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Power Consumption Considerations of GSM-connected Sensors in the AgroDat.hu Sensor Network

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Abstract: The number of large sensor systems is rapidly growing nowadays in many fields. Well-designed Big Data solutions are able to manage the enormous data flow and create real business benefits. One dynamically growing application area is precision farming. It requires robust and energy-efficient sensors, because the devices are placed outdoors, often in harsh conditions, and there is no power outlet "in the middle of a corn field". Power efficiency is in general one of the major themes of the Internet of Things (IoT). According to the IoT vision, embedded sensors send their data to processing units (either located near to the sensor or on some intermediate "gateway" device or in the cloud) using heterogeneous transport networks. Some sensors employ short-range network like Bluetooth and some "gateway" device like a tablet. Other sensors directly connect to wide-area networks like cellular networks. This paper will analyze different communication patterns accomplished over GSM network from the viewpoint of the energy consumption of the sensor device with the assumption that the sensor is stationary. The measurements were done using two different GSM modems designed for embedded systems to ensure that the results represent a wider picture and not some implementation property of a particular GSM modem. Recommendations are given about the strategies applications should follow in order to minimize the energy consumption of their GSM subsystems. *Copyright © 2015 IFSA Publishing, S. L.*

Keywords: Agriculture, Soil sensor, Power efficiency, Cellular communication, Communication strategies.

1. Introduction

[1]Internet of Things is often considered a recent trend but the vision was presented first in 1991 [15]. Weiser envisioned computers that "disappear into the background" and are connected with wired and wireless links. One key element of Weiser's ubiquitous computing was the low-power nature of the computing elements that are able to function for an extended period of time without recharging otherwise battery issues would prevent the devices from "disappearing into the background". Low-power and ultra lowpower energy consumption has been a key IoT research theme ever since [14, 16].

IoT systems employ heterogeneous networks to connect the sensors to the data processing units. Some solutions are based on short-range networks (e.g. Zig- Bee, Bluetooth), the data is collected by some "gateway" device (e.g. smartphone, tablet, set-top box) which then connects to a wide-area network. Isolated sensors that are rarely visited by humans and are far from any other elements of the ubiquitous network cannot adopt this solution, these sensors

[1] This article is an extended version of our SENSORNETS 2015 paper [11].

have to connect to the wide-area network directly. The most common wide-area network with low connectivity cost and large coverage is the public cellular network.

2. The AgroDat Project

Today sensors and sensor networks gain more and more importance in many application areas. Machines (including cameras, sensors, satellites, imaging devices, etc.) are already generating more data than we, humans and business processes (Fig. 1). These devices often operate in a harsh environment without access to electric networks, where robustness and energy efficiency are very important characteristics.

One such application field is agriculture. Precision agriculture is an integrated agricultural management system incorporating several technologies. This technology can reduce the cost of producing crops and the risk of environmental pollution [4]. The Agro- Dat R&D project with notable industrial and scientific partners aims to build an agricultural information system in Hungary. The system relies on collecting and analyzing high-volume data about crops and environmental conditions, like soil moisture and temperature, air temperature, precipitation, solar radiation, etc.

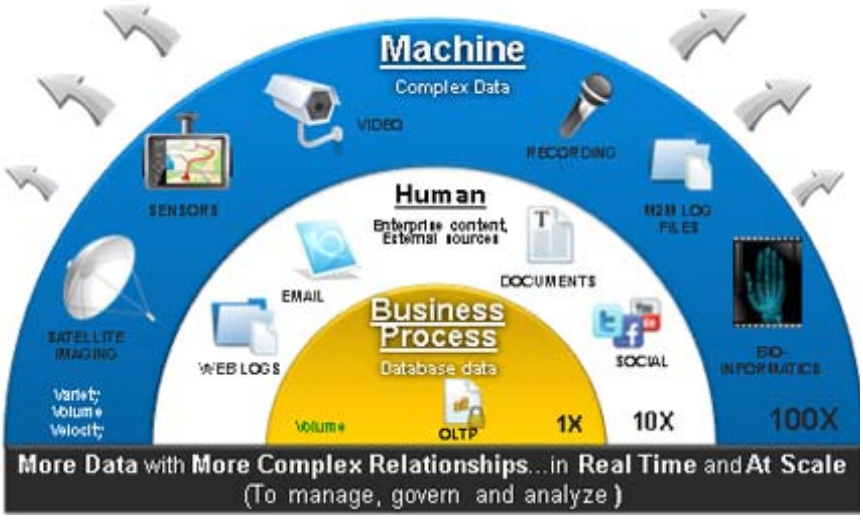

Fig. 1. Sources of the data growth (source: TDWI).

