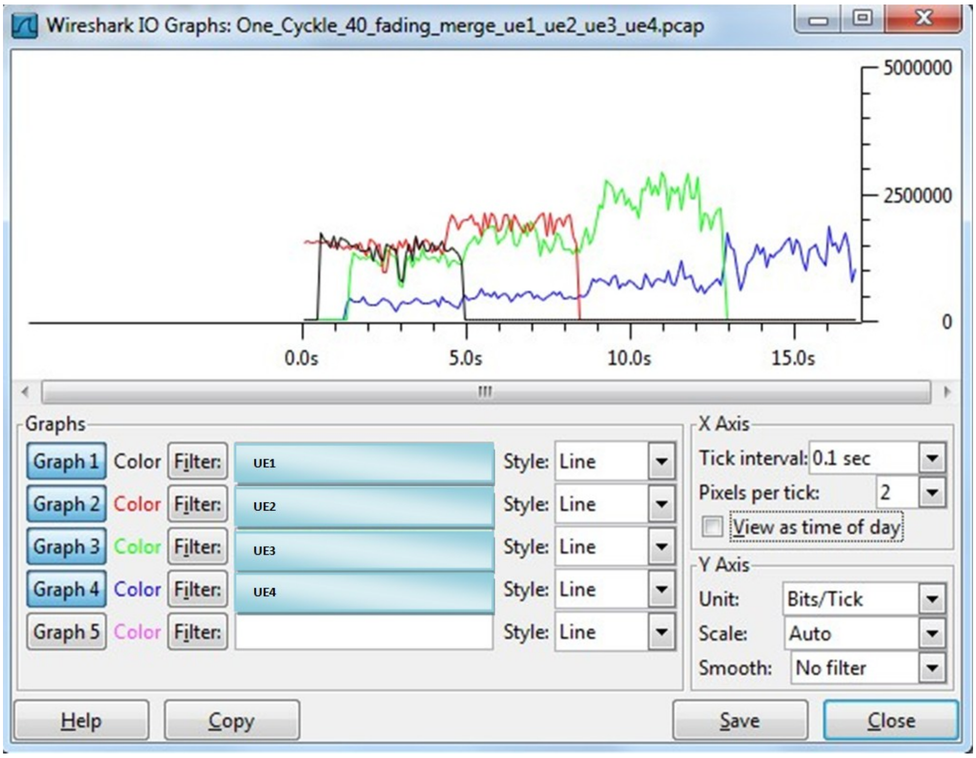

Figure 18: Received data at UEs with activity load 40 % and fading

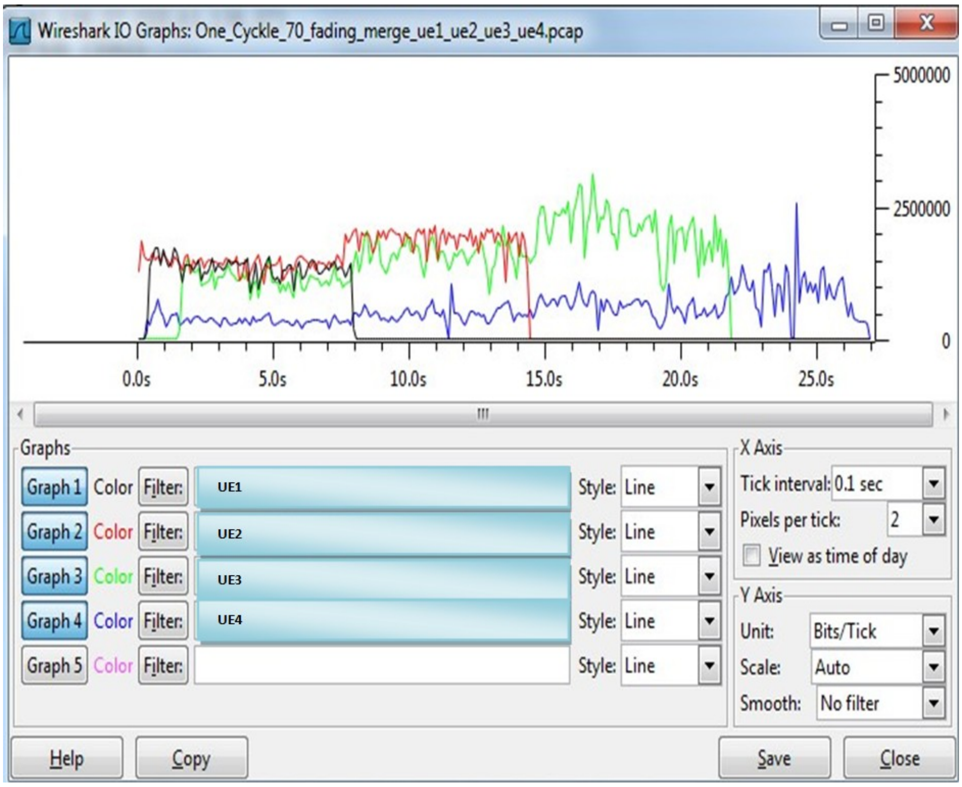

Figure 19: Received data at UEs with activity load 70 % and fading

Table 12: Measured data without fading

	Pure radio channel i.e. no fading added		
	Average Throughput [kbps] over 40 seconds	**Average Consumed Power [W]**	**EE [kbps/W]**
10 % activity load	4 624	240	19
40 % activity load	18 090	275	66
70 % activity load	30 692	305	101

