Environmental Data-transmission Using Low Earth Orbit Satellites

Paul Skritek¹, F. Lukasch¹, K. Din¹, Th. Hodi¹ and Hermann Stadler²

Abstract

Low Earth Orbit Satellites (LEOS) provide world-wide data-communication using low-cost and low-power equipment and allow to exploit also those regions, which up to now where inaccessible by cables, land-based wireless or geo-stationary (GEO) satellite systems. A detailed report of a hydro geological prototype implementation for remote water-quality monitoring using LEO satellites is presented. The paper describes the setup, obtained results, conclusions and future aspects as well as costs. As a result, LEO satellite data transmission has proved as a ubiquitous reliable low-cost alternative for environmental low-volume data-transmission, allowing "near on-line" worldwide monitoring even from most exposed and inaccessible measurement sites.

1. Motivation

Low Earth Orbit Satellites (LEOS; orbit altitudes of approximately 1000km) provide worldwide wireless data-communications between arbitrary locations using low-cost equipment. This allows to exploit also those regions and dead spots, which up to now were inaccessible by land-based wireless (e.g. GSM) or geo-synchronous satellite (GEO) systems [1,2,4,6,7,14].

Our project³ among others focused on innovative low data-rate transmission scenarios for environmental applications [8,9,10,11]. Even Austria's geographic structure causes numerous "coverage gaps" for land-based wireless (e.g. GSM) or GEO satellite systems (e.g., limited southbound elevation angles, required high transmitter power).

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³ The Project „3rd-Generation Satellite Communication Networks“ was sponsored by „Impulsaktion Kooperation Fachhochschulen-Wirtschaft“, Project-No. 800 018
2. LEO Satellite Environmental Data Transmission

A distinct environmental application – water quality monitoring – was selected for developing a prototype data-transmission via LEO satellites [12, 13]. Due to climate changes and growth of earth’s population, potable water may be a most valuable resource within the next decades, requiring continuous data collection for permanent quality monitoring of spring water (or for sewage; for inundation or avalanche protection). Measuring stations, however, are often located inaccessible and manual data-retrieval is very expensive. Now LEOS enable world-wide uniform data-collection systems, which are not be restricted to certain regions. Also in Austria, many important springs (e.g., of Viennese and Graz water authorities or at the research project “Vordere Rettenbachquelle”) are not covered by land-based GSM-Systems or GEO-satellites. Up to now, data had to be retrieved manually, which often caused several months delay, because many springs are inaccessible during winter.

Another important point for reinforced use of LEOS in hydrology is the strong trend to in-situ measurements of most different parameters. Ion-selective electrodes and other measuring systems require maintenance and calibrations, that can be optimized by the immediate transfer of the measured data. In future also the control of automatic water samplers for event-monitoring is possible by means of bidirectional satellite data transfer.

3. LEO Satellite Systems

Fig. 1 compares parameters of LEO-, MEO- and GEO-Satellite systems [1,2,4,14].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LEO</th>
<th>MEO</th>
<th>GEO</th>
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<tbody>
<tr>
<td>Orbit Altitude</td>
<td>1000 km</td>
<td>10 000 km</td>
<td>36 000 km</td>
</tr>
<tr>
<td>Orbit Period</td>
<td>105 min</td>
<td>6,5 h</td>
<td>24 h</td>
</tr>
<tr>
<td>Satellite Visibility</td>
<td>17 min</td>
<td>130 min</td>
<td>24 h</td>
</tr>
<tr>
<td>Satellites required</td>
<td>30 - 70</td>
<td>10 - 15</td>
<td>3 – 5</td>
</tr>
<tr>
<td>Global Coverage</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Free Space Loss</td>
<td>150 MHz</td>
<td>136 dB</td>
<td>(156 dB)</td>
</tr>
<tr>
<td></td>
<td>1.5 GHz</td>
<td>156 dB</td>
<td>176 dB</td>
</tr>
</tbody>
</table>

Fig.1: Comparison of LEO-, MEO- and GEO-Satellite System Parameters

Based on previous elaborate verification measurements, the ORBCOMM LEO Satellite system was selected for prototype field tests [15-17]. ORBCOMM is a “Little-LEO” system with up to 36 satellites (currently 30 in service) in 6 orbital planes of 800km altitude (Fig.2). It is intended for “short message” bi-directional data-transfer (typically a few 100 Bytes) at 2400/4800 bps. It covers the entire globe, but “gaps” of typically 20 minutes may occur between satellite passes. Moderate operating frequencies (≈ 149 MHz uplink; 138 MHz downlink) provide large satellite foot-
prints and low-cost/low-power equipment, allowing, e.g., simple whip-antennas without critical alignments and small solar-panels as power-supply.

ORBCOMM satellite modems are “smart devices”, comprising a user programmable microcontroller with several I/O-lines and AD-/DA-converters (eventually also a built-in GPS-receiver) and thus can operate as “stand alone” data-acquisition systems [15–16]. The modems (“communicator”) store the data in the input-queue and automatically up-link it as soon as a satellite comes in view (similar to CSMA/CD technique used in LANs). Down-link transmission is performed either directly from the satellites to a Gateway Earth Station (approx. 15 stations worldwide) or as “Globalgrams”, where the data is stored in the satellite and down