Soil sensors (see Fig. 2) can measure water potential, electric conductivity, volumetric water content, soil temperature etc. Electric conductivity correlates with salt content, influencing plant growth. Water potential refers to the water available for plants. This data can be used for planning irrigation, forecasting plant diseases, and analyzing soil aspiration. Light sensors (see Fig. 2) can measure the intensity of photosynthetically active radiation, or the spectrum of incoming and reflected light in certain bands, which can then be used to calculate the Normalized Difference Vegetation Index and Photochemical Reflectance Index [6]. These indexes correlate closely with vegetation and photosynthetic activity respectively, and they are good indicators of biomass and plant stress. Sensors can measure relative humidity, air temperature or vapor pressure. These values are linked with plant evaporation. Leaf wetness sensors are designed to detect wetness (presence and duration) and ice formation on leaf surfaces. The data is useful for forecasting plant diseases and planning spraying actions.

Combining different sensors into a sensor group creates synergies, and during the design of such a sensor unit, low energy consumption and ability to withstand harsh environmental conditions are important objectives. Much of the data needed for the agricultural information system can be collected by these sensor units, which can make measurements even on a minute-rate. Data from the sensors across the fields will be sent via GSM networks onto central servers.

Fig. 2. Decagon soil and light sensors (source: Decagon).

Sensors are very different in terms of their data communication requirements. Some sensors may send large amount of data, even in real-time (like streaming video). The current batch of agricultural sensors being developed by our project has the following properties.

- These sensors are stationary. Once installed, they move very rarely.

- Their environment changes only slowly. For example sudden changes in ground temperature or ground moisture are rare. This means that sensor values can be sampled with quite long sampling periods (multiple hours or even daily).
- The quantity of the data to be transmitted is relatively small. One measured quantity is a scalar value and the sensor equipment measures about 10-20 such quantities.
- These sensors are installed on locations that are rarely accessed and are far from the usual network infrastructure endpoints. For example one of our sensors is meant to be installed on large corn fields. Long, unassisted operation is an important requirement.

These requirements have led to the following high-level design decisions.

- The sensors will be connected using ordinary GSM network directly, without the help of some "gateway" node. Each sensor will be a GSM endpoint.
- Low-bandwidth data bearers like SMS or GPRS satisfy the transfer requirements.
- Low energy consumption/long operating time without on-site service is crucial.
- Remote manageability of the sensor is a must.

The remaining sections of the paper will discuss the proposed communication architectures, the sensors supported by the sensor station, the communication alternatives we have evaluated and the evaluation results.

3. The Sensor Station

The parameters measured by the sensor station were established according to a risk analysis of the corn production [5]. The sensor station comes in two variants. One variant measures only underground parameters. Except for a plastic dome protecting the GSM antenna, this station has almost no parts above the ground (see Fig. 3). In addition to the underground variant, the sensor station can be equipped with a pole that contains instruments above the ground. This extra pole is shown in Fig. 4. The underground sensor set can measure the following parameters:

- Soil temperature (depth: 5-20-40-60-80 cm)
- Soil moisture (depth: 5-20-40-60-80 cm)
- Concentration of salts in groundwater
- CO_2 concentration in the ground

The sensor station measures the following parameters above the ground.

- Air temperature (height: 20 cm, 2 m)
- Humidity (height: 20 cm, 2 m)
- Rainfall (height: 1 m)
- Wind speed and direction (height: 2 m)
- Solar radiation intensity (height: 2 m)
- Leaf wetness (height: 1 m)

The construction of the sensor station is modular. The sensor control (based on a microcontroller and I2C bus) and the battery units are always present. The sensor control unit is connected to the communication unit by means of an asynchronous serial interface. The modular construction allows the usage of different communication units.

Fig. 3. Underground part of the sensor housing.