Table 13: Measured data with fading included

	Radio channel which includes fading		
	Average Throughput [kbps] over 40 seconds	**Average Consumed Power [W]**	**EE [kbps/W]**
10 % activity load	3 298	241	14
40 % activity load	13 010	277	47
70 % activity load	20 534	308	67

5.2.5 Conclusion

Measurements have confirmed the importance of including fading in the dynamic measurement procedure of TS 102 706 [i.1]; a degradation of calculated energy efficiency is in the order of 50 % for WCDMA and around 30 % for LTE compared to when fading is not included.

Introducing fading into the radio channel under the test is therefore necessary to obtain a more realistic view of an RBS' energy efficiency.

In the next release of the standard a fading model may need to be specified, as well as a method describing how to generate it.

It was observed that the specified signal level worked fine for LTE but could not be achieved with WCDMA tests (subject to further investigation).

5.3 Interference and noise

The current energy efficiency measurement procedure requires that measurements be carried out in a test lab with a single RBS shielded from the environment. The primary limiting factor for the measured data throughput is therefore thermal noise from the involved equipment. In a practical network, especially in broadband networks like WCDMA and LTE with a frequency reuse factor of one, the actual achieved throughput is limited by interference. Efficiency figures obtained according to the current ETSI specification are therefore not achievable under real network operating conditions.

5.4 Measurement test setup including interference and noise

RBS interference tests are specified in the relevant 3GPP specifications for type approval. Interference characteristics vary considerably depending on their source. It can include anything from a narrowband signal with widely varying amplitude (like RADAR) to a broadband interference with relative constant power level. Interference tests are separated into three basic categories:

- Out-of-band interference;
- In-band interference;
- Co-channel interference.

Out-of-band interference is frequency band specific and for RBSs it is often additionally location specific. It covers typically a frequency range from 100 kHz to around 12 GHz. Required out-of-band interference robustness depends to a large extent on the antenna filters. Out-of-band interference is essentially unpredictable.

In-band interference robustness is mostly determined by the performance of the analogue part of the receiver. In-band interference in cellular networks is to a certain degree predictable, as they operate in licensed bands with defined emission levels.

The co-channel interference performance is determined by the applied modulation and coding scheme and to a certain extent also by the receiver's signal processing capability. Co-channel interference is usually quite predictable and has typically similar signal characteristics as the wanted signal. Some receivers utilise this a priori knowledge for interference mitigation.

In order to receive type approval all RBS have to fulfil certain interference robustness requirements. In practice provide commercial RBS a more or less better performance. Interference is a very location specific effect, and the interference robustness of a receiver depends on its architecture and hence varies from frequency to frequency. The requirements as specified in the corresponding standards are usually seen as sufficient. Additional RF filtering to handle location specific out-of-band interference is in some cases negotiated separately.

As interference can occur over a very wide frequency spectrum, with very different signal levels and modulations depending on the interference category, an interference test would add not only significant complexity to the test setup but also requires a tremendous amount of test specification work. An interference test would have to be defined specifically for every standard and for every frequency band.

5.4.1 Results and analysis

Interference robustness of radio equipment is a receiver performance measurement and indicates the equipment's ability to receive the wanted signals in the presence of other electromagnetic emissions from all kind of electronic equipment. The effect of interference on the RBS efficiency measurements are different for UL and DL, they have to be considered separately for the different performance indicators.

Interference robustness of the RBS affects the uplink performance of the RBS and therefore the coverage efficiency. The RBS capacity efficiency in downlink is mostly affected by the interference robustness of the user equipment.

Coverage efficiency (UL performance):

The basic assumption in the current standard is that the RBS coverage is UL limited. RBS receiver interference robustness therefore directly affects the achieved coverage efficiency. However, the coverage test is done under the assumption that the RBS is operated in a rural environment. Therefore, we can assume that in-band and co-channel interference is very low and the limiting factor is thermal noise. To achieve a more realistic efficiency test value additional noise could be added during testing.

