Measurement Unit for Energy Efficient M2M Mobile Communication

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Abstract

Machine-to-machine communication is continuously extending to new application fields. Especially smart metering has the potential to become the first really large-scale M2M application. Although in the future distributed meter devices will be mainly connected via dedicated primary communication protocols, like ZigBee, Wireless M-Bus or alike, a major percentage of all meters will be connected via point to point communication using GPRS or UMTS platforms. Thus, such meter devices have to be extremely cost and energy efficient, especially if the devices are battery based and powered several years by a single battery. This paper presents the development of an automated measurement unit for power and time, thus energy characteristics can be recorded. The measurement unit includes a hardware platform for the device under test (DUT) and a database based software environment for a smooth execution and analysis of the measurements.

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***Index Terms*—Machine to machine communication, energy optimization, measurement unit, energy consumption of GSM modules.**

I. Introduction

The number of M2M-applications is rapidly increasing. Whereas development and installation of standard mobile communication systems is a mere development task, the implementation of battery-powered sensor systems comes with severe challenges, especially if long operation times in the range of years should be achieved. For these systems, optimization not only from hardware, but also from firmware side is required. Mobile communication protocol usage must also be optimized.

For this analysis, an automated measurement unit was developed, which is presented in this contribution. In chapter II, the general challenges for the power and energy measurement of communication equipment are described. Ch. III describes some basics about current measurement and the hybrid layer capacitor. These challenges lead to the use of a flexible, off-the-shelf measurement device, and to the development of an own portable and optimized measurement unit. Both are described in chapter IV. An important part of the automation process comes from the software environment, which is presented in ch. V. Finally, chapter VI shows results of the representative measurements.

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II. Challenges

For power consumption measurement of a GSM/GPRS module the main challenge is the high dynamic range of the current that the module consumes. During communication, a module may consume peak currents of up to 2 A during a TDMA time slot of 577 µs every 4.615 ms. During the remaining (passive) time slots, the power consumption is typically in the range of 10 mA. During power down modes, the power consumption goes down to around 50 µA. There exist also certain sleep modes where power consumption still is around 1…2 mA. This high dynamic range needs to be taken into account in terms of current as well as timing resolution. Thus, the following requirements for the measurement unit can be derived:

- Current range of 0…2 A
- Current resolution of 100 µA for a lower range
- Current resolution of 1 mA for a higher range
- Measurement sample rate of up to 20 kS/s to have approximately 10 samples of current peaks

III. Basics

A. Current measurement

Typically a current is measured over a shunt resistor via the voltage drop across the resistor. The voltage is measured behind the current measurement. This is also the approach that was followed for the measurement unit. Fig. 1 shows the block diagram for such a typical high side current and voltage measurement.

On the one hand the shunt resistor must be sufficiently small so that the voltage drop at the maximum current is still within the tolerance for the communication module. On the other hand it must be sufficiently

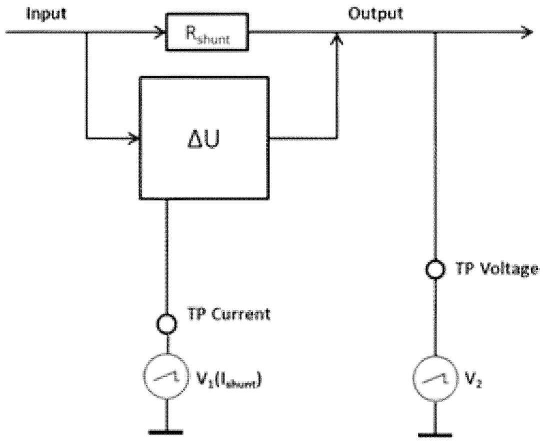

Figure 1: Typical current measurement setup.

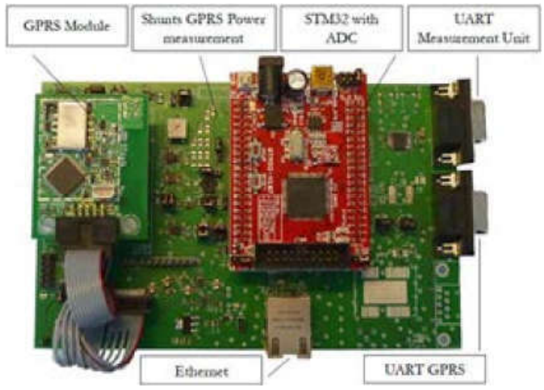

Figure 2: Portable Measurement Unit.

large to achieve the required accuracy at small currents.