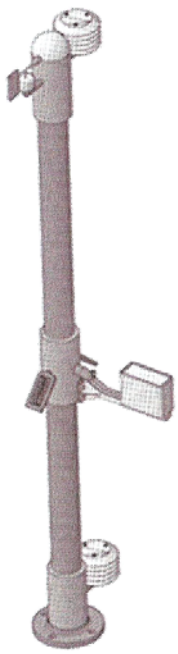

Fig. 4. Pole with sensors above ground.

4. Communication Architecture of the AgroDat.hu Network

As the first version of the AgroDat.hu sensor network will target corn, typical cornfield locations were considered when designing the communication architecture. Due to large field sizes and the production area often located far from existing infrastructure, only a radio technology with large

coverage area was acceptable. There are a number of alternative radio technologies with this characteristic (e.g. WiMax or custom VHF/UHF system) but due to its wide availability, low cost and well-established regulatory framework, we decided to use the GSM mobile network.

The first version of the sensor network collects data that change slowly (e.g. soil temperature, soil moisture) and the data representation requires only short data packets (with our coding format it means 200- 400 bytes of data). This means that the sensor communicates on the mobile network relatively rarely (1-3 times a day) and even then only low amount of data is sent. Part of the sensor stations is only equipped with underground sensors and minimally protrude above ground level therefore solar cell-based power supply was not possible. Energy efficiency was a key requirement when designing the sensor station. Due to the low amount of data transfer and the energy efficiency requirement, the prorotype was designed using the low-bandwidth services of the GSM network. This may mean GPRS or SMS-based data transfer.

We prepared two versions of the communication architecture. The first is based on GPRS, the second uses SMS-based data transfer. In case of GPRS the sensor may access the web infrastucture directly over the HTTP protocol. This is advantageous from the point of view of the server side as numerous solutions providing extreme scalability are available based on the HTTP protocol.

The relatively low amount of data and the compact binary encoding permits the data transfer over the Short Message Service (SMS). Even when encoded into textual format, our measurement data can fit into 3-4 Short Messages (SM). Assuming 3 measurements per day, this means maximum 12 SMs per day which is a reasonable cost. From the architectural point of view, the SMS infrastructure can be connected to as mobile endpoint or through the application protocol of the SMS Center (SMSC). Both solutions require an additional software component between the SMS infrastructure and the application server. This software component adapts the SMS interface of the mobile endpoint or the SMSC application protocol interface to the application server and compared to the variant using only HTTP, it means a more complicated architecture. The other consideration is the power consumption of the sensor unit. As we will demonstrate later, sending 112 bytes requires an order of magnitude less power when using SMS compared to GPRS. On the other hand, the battery power required by data transfer operations is still negligible compared to other elements of the power consumption, namely keeping the module registered on the network. We decided that the advantages of the direct HTTP communication exceed the disadvantage of the slightly higher overall power consumption and we decided to use a GPRS-HTTP-based architecture. Fig. 5 shows the GPRS-HTTP-based communication architecture.

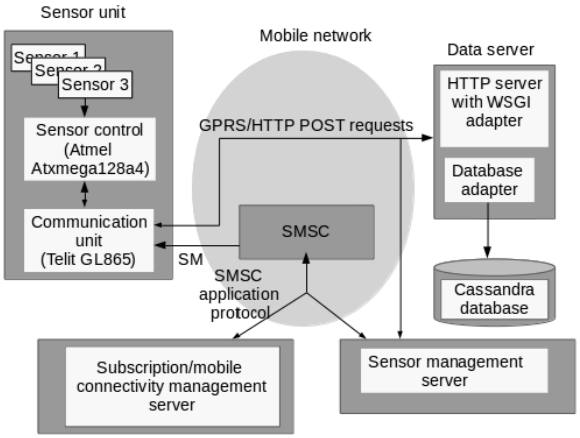

Fig. 5. Conceptual communication architecture.

According to the plans, the sensor network will consist of 300-1000 sensors. Efficiently operating so many endpoints cannot be accomplished without a remote management solution. According to the plans, the sensor network will be managed by two separate sensor management systems. The HP Dynamic SIM Management (DSM) system will manage the SIM cards which include the inventory of SIM cards, the assignment of the SIM cards to sensors, monitoring the operation of the mobile endpoints and security services like checking whether a specific SIM card is still in its assigned sensor. HP DSM implements a subset of with a SIM Toolkit application installed in the SIM cards. This SIM Toolkit application communicates with the HP DSM server components using the SMS infrastructure.