Capacity efficiency (DL performance):

Down link capacity has been considered as the most relevant performance factor for radio standards in general and also for RBS energy efficiency testing. As outlined above, the impact of interference on DL performance is affected by the interference robustness of the user equipment and not of the RBS.

If we assume a constant interference level, like co-channel interference typically experienced in WCDMA systems, the effect is very similar to an increased thermal noise level. The situation is a bit more complex in OFDMA as applied in LTE but the noise approach could still be used (see for example https://www.jerryweb.org/public/files/interference_estimation.pdf).

Downlink throughput could be affected if interference in the uplink causes the RBS to terminate the call, requiring repeated transmissions or call setup. In this case we will see an impact on the capacity efficiency of the base station. To access this affect, a well specified UL interference scenario has to be specified for the DL capacity measurements.

5.4.2 Conclusion

For the coverage efficiency test the impact of additional noise or a constant interference level could be achieved with moderate complexity, but the energy efficiency assessment result is most likely very similar for all equipment and therefore not suitable for product differentiation. A similar result could be achieved by including a constant degradation factor in the standard.

In the capacity efficiency test with interference in the DL the energy efficiency assessment results will be mostly depending on the UE performance and only to lower extent by the RBS.

Adding interference to the efficiency test method would increase complexity and reduce accuracy of the results significantly, unless the used user equipment is precisely calibrated.

5.5 The effect of RBS temperature variance related to energy efficiency

There has been a proposal to increase the range of temperature during the test i.e. to test the RBS in 10, 25, 30 and 40 °C.

The group members have decided to keep the temperature values as currently defined in TS 102 706 [i.1] (i.e. for static measurements 25 °C and 40 °C are mandatory and for dynamic measurement setup 25 °C is mandatory).

5.6 Two or more WCDMA carriers present in dynamic EE test

5.6.1 Introduction

TS 102 706 [i.1] specifies the EE test of WCDMA radio base stations to be carried out with a single carrier (5 MHz channel bandwidth). However, most WCDMA/HSPA installations have two carriers and essentially all modern equipment is able to handle multiple WCDMA carriers simultaneously. Two-carrier testing therefore seems more appropriate.

5.6.2 Current standard

A single carrier WCDMA/HSPA test was chosen in TS 102 706 [i.1] for simplicity. However, in the field we have a large number of two carrier installations and essentially all newer radio base stations are multi carrier capable. Two-carrier testing seems therefore more appropriate.

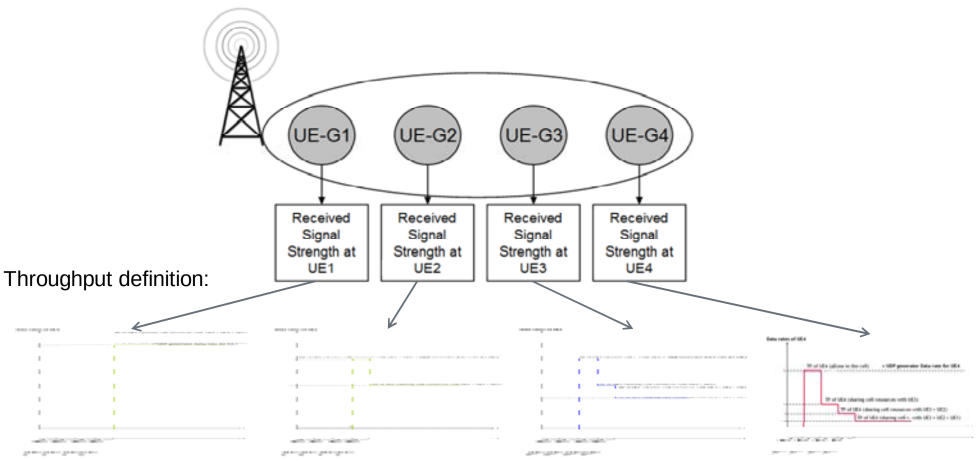

Figure 20: Dynamic UE timing schedule

5.6.3 Proposed Solution

The UE load procedure as described for a single carrier (as described in TS 102 706 [i.1]) should be used. To achieve equal load on the carriers the two-carrier test should utilize the network PLMNID (Public Land Mobile Network Identifier) parameter. The PLMNID parameter allows network sharing between two operators. A single BTS could be shared by two operators independently via the PLMNID. In this case one carrier is assigned to operator 1 and the second to operator 2. Each carrier should be loaded with 4 UE according to the already described method but with different operator IDs to guarantee equal and controlled load during the test.

Multi-operator core network (MOCN) and PLMNID are standardized and supported in 3G and in LTE.

5.7 GSM dynamic energy efficiency measurement test setup

GSM static measurement test method for energy efficiency has been specified in TS 102 706 [i.1] but the dynamic measurement test method for GSM has not been included yet.