Typically, the voltage drop across the shunt is amplified by a high-side current sense amplifier and measured by an ADC as voltage level proportional to the current. To achieve higher precision of the power measurement, the voltage is measured after the shunt. Thus the voltage drop of the shunt resistor is taken into account.

B. Hybrid Layer Capacitor

Typically the DUT has its own power supply for the GSM/GPRS module. But since the GSM/GPRS module consumes a high current in such a short time this power supply is supported by a so called Hybrid Layer Capacitor (HLC). This capacitor prevents a voltage drop the power supply would generate at the rising of the peak current. This has to be taken into account in such way that the measurement of the GSM/GPRS module has to be between the HLC and the module itself and not between the power supply and the HLC or even for the whole DUT.

IV. MEASUREMENT UNIT

A. Off-the-shelf power analyzer

There are devices on the market that allow exactly the type of measurements required for this application. Such a device is the Source/Measurement Unit (SMU) provided as module of the DC Power Analyzer [1]. The seamless measurement ranging allows the measurement of low currents down to 100 nA as well as peak currents of up to 3 A, both with full resolution of 28 bits. Seamless ranging enables range changes without losing any reading and keeping the output voltage stable. Measurements can be displayed in the form of meter, scope waveform or data logged over extended periods of time.

B. Portable measurement unit

Whereas power analyzers available on the market allow very precise measurements, a Portable Measurement Unit (PMU) was developed and produced for distributed and mobile measurements. It is shown in Fig. 2.

It is controlled by an STM32-microcontroller [2] and hosts the DUT. The two ADCs measure with a 12 bit resolution in a range of 0 to 3.3 V. As input for the ADCs 16 different channels can be assigned. The maximum sampling frequency is restricted to 2 MS/s. These two ADCs are used simultaneously to measure voltage and current values at a time [3]. Since multiplexing of the channels costs time the maximum sampling frequency decreases. Another bottleneck is the communication via the serial port. These two facts cause a reduction of the sampling frequency from 2 MS/s down to 3 kS/s. Theoretically it works with a much higher sampling frequency but tests show that 3 kS/s is the highest value that runs stable. Taken a peak of around 500 µs just one or two samples describe this peak. But taken into account the simple structure during the TDMA timeslots shown in fig. 3 this data can be interpolated by the software environment described in the next chapter. The red graph in fig. 3 shows the used model for the interpolation. This model was chosen after measurements with the DC Power Analyzer described in the previous section. In this model noise was neglected.

To handle at the same time the high dynamic range of the current and the precise resolution in the lower current range, two current measurements are provided, one for the range of 0…200 mA and one for 0…2 A. By this a resolution of 100 µA in the lower range can be achieved. At the same time the peaks can be measured with a 1 mA resolution. These currents are sampled directly one after another.

However, this is not implemented yet but taken into account that during the whole measurement the GSM/GPRS module is either in an active mode (> 10 mA) or in a passive mode (~ 10 mA) the higher

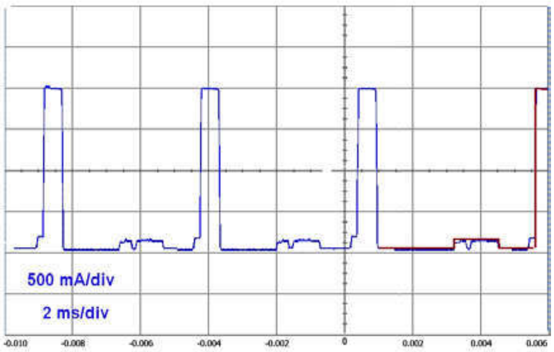

Figure 3: Current drain measurement of a GSM/GPRS module [1] during a TDMA timeslot (blue curve) and its interpolant (red curve).

range suffices. In this higher range it would not be able to measure currents during sleep or power down modes with currents around or even smaller than 1 mA but they do not occur during the measurement.

As described in chapter III.A, the current through the shunts is amplified and then sampled by the ADC. High precision high-side current-sense amplifiers by Maxim [4] are used due to their advantages comprising high precision and temperature stability and their availability in different gains. Different gains are necessary since different shunts are used.

