Efficient Power Consumption Strategies for Stationary Sensors Connected to GSM Network

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Abstract: The number of large sensor systems are 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 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 analyse 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.

1 INTRODUCTION

Internet of Things is often considered a recent trend but the vision was presented first in 1991 (Weiser, 1991). Weiser envisioned computers that ”disappear into the background” and are connected with wired or 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 low-power energy consumption has been a key IoT research theme ever since (Sundmaeker et al., 2010), (Zorzi et al., 2010).

IoT systems employ heterogeneous networks to connect the sensors to the data processing units. Some solutions are based on short-range networks (e.g. ZigBee, 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 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 (Figure 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 (Earl et al., 1997). The AgroDat R&D project with notable in-

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dustrial 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.

Soil sensors (see Figure 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 Figure 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 (Garrity et al., 2010). 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 determining 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. Sensors are very different in terms of their data communication requirements. The current batch of agricultural sensors being developed by our project have 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 numerical 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 are meant to be installed on large corn fields. Long, unassisted operation is an important requirement.

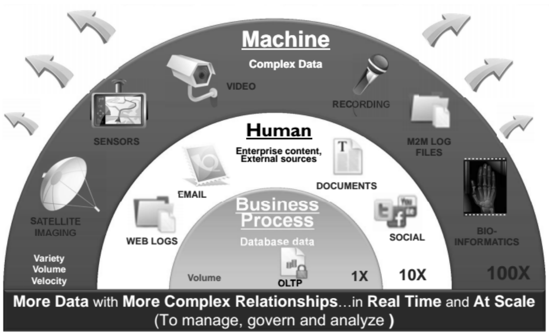

Figure 1: Sources of the data growth.

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

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 conceptual architecture of the system can be seen in Figure 3.

3 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 has 2.5G network support which means that it can access GSM (voice call and SMS) and GPRS network services. The modules can be used in GSM modem mode when the application code is executed by some

[1] GL865-QUAD, http://www.telit.com/products/product-service-selector/product-service-selector/show/product/gl865-quad/

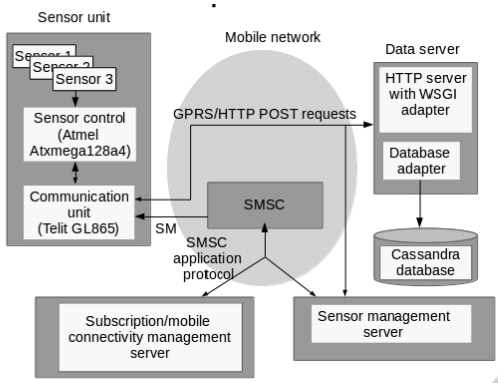

Figure 3: Conceptual architecture.

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. SIMCOM's SIM900 module [2] was selected to cross-check the power consumption measurement results of certain communication scenarios on a different GSM modem implementation. It is a more traditional unit in the sense that SIM900 needs an external CPU to execute the application logic.

Power consumption measurements were accomplished with about 3 Hz sampling the filter capacitors on the power lines filter out higher frequencies. The samples were further analysed using the R/R Studio mathematical suite [3].

4 COMMUNICATION SCENARIOS

4.1 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. Figure 4 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

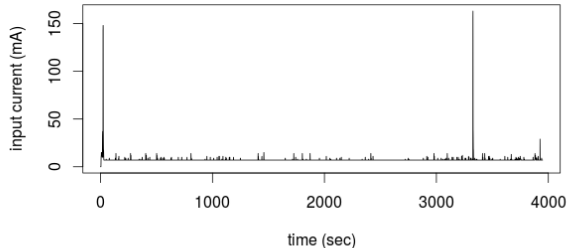

Figure 4: Telit GL865 power consumption (initial registration and location update).

used during the measurements (Telenor Hungary) in about every 55 minutes. This is a configuration value chosen by the network operator and can be expected to be between 30 minutes and 2 hours. Typically this value is constant for the same network. It is more important to note, however, that the idle power consumption of the module is about 7mA. 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. 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.

The results are very similar with the SIM900 module. 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. 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

[2] SIM900 Specification, http://wm.sim.com/downloaden.aspx?id=2972

[3] http://www.rstudio.com/

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.

4.2 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 numerical values) relatively rarely (1-2 times a day) so network bearers with lower bandwidth were analysed. A wide variety of data encodings have been proposed for IoT applications but the area is far from settled. XML-based formats (Su et al., 2014) and publish-subscribe frameworks are being proposed for IoT (Hakiri et al., 2013).

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) (Kaliski and Jr., 1993). These BER data structures were then sent to the server using HTTP implemented on top of the modules' native TCP support.

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.

4.3 SMS Bearer

Data may also be sent using short messsages, 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. Figure 5 shows the power consumption using the SMS bearer with a 112 byte long data packet (which is actually 154 character long after Base64 encoding) and Figure 6 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 signalling 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.

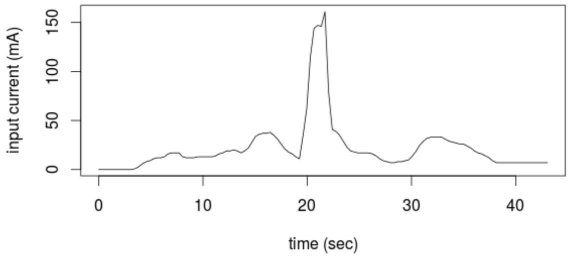

Figure 5: Power consumption of the data transfer with SMS.

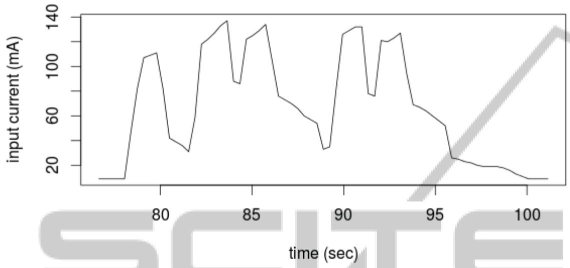

Figure 6: Power consumption of the data transfer with GPRS.

4.4 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 initated 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. 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 (Guha et al., 2008). 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 (Price and Tino, 2010), (Haverinen et al., 2007) 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. 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. 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.

5 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.

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.

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