Three different RBS configurations for GSM have been introduced in the static measurement part of TS 102 706 [i.1]. These configurations are: 2x2x2, 4x4x4 and 8x8x8. For EE dynamic measurement method for GSM it would be sufficient to use only 4x4x4 configuration.

The method and test setup for how to measure dynamic energy efficiency for GSM could be subject to further investigation.

Annex A: Signal Quality

A.1 The Importance of Linearity in Cellular Systems

Modern cellular radio systems have increased their maximum data rates by orders of magnitude compared to earlier systems. Early GSM, as an example, had a data rate of about 10 kbps, whereas LTE may reach 100 Mbps and LTE-A perhaps 1 000 Mbps. Various techniques have been used to improve overall spectral efficiency (i.e. bits/second/Hz); changing the modulation scheme has been one such technique.

For any modulation scheme to be successful, radio systems have to exhibit a certain degree of linearity. Non-linear radio creates inter-modulation (IM) products which pollute radio spectrum. This results in overall system degradation and lower system capacity. A look at modulation schemes used in contemporary cellular systems illustrates the need for linearity. Figure A.1 shows the GMSK modulation in GSM.

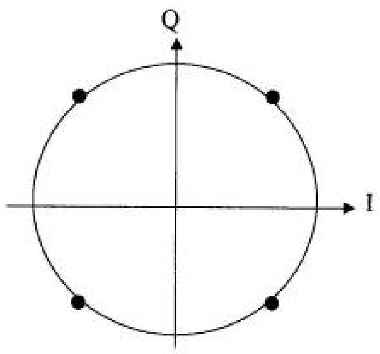

Figure A.1: GMSK modulation, which is used in GSM

One major advantage of GMSK is the relative ease with which the transmitted bits can be decoded by the receiving circuit. Successful transmissions can occur with relatively low system requirements for linearity (i.e. it is sufficient to hit the circle with a limited amount of accuracy). These lower linearity requirements resulted in higher power efficiency amplifier designs (already 30 % to 40 % in the earliest days).

Data rates in GSM were then increased within the existing system (e.g. existing frequency allocations), by incorporating the 8PSK ($3\pi/8$) modulation scheme (Figure A.2). This made decoding the received signal more challenging, and thus considerably increased the required system linearity requirements. The system's overall power efficiency decreased as a result.

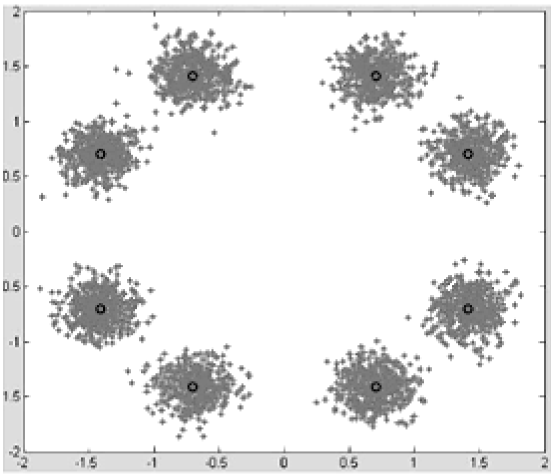

Figure A.2: 8PSK (3π/8) modulation, used in radio technologies such as GSM EDGE, showing ideal constellation points and the decoded constellation points within a noisy environment

When mobile broadband cellular systems such as WCDMA were introduced, higher order modulations such as 64 QAM were employed (Figure A.3), thereby further increasing linearity requirements. Power efficiency was reduced further as a result, partially due to the higher cost of linearity (in terms of power) but also due to the higher bandwidths associated with the technology.

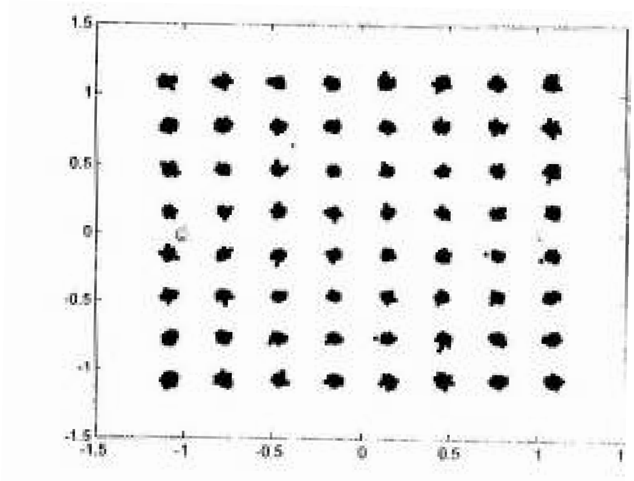

Figure A.3: 64 QAM modulation, used in e.g. WCDMA

As suggested in the previous two figures, higher-order modulations increase the radio's challenge to accurately produce (in the transmitter) and identify (in the receiver) the constellation points. A transmitter without sufficient linearity will not generate these points in the right positions, and/or will produce "smeared" points which may be misinterpreted by the receiver. Similar linearity requirements exist for the receiver, which exist to assist the decoding of constellation points with sufficient precision.