A custom management system is provided to handle the non-telecommunication-specific properties of the sensor station. For example such properties are the configuration of the measurement times or the reception of error reports from the sensor. This sensor management system also uses the SMS infrastructure for sending asynchronous messages to the sensor while management operations requiring larger transfer sizes are accomplished over the GPRS-HTTP bearer. Energy efficiency issues related to the messages sent from the server to the sensor will be discussed later in the paper.

5. Evaluated GSM Modems

In order to ensure that we are really evaluating the communication alternatives, we chose to run our measurements from two different GSM modem vendors.

GL865-QUAD is a variant of Telit's extremely popular GE865 product family [1]. The module comes in DUAL (GSM900, DCS1800 frequency bands) and QUAD (GSM900, DCS1800, GSM850 and DC1900 frequency bands) variants. The module has 2.5G network support which means that it can access GSM (voice call and SMS) and GPRS network services. 3G and higher is not supported by

this family of modules. Telit offers 3G modules too but as many sensor applications can be implemented with 2/2.5G, the lower cost and power consumption make these 2/2.5G modules very popular with connected sensors.

Unique property of the Telit modules is that many of them, including the GE/GL865 family include an entire runtime for application logic. The modules can be used in GSM modem mode when the application code is executed by some external CPU (e.g. a microcontroller) but a standalone mode is also available when the application code is executed by the on-chip Python interpreter. The module offers features of a sophisticated embedded platform: non-volatile memory in the form of a file system, A/D and D/A converters and general-purpose I/O pins, all accessible from Python code. The GE/GL865 can therefore implement the entire sensor control, not just the cellular communication aspects.

SIMCOM's SIM900 module [3] was selected to cross-check the power consumption measurement results of certain communication scenarios on a different GSM modem implementation. The SIM900 is a quadband GSM modem. It is a more traditional unit in the sense that SIM900 needs an external CPU to execute the application logic. SIM900 also has a set of built-in peripherals, including real-time clock, A/D converter and general-purpose I/O pins. These peripherals can be manipulated by custom modem commands.

Power consumption measurements were accomplished by inserting a serial 0.1 Ohm resistor into the power line of the GSM modules. These GSM modules also include the RF power circuits so the consumption of the whole communication hardware, including the RF power amplifiers was measured. Additional interface circuits, e.g. RS232C drivers were not incorporated into the measurements but these circuits are not necessarily present in embedded sensors. The voltage drop on the serial resistor was measured with a digital multimeter which measured with about 3 Hz sampling frequency and sent the samples to the PC where the samples were recorded. The effect of the filter capacitors on the power lines is such that higher frequencies are filtered out so this relatively slow sampling rate was acceptable. The samples were further analyzed using the R/R Studio mathematical suite. (http://www.rstudio.com/)

6. Communication Scenarios

6.1. Network Registration

This is seemingly the simplest scenario but it comes with the most complications. Registering on the network and staying registered involves network registration and location update procedures but more importantly, it requires that the GSM module is active and listens to network events. As we assume stationary operation, procedures relevant to mobility management e.g. cell handover do not occur but in order to stay registered on the network, periodic location update has to be executed. Fig. 6 shows the power consumption of the Telit GL865 executing this scenario. The two spikes of power consumption are related to the network registration and location update procedures. Location update occurs on the network used during the measurements (Telenor Hungary) in about every 55 minutes which is a quite typical value and can be expected to be between 30 minutes and 2 hours. It is more important to note, however, that the idle power consumption of the module is about 7 mA. This means that while the actual network procedures consume 720 mAs (milliamper-second) for the network registration and 400 mAs for one location update (with this network, there are about 26 location updates per day which means about 10400 mAs or 2.89 mAh cost for location updates), keeping the module operational costs about 170 mAh for a day.

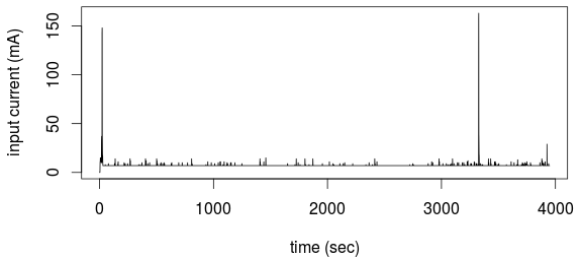

Fig. 6. Telit GL865 power consumption (initial registration and location update).