For accuracy reasons, the described measurement ranges can be adjusted by hardware modification, i.e. exchanging the shunt resistors. The power consumption of the portable measurement unit is in the range of 200 mA allowing extended battery operation.

For communication between the STM32 and a PC the measurement unit is equipped with a serial port and for higher data throughput with an Ethernet port. The communication between the DUT and the PC is realized via a second serial port.

V. Software Environment

As the measurement results depend on the environment and show a statistical distribution, it is necessary to perform a larger number of consecutive measurement runs. For efficiency reasons, an automated test environment was designed and implemented.

The Software Environment (SE) controls the GSM/GPRS module (DUT) and the power measurement unit as shown in Fig. 4. To perform one measurement iteration the SE sends the command to start the measurement to the PMU. Then the PMU starts the DUT by setting the ON/OFF pin of the GSM/GPRS module. When the SE receives the message from the GSM/GPRS module that it is turned ON it sends the AT commands for initiating the network connection and for transmission of the data. If the transmission was successful the GSM/GPRS module disconnects from the network, the PMU sets the

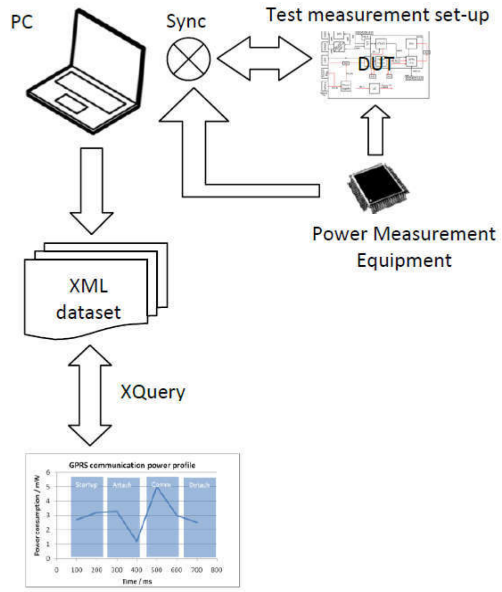

Figure 4: Software Environment.

ON/OFF pin in such way that the module shuts down and it stops the measurement.

In the next step, the data is stored in a Berkeley XML database by Oracle. This allows powerful queries across different measurement runs. The statistical evaluation of the data includes comparisons between

- modules from different manufacturers,
- different locations,
- different GSM providers and
- GSM module antenna configurations.

Finally, reports provide evidence of the energy consumption and the timing under these different conditions.

VI. Results

A. Time and Energy vs. Phases

The resolution in time gives a very informative view on the different phases of the communication. Fig. 5 shows the distribution of time in percentage of the mean of 700 measurements in different locations with two different GSM modules and two different providers. For each configuration the same amount of data is being collected.

For the transmission of 4 kB of data the longest part falls to the attachment process to the network and to the connection establishment. It is possible that the time from starting up the modem until the start of the TCP communication takes 64 % of the total.

In contrast, the energy consumption is slightly different. Data transmission requires the most significant amount of energy whereas the phases from start-up until opening the TCP connection requires only 50 % of the overall energy consumed. Based on these fig-

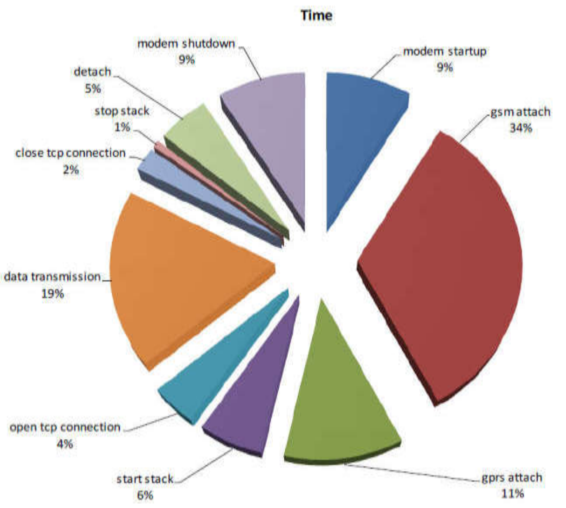

Figure 5: Average distribution of time per phase in percentage of 700 measurements.