Failing to live up to linearity requirements in either the transmitter or the receiver will result in data re-transmissions and lower modulation schemes hence lower data rates and overall system capacity.

The most common methods used to specify linearity in cellular systems focus either on power leakage into adjacent channels (i.e. ACLR, Adjacent Channel Leakage Ratio), or on the difference between ideal and actual location of received constellation points (i.e. EVM, Error Vector Magnitude). ACLR focuses on the spectral aspect of radio transmissions (Figure A.4), while EVM focuses on the system capacity aspect, however both aspects are essential.

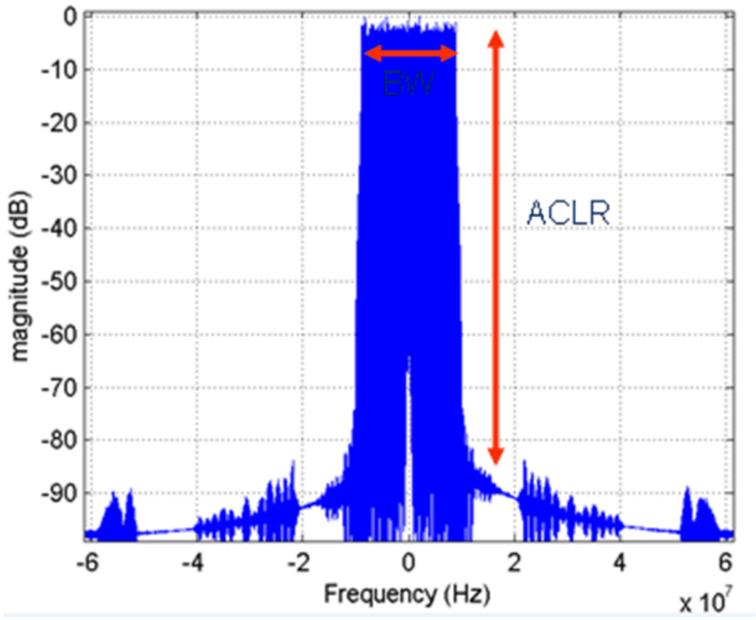

Figure A.4: Definition of ACLR

Figure A.5 shows how linearity (as described by ACLR) might be considered in a real radio environment to generate the resulting link budget. The figure shows how an RBS needs to be designed to handle impact of interference, noise and fading.

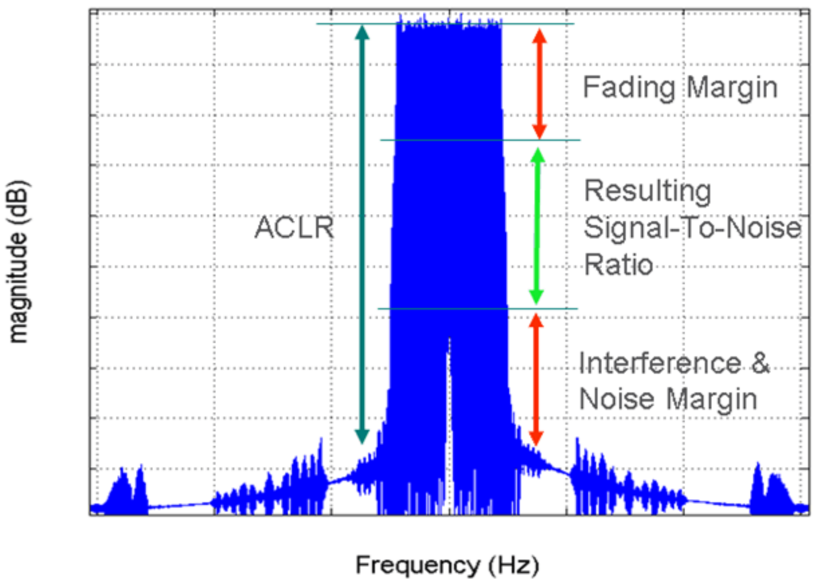

Figure A.5: Resulting signal-to-noise radio by adding radio effects to the radio channel

A.2 PA Linearity measurements

Linearity is essential in radio transmission, as it enables higher levels of spectral efficiency, data throughput and system capacity. Low linearity pollutes spectrum, resulting in an overall lower system capacity. It is well-known that cellular systems usually require higher linearity than specified by standardization - one of many parameters open to competition.

Unfortunately, the price for high linearity is high, both in component cost and energy efficiency.