Note that these values are relatively unaffected by the received signal strength. The measurements were done with RSSI=5, RSSI=4 and RSSI=2 signal strengths and the results were very similar. The reason of this similarity is that actual network transmission is very short in these scenarios, transmission power difference hence averages out.

The results are very similar with the SIM900 module (Fig. 7). Short power consumption spikes related to the network registration and location update procedures can be observed but it is more important to note the idle current consumption of the module which is close to 20 mA. While the network registration procedure costs only 834 mAs and 26 location updates cost 2.71 mAh, keeping the module operational costs 456 mAh for a day.

Both modules offer custom power saving modes. The idea behind these modes is that only the functional units executing GSM procedures remain operational, units communicating with the application CPU (and in case of the Telit module, units executing the application logic) are switched off. In case of the Telit GL865 this mode is activated by the MOD.powerSaving() Python call that places the module into power-save mode for the specified duration of time. If an event (e.g. incoming network event) occurs during this period, the power-save

mode is exited and the application logic may start processing the event. As SIM900 does not have an application execution environment, powersave mode is offered differently. The AT+CSCLK ("slow clock") command with parameters of 1 or 2 switches off the interface with the application processor with slightly different wake-up mechanisms. Either the communication interface is re-activated when DTR is low (AT+CSCLK=1) or the module is reactivated when there is data available on the serial interface serving the application logic (AT+CSCLK=2).

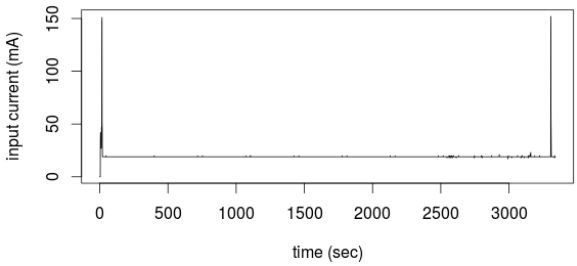

Fig. 7. SIM900 power consumption (initial registration and location update).

With these power saving modes, the idle consumption of the devices decreases quite dramatically. For both the GL865 and the SIM900, the idle power consumption falls below 1 mA. Specifically, for the GL865 the power consumption needed to keep the module operational for a day is about 11 mAh while network procedures cost additional 2.9 mAh, resulting a total of 14 mAh for a day. For the SIM900, the idle power consumption for a day is about 23.3 mAh and network procedures add 2.71 mAh, resulting a total of about 26 mAh for a day.

These measurements show the importance of implementation-specific power-save modes and highlight the fact that the Telit GL865 is about twice more efficient than the SIM900 when it comes to low-power operation. It is a much more important observation, however, that even with power-save modes active, the continuous operation of the module has by far the highest cost. For the Telit GL865, only 20 % of the power budget is spent on actual network procedures, the remaining 80 % is the cost of keeping the module operational. The difference is more dramatic for the less power-efficient SIM900: only 10 % of the daily power budget is spent on network operations, the remaining 90 % is needed to simply keep the module active.

6.2. Data Communication

So far only the cost of being registered on the network was calculated. Data communication comes with additional costs. Our sensors send relatively small amount of data (10-20 scalar values) relatively rarely (1-2 times a day) so network bearers with lower bandwidth were analyzed. A wide variety of data encodings have been proposed for IoT applications but the area is far from settled. XML-based formats [13] and publish-subscribe frameworks are being proposed for IoT [8].

Our intention was to keep the amount of data transmitted, the power needed for data transmission and the CPU cycles needed to encode/decode packets low so we adopted a size-efficient data encoding based on ASN.1 and Basic Encoding Rules (BER) [2]. These BER data structures were then sent to the server using HTTP. Specialized protocols like CoAP have been proposed for IoT applications to replace the widely deployed Internet protocol suite (HTTP, FTP, TCP ...) [10] but CoAP is not that attractive on GSM transport networks where the limitations of 802.15.4 do not apply. Both GL865 and SIM900 support TCP by custom modem commands. Using the modules' native TCP support, HTTP was implemented in the application logic.