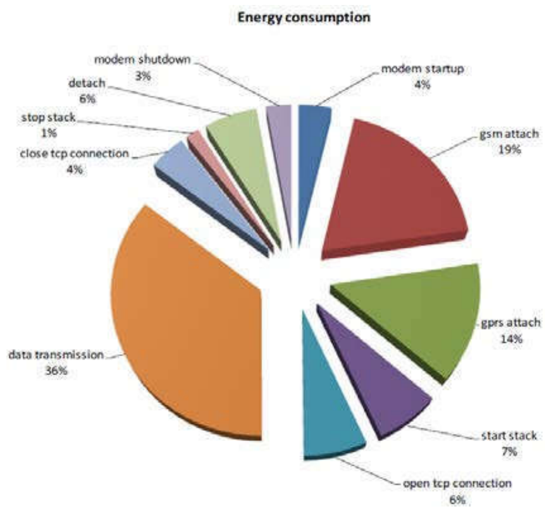

Figure 6: Average distribution of energy consumption per phase in percentage of 700 measurements.

ures the data must be analyzed further in terms of GSM modules, providers and locations.

B. Time and Energy for different GSM modules and providers

For the analysis and comparison of the energy consumption depending on different modules two different modules MOD_A and MOD_B of different manufacturers were used. Both were tested with the same external antenna. Additionally, tests with different providers (T-Mobile and Vodafone) in their home networks and in international networks using roaming were performed.

These tests are based on 657 measurements at three different locations and they are shown in fig. 7 and fig. 8. Each measurement is represented as bar in the diagram. The measurements are grouped by module and provider.

Fig. 7 shows the timing diagram. A critical situation can be observed in the phase “06 data transmission”. The combination of module A with the provider T-Mobile shows a significant variance in the time used. Certain test runs use even more than 40 s for the data transmission. However, the same module with a different provider shows a much lower data transmission rate.

Energy measurements shown in fig. 8 are based on the energy consumption of the GSM module. It is calculated as work in mWh per phase. It is based on the same data as used in the previous chapter but the data on the y-axis is the work consumed by the GSM module.

This illustration shows clearly that a main portion of the energy consumption lies in the data communication. In addition, the attachment process still consumes a significant amount of energy. It is slightly higher for module B compared to module A. In the main parts the energy consumption reflects the time requirements. In [5] different optimization approaches based on this data are shown.

VII. Conclusion

General challenges with high dynamic range current measurements on GSM/GPRS modules are discussed and analyzed. By implementing two current measurements, one for the precise resolution in the lower current range and one for the higher current range with less precision, these challenges are overcome.

Instead of having a sampling rate in the range of MS/s, approximately 3 kS/s are sufficient for interpolating the actual energy consumption. With this technique it is possible to show the energy consumed by the modules in each communication phase. Measurements with the DC Power Analyzer described in chapter IV.A show that the inaccuracies of the minor time resolution and the higher range are still in a reasonable dimension.

