Energy efficient sensor nodes

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The phasing out of the traditional light bulb, starting in 2009, is very controversially discussed in engineering papers as well as on the consumer side. But this marks just one visible effect of many programs and research activities to reduce worldwide energy consumption by increasing the efficiency of electrical and electronic systems.
The increase of efficiency is not only interesting for consumer goods with large volumes, but also for applications that are mobile and therefore battery powered. The saving of energy in such applications has more aspects than just reducing waste, etc. – In most cases it is a requirement of maintenance that drives the development of energy-efficient low power systems.
But before going into details about efficient technical approaches, I want to give a short outline of efficiency. – Efficiency in physics meaning the „energy conversion efficiency“ of a system is defined as the ratio between a useful output and the necessary input in terms of energy. Transferring this basic input-output formula to more complex systems like communicating sensor nodes or full mesh enabled sensor networks is not done in a straight forward way, because of the multiple parameters that have to be calculated. Also different perspectives on efficiency have to be considered – especially the definition of the „useful output“ is very specific to the system and has to be done from scratch in the beginning of the system development process.
Looking at the nodes of modern wireless sensor networks, the system structure always consists of hardware and software parts working together. The hardware components typically include sensors, a microcontroller and a transceiver for RF-communication. Using state-of-the-art components increases the efficiency of the system. Because there is such a huge variety of different sensors for different physical values a short comparison of their power consumption in means of efficiency is impossible. From a systems aspect the sensors mostly are not the biggest factor on the bill of the power demand, so we must have a look to the microcontroller side.
The following comparison of the MIPS-values per milliwatt of three different microcontrollers shows the increase in efficiency over the years. Although the architectures CISC/RISC and the basic controller technology is not directly comparable, it is obvious that using a more recent technology reduces the power consumption dramatically.

Microcontroller	Voltage	Average operating current	Instructions per second	MIPS per mW
CISC, SAB8032A	5V	175mA	1 MIPS	0.001 MIPS/mW
RISC, Atmega8	3V	5mA	4 MIPS	0.3 MIPS/mW
RISC, AtTiny48	3V	1.4mA	4 MIPS	1.0 MIPS/mW
RISC, AtTiny48	2V	0.2mA	1 MIPS	2.5 MIPS/mW

Table 1 – Comparison of computing efficiency of microcontrollers

In addition to the much higher efficiency when in working mode, current generation microcontrollers offer various power saving features like sleep modes or modes with partial cutoffs of internal devices. Comparing the power consumption of the above mentioned controllers in their power down modes shows how huge the differences are. The possibilities of extreme power saving operating modes clear the way for energy-independent (e.g. battery-powered) sensor nodes.

Microcontroller	Voltage	Sleep currents	Sleep mode power consumption
CISC, SAB8032A	5V	PD Mode: 15mA	75mW
RISC, Atmega8	3V	Idle Mode: 1mA Sleep Mode: 0.5µA	3mW 1.5µW
RISC, AtTiny48	2V	Idle Mode: 0.03mA Sleep Mode: <0.2µA	0.06mW <0.4µW

Table 2 – Comparison of microcontroller power saving modes

As already mentioned, comparing the efficiency of different microcontroller architectures is very difficult and results have to be interpreted more as a qualitative analysis. The comparison of single-chip RF-transceivers is much easier and the results have a more quantitative character. The selected parameters for such a comparison are the power consumption (current and voltage), the transmit power at the same frequency and similar datarates. The candidates for this are the Chipcon CC400, CC1100 and the Axsem AX5042.

Transceiver	Voltage	Tx current 6 dBm, 433MHz	Power consumption
Chipcon CC400	3.3V	44mA	145mW
Chipcon CC1100	3.0V	23mA	69mW
Axsem AX5042	2.5V	24mA	60mW

Table 3 – Comparison of power consumption of single-chip transceivers

For the development of wireless sensor nodes some general conclusions can be drawn from the comparisons above:

- Although reusing old designs may save development time - use state-of-the-art components (sensor & µC & radio) for an efficent low-power design.
- Rate the components concerning their power consumption.
- Evaluate possible sleep or power down modes before starting development.

Every hardware is just as good as its software. – The firmware of the sensor network nodes is the key for saving a lot of energy and making a system really low-power capable. Intelligent firmware uses timer routines for waking up, doing short processing, eventually transmitting/receiving data and then going to power save mode again. The duty cycle of the wakeup-period must be extremely low (< 1%) to achieve long battery lifetimes. Because the system's wakeup time is very short and the point in time is mostly random, transmitting information wirelessly from a node to a basestation (or another node of course) creates some extra requirements. The straight-forward approach of solving these issues is keeping the basestation powered to receive the nodes transmission.
Thinking of a mesh network like ZigBee, in principle only end devices or so called "reduced function devices" (marked with 'R' in figure 1) can be low-power. – All nodes fulfilling routing tasks ("full function devices") have to keep their receiver continously on and this increases the power consumption in a way that these nodes have to be mains powered.