The power consumption was measured with increasing amount of data items (16 bit values) using the BER encoding mentioned earlier. With regards to PDP context handling, two different approaches were implemented. The first approach activates the PDP context, sends the packet then deactivates the context. This is closer to our data communication scenarios when we send data packets only rarely. In order to evaluate the cost of PDP context activation, the second approach activates the PDP context once, sends all the test packets then deactivates the context after all the packets are sent. Table 1 shows the results for the first approach while Table 2 shows the results for the second approach using the GL865 module. It can be observed that PDP context activation adds a constant but not too significant power cost to the communication scenario.

Table 1. Power consumption of data communication, PDP context activated/deactivated for each packet.

Data items	Packet size (bytes)	Power consumption (mAs)
16	287	2370
32	511	2595
64	1981	2945
128	4157	3307
256	8509	3951

Table 2. Power consumption of data communication, PDP context activated only once.

Data items	Packet size (bytes)	Power consumption (mAs)
16	287	1987
32	511	2180
64	1981	2590
128	4157	3270
256	8509	3570

Conclusion is that data size/data format optimization does matter when trying to lower power consumption. To significantly increase power consumption, however, data sizes must be several times larger than the baseline data size. Optimization of data sizes may be more relevant for ensuring data transfer in case the radio path between the base station and the sensor is not very optimal and hence the bit error rate is higher which is a common case for our agricultural sensors, some of them deployed at remote locations with less than optimal network coverage.

6.3. SMS Bearer

Data may also be sent using short messages, popularly called SMS. Binary SMS is often filtered by operators so we employed Base64 encoding and sent the ASN.1 BER content in textual format. Fig. 8 shows the power consumption using the SMS bearer with a 112 byte long data packet (which is actually 154 characters long after Base64 encoding) and Fig. 9 shows the sending of the same packet using GPRS. Intuitively, it seems that SMS requires much less power and it is indeed the case: GPRS requires 2347 mAs power while SMS needs only 247 mAs power. The large difference is caused by the fact that SMS uses signaling radio channels that are already allocated when the module registered with the network while GPRS has to allocate (and deallocate) additional radio channel for the data transfer. SMS is therefore attractive due to its much lower power consumption requirement but quite frequently the pricing of the subscription prevents using SMS extensively for data transfer.

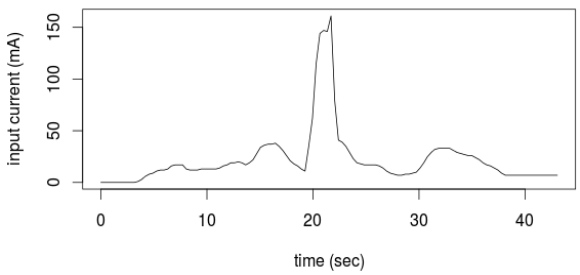

Fig. 8. Power consumption of the data transfer with SMS.

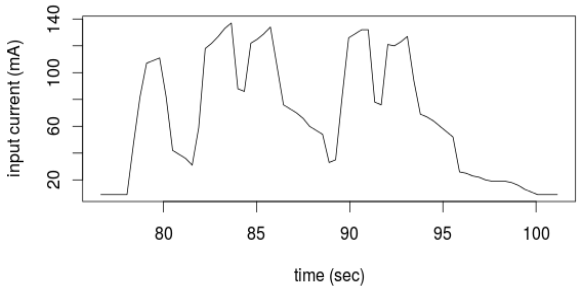

Fig. 9. Power consumption of the data transfer with GPRS.

6.4. Push Bearer

One strong requirement for our remotely placed sensors is manageability because physically accessing the sensors' location is not always feasible. Management operations are usually initiated by the management server operator asynchronously, independently of the sensor's scheduled operations. This requires a push bearer that can be used to instruct the sensor to contact the management server.

If the sensor is not registered to the network, such an operation is impossible. The management server operator may have to wait for the sensor to contact the server when the sensor sends in its scheduled batch of data and may send its management commands in the context of the sensor data sending session. While this approach is attractive due to its low power consumption, it makes life of management operators much harder because configuration updates or other management commands cannot be executed at any time, only after the sensor contacts the server for scheduled data sending. Also, in case of doubt (e.g. when an accident damaging the sensor is suspected), the sensor's health cannot be verified immediately which may prevent timely maintenance operations. Management requirements create a strong incentive to register the sensor to the mobile network continuously.