Thus, when comparing the power efficiencies of radio base stations, signal quality should be taken into consideration. By isolating the two design goals, there is substantial risk that poor signal quality will be designed into the system in the quest for better PA power.

A test was subsequently designed to answer the following questions:

- To what extent does PA linearity impact its Power Efficiency?

  Can this impact be quantified?

- Can we compare the efficiencies of PAs with different linearity values?

  Can a normalization factor be extracted from the results?

In the test, an LTE baseband signal would be up-converted and amplified by a transmit chain. Non-linearities imposed by the transmit chain would be noted via ACLR and EVM measurements, and the PA input power would also be recorded. By varying the voltage drain in subsequent measurements, it could be determined whether there is a predictable relationship between the linear properties of a power amplifier and the power required to operate it.

A.3 Measurement Setup

The measurement setup is described in Figure A.6.

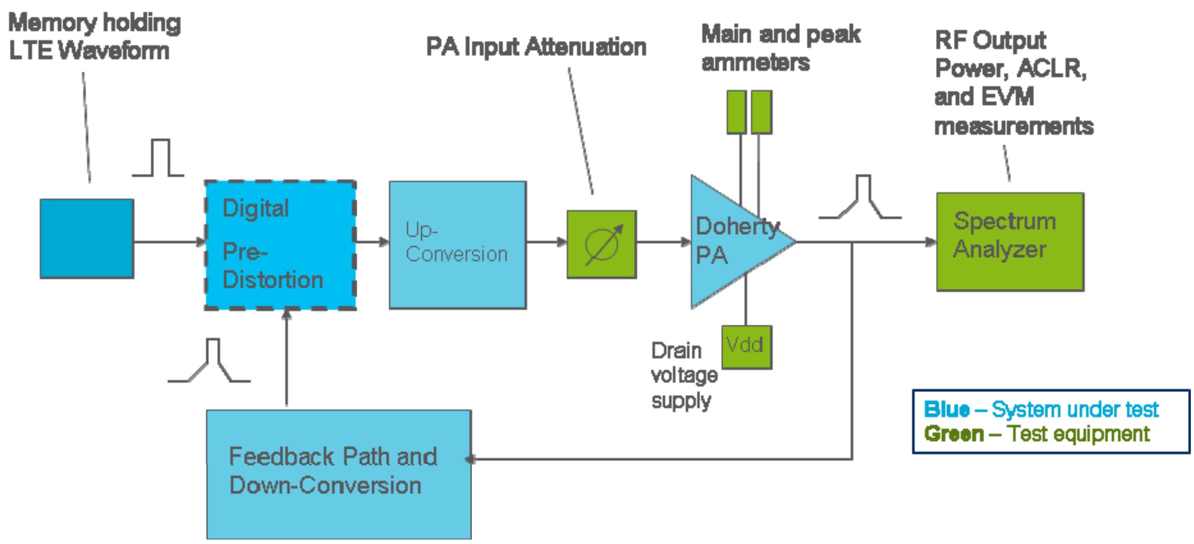

Figure A.6: Lab setup

The PA used in the measurement setup was designed for test purposes only, and was not used for product.

The input signal used for the measurements was a single carrier LTE signal. It had a bandwidth of 20 MHz and was centred at 1 960 MHz. It was compliant to the E-UTRAN test model E-TM3 3.1.

In the initial set of measurements, the crest factor of the input signal was set to ~6 dB, resulting in an EVM of 6 %. The measurements were first performed without digital pre-distortion (DPD), and then repeated with DPD turned on.

In the final set of measurements, the crest factor of the input signal was increased to ~12 dB, resulting in an EVM of ~0,3 %. Again, the measurements were performed both with and without DPD.

The DPD algorithm used in the measurement procedure was not optimized for the PA used, however as will be evident in the results, the DPD performed surprisingly well.