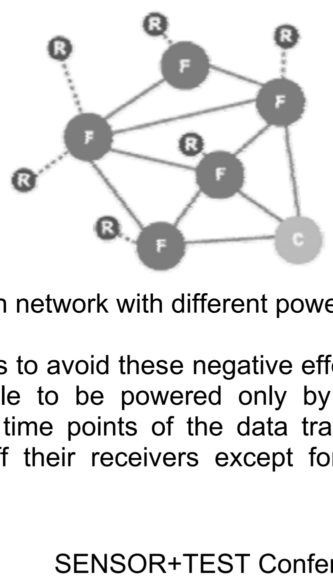

Figure 1 – Mesh network with different power requirements

There exist already some approaches to avoid these negative effects on power consumption, creating full mesh networks that are capable to be powered only by batteries. The power efficiency is accomplished by synchronizing the time points of the data transmission between the nodes. The router nodes are able to switch off their receivers except for a short period of time when the

transmissions of the nodes are likely to be received. The clocks inside the nodes have to be very accurate for this to function and every data transmission must include information for the resynchronization of the clocks.
The reduction of the power consumption in such a synchronized network can be further optimized in terms of peak power consumption, which is mostly limited by the battery type. Also the overall power consumption can be further reduced by reassigning the duties of the sensor node. Traditionally the RF transceiver is a relatively stupid piece of silicon, just for “raw” transmitting and receiving data. A new approach of a European company adds some additional data logic to the transceiver, implementing a whole MAC layer in hardware. In the first instance this unburdens the microcontroller from serving lower level protocol tasks and enables longer sleep periods of the controller. A positive side-effect is the saving of program and data memory in the controller as well as the higher flexibility in software development.
In addition to the migration of parts of the protocol stack, the frequency generation for the microcontroller can be done by the transceiver. This does not only save the cost for the controller crystal in the BOM – together with a high precision timing engine it permits the elimination of timer routines running in the microcontroller. So we can get rid of unnecessary timer interrupts, waking up the microcontroller and consuming precious energy for tasks the transceiver can handle on his own.
The change in perspective concerning determination of wakeups and frequency generation leads to a more challenging firmware development, but opens up the possibility of saving up to 60% of the energy a traditional design would need.

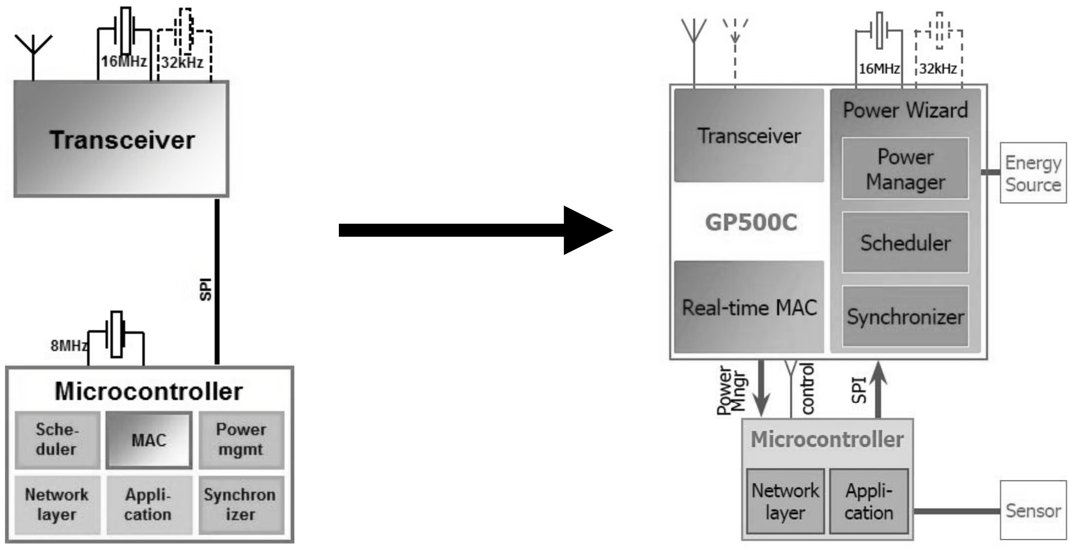

Figure 2 – Traditional design of a sensor node vs. design with ‘intelligent’ transceiver

To conclude, there are lots of possibilities for the development of energy efficient sensor nodes. Besides using up-to-date hardware components, the most effect on efficiency can be achieved by doing a sophisticated firmware development with power management (duty cycling) algorithms for all components of the node. Introducing a specialized, intelligent communication controller instead of a traditional ‘stupid’ transceiver marks a turning point in hardware and firmware development for wireless sensor networks, leading to an energy efficiency that cannot be accomplished with a traditional setup.

[1] – SAB8032A, Siemens AG
[2] – AX5042, V2.2, AXSEM AG
[3] – Atmega8, Rev. 2486M-AVR12/03, Atmel
[4] – AtTiny48, Rev. 8008B-AVR-06/08, Atmel
[5] – CC400, Rev. 3.2, Chipcon AS
[6] – CC1100, Rev. 1.1, Texas Instruments