If the GSM module is registered continuously, short message service (SMS) may be used to send alert to the sensor to connect to the management server for management operations. As we have seen, SMS is very power-efficient and management operations are infrequent enough so that SMS pricing is not so much of an issue. Another option is to simulate the push bearer using TCP.

TCP-based push bearer simulation relies on the sensor to maintain a TCP connection to the management server. When the server wants to send a management packet, it may use the duplex nature of TCP streams to send the packet to the sensor. Timeout issues, however, make this solution tricky to implement. TCP timeouts on the sensor and on the server-side can be controlled by the implementation but mobile and backbone networks between the mobile network gateways to the servers often employ Network Address Translators (NATs) that remove IP address associations for TCP streams that look idle. The problem was demonstrated with a test program implemented on both the GL865 and SIM900 modules and a test server application deployed on a cloud-based Windows Server. The GSM modules attached to the mobile network (Telenor Hungary), opened a TCP connection to the server and left the connection idle. After a timeout expired, a packet was sent from the server to the GSM module. It was found that the maximum safe timeout period was 2 hours which is consistent with the recommendations in [7]. Longer timeout resulted in the server and the GSM module to be silently disconnected by some NAT on the network without either of the communicating parties being aware of the

disconnection. The results were consistent with both GSM modules, demonstrating that this behaviour is the property of the network between the GSM module and the cloud-based server. Without deeper investigation of the full network topology, it is hard to say where the NAT was located that terminated the connection.

Reliable implementation of the TCP-based push bearer must use a heuristic algorithm [12, 9] to estimate the timeout between the GSM module and the server by sending test packets with different timeouts. The heuristic algorithm must also be prepared for the fact that this timeout may also change dynamically, due to changes in the network topology. Once that timeout is known, a keepalive packet must be sent in any direction over the TCP stream to prevent any NAT that may be present between the GSM module and the server to terminate the connection. This keepalive operation has a power consumption cost.

Both modules are able to wake up from power-save mode when an incoming data packet arrives on a TCP connection that has been opened previously. The prototype for this test relies again on the built-in TCP stack in case of both modules. For the GL865, the reception of one such packet costs 942 mAs. Using 2 hour timeout (hence 12 such packets per day), the daily power consumption cost is about 3.1 mAh. The SIM900 performs better in this test, the cost of one keepalive packet was 570 mAs which means 1.9 mAh for a day. This means that the power consumption cost of maintaining one TCP connection is comparable to the cost of the location update operations that keep the module registered on the mobile network. For the Telit GL865, such keepalive procedure increases the daily power consumption by 22 %. For the SIM900, the increase is only 7 % due to the higher baseline power consumption of the module and the better TCP packet reception power cost. It must be noted that the GL865 also executed the application logic for this test but the SIM900 acted only as a modem. This means that additional power consumption cost must be calculated for the CPU that runs the application logic for the SIM900.

TCP-based push bearer comes with other problems on the server-side like keeping a large amount of TCP connections open at the same time but these issues are not discussed in this paper.

7. Conclusions

Directly connecting a remotely located, battery powered sensor to the GSM network comes with a set of compromises. In our case, the power consumption and manageability requirements were in direct conflict with each other. From the power consumption point of view, the best solution would be to attach the sensor to the mobile network only for the duration of sending the scheduled measurement data package. This would also decrease the load on the mobile network infrastructure in case of a large number of sensors. This approach would make the sensors more complicated to manage, however. In order to send a management operation, the management server operator should wait until the sensor connects back to the server for the scheduled data sending operation. If this never happens (e.g. the sensor is damaged, vandalized or misconfigured) then the sensor's deployment location must be visited which may not be simple for a remotely placed sensor.

The compromise may be the power-saving mode of the GSM modules. Both GSM modules we evaluated have such mode even though these features are non-standard and are specific to the particular GSM module. A daily consumption of 15-30 mAh means 80-160 days of operation with a low-cost 2400 mAh battery pack. As special, high capacity batteries are now commercially available, this operational time may be increased dramatically.