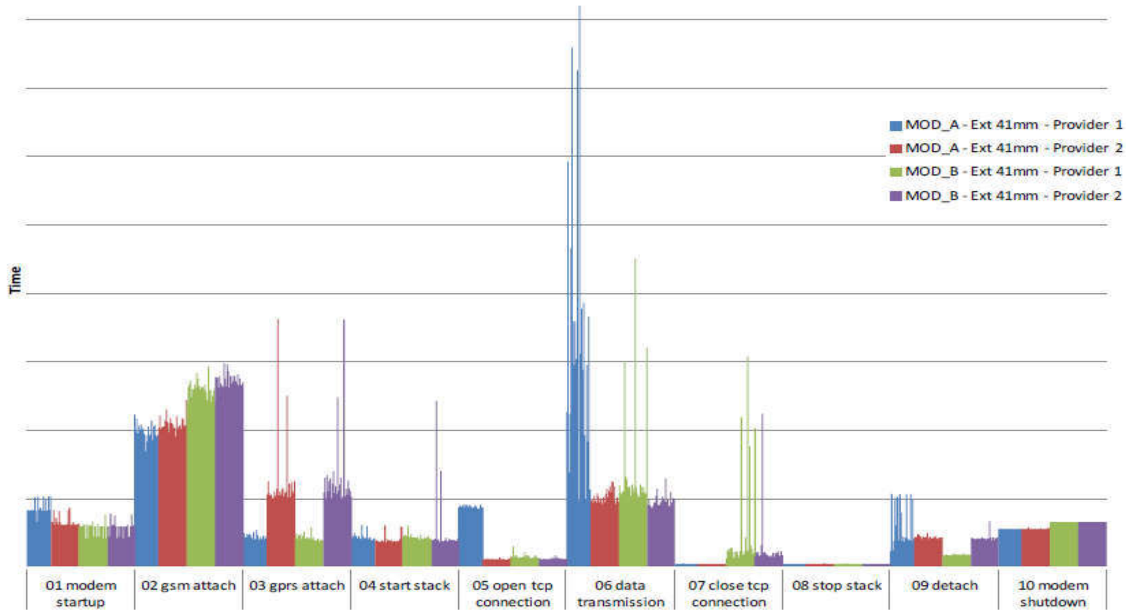

Figure 7: Timing Diagram with two different GSM modules and two different providers (Provider 1 = T-Mobile, Provider 2 = Vodafone).

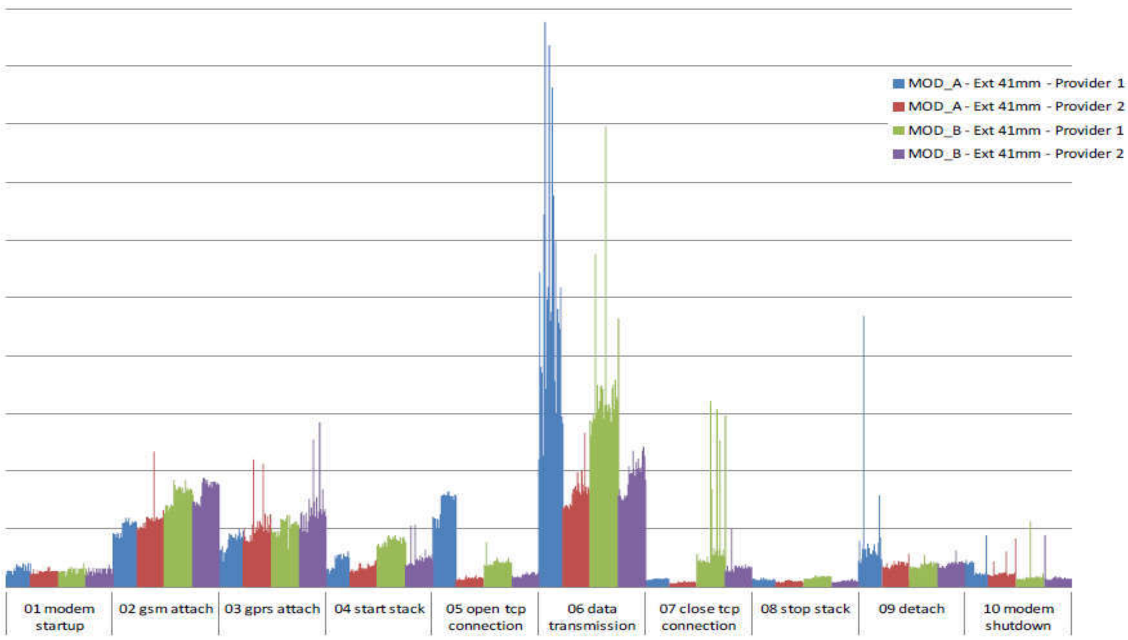

Figure 8: Diagram showing the energy consumption with two different GSM modules and two different providers (Provider 1 = T-Mobile, Provider 2 = Vodafone).

With the described PC software environment it is possible to save all measured data in a database to run powerful queries across different measurements. Finally, reports give evidence that the startup phases (modem startup until TCP connection established) takes 64 % of the time but just 50 % of the energy taking into account that 4 kB of data are transmitted. The transmission of this data takes 19 % of the time but 36 % of the energy. Furthermore two different modules with two providers in numerous locations were checked. Depending on the phase and the modules there are severe differences in the time and energy consumption that have to be taken into account when dimensioning batteries for M2M applications.

The next steps are implementing the second range in software and the Ethernet connection on the PMU to obtain a higher sampling rate and a higher current resolution.

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Dr. Sikora is founder and head of Steinbeis Innovation Center Embedded Design and Networking (sizedn). He is author, co-author, editor and co-editor of several textbooks and numerous papers in the field of embedded design and wireless and wired networking, and head and member of numerous steering and program committees of international scientific conferences.