A.4 Measurement results

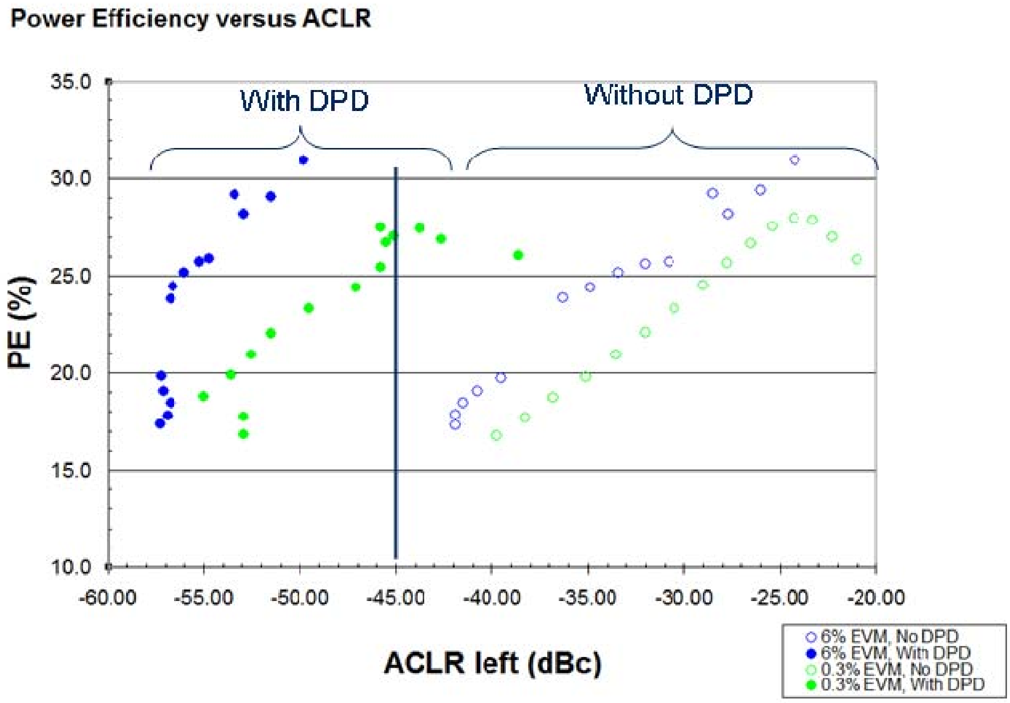

Figure A.7: Measured results

The resulting measurements, as plotted in Figure A.7, showed a definite relationship between the ACLR of a PA and the PA's power efficiency.

Figure A.7 shows curves for the 6 % and 0,3 % EVM signals, reflects a set of measurements where the Digital Pre-Distortion, DPD was switched off and another set where DPD was on. The 3GPP linearity (signal quality) requirement is indicated in the figure by the line at -45 dBc. It can be observed that each set of measurements forms an approximate line with the same slope for all measurements. The far end measurements are impacted by other conditions in the power amplifier and should be discarded. Note these measurements were only preliminary.

A.5 Other studies

The relationship between the efficiency and linearity of various power amplifier designs is well documented in other articles and papers. One common result from studies of these articles is that they confirm higher linearity comes with the cost of lower efficiency.

A.6 Possible Impact on Standardization

The fading and linearity measurement results suggest possible changes to the way RBS power efficiency and energy efficiency are measured and reported.

Recognizing that radio aspects affect the throughput of the link between the RBS and the UE, the standardized test procedures can be updated to include major effects like interference, noise, and fading. PA amplifiers with poor linearity increase the ACLR of the transmitted signal, while radio effects reduce the received signal's strength. These two things reduce the receiver's overall ability to detect and decode the received signal (because the signal-to-noise ratio is reduced).

A realistic test setup in lab has to include all the main radio aspects mentioned above. This is for further discussion but the test setup in Figure A.8 shows one possible solution.

The box between the RBS and the UE groups that indicates the interaction of noise, fading, etc. are not yet specified and for further study. The dotted boxes inside are modules that should be easy to switch on and off so one radio aspect could be tested independent of others as well as combined.