Push bearer is required for asynchronous management operations. SMS offers an attractive alternative. TCP-based push bearer is possible to implement with relatively minor increase of the power consumption but is problematic to make reliable due to NAT issues and limitations of the number of the TCP streams on the server side.

We aim to proceed in this research project with adding more sensors to the sensor station. Currently we are investigating imaging type of sensors that generate much more data and we expect that these new requirements lead to a better understanding of energy efficient sensor communication on cellular networks.

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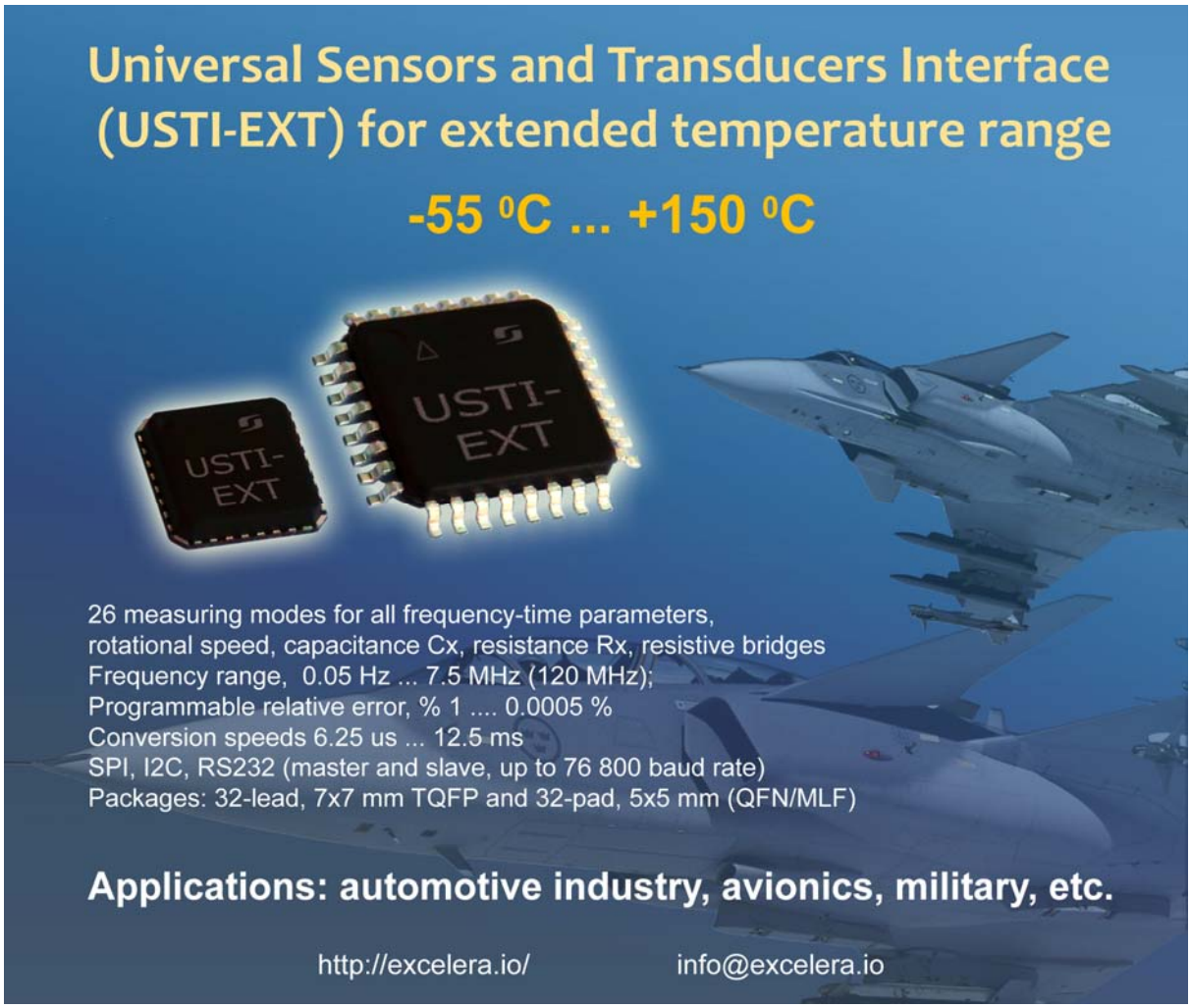
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