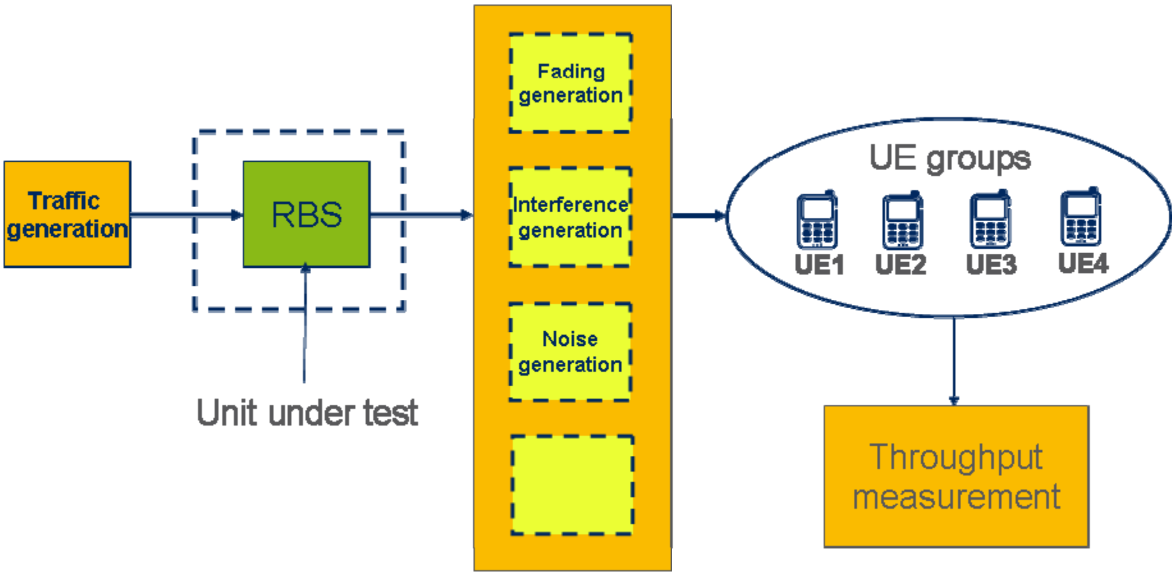

Figure A.8: Realistic test setup proposal

To credit designs for the power efficiency cost of excessive linearity, a normalization factor can be applied to the measured power efficiency value. Figure A.9 provides an example of how this normalization factor can be determined.

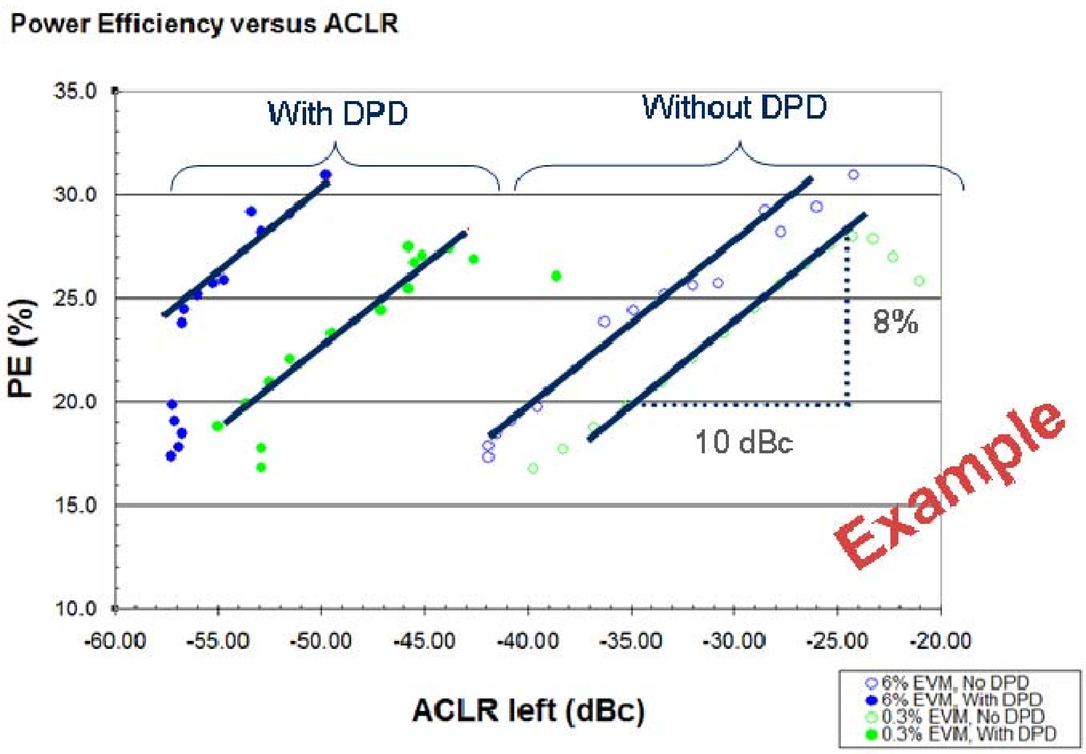

Figure A.9: Example: Power Efficiency Normalization Factor

Figure A.9 shows an increase of 0,8 % in the tested PA's power efficiency for every dBc increase in the PA's ACLR value. This slope was also consistent for all tests where DPD was switched on and off and for the EVM of the input signal of 0,3 % and 6 %. Note that this is for a PA only and not an entire RBS. Since a PA consumes only a part of the power required by the RBS, the slope would be proportionally smaller.

Thus when determining the normalization factor, the PA's share of the RBS would have to be estimated, and the ACLR value would have to be directly measured or specified by vendor 2. It would also be based on the difference between the stated ACLR of the RBS, and the 3GPP minimum ACLR requirement (-45 dBc).

A.7 Conclusion

Energy efficiency measurement procedures which exclude some radio aspects like fading, noise and interference will not produce realistic results. Including effects such as noise, interference and fading provide results which are more reflective of reality.

Current standardized test procedures do not include radio aspects, thus the RBS's linearity (or lack thereof) has no impact on throughput measurements. The most accurate way to measure RBS throughput (and therefore RBS energy efficiency) is to use a realistic test setup which includes radio effects.

In the absence of realistic test conditions, it is possible to normalize an RBS power efficiency measurement using its ACLR value (i.e. linearity measurement).

History

Document history		
V1.1.1	October 2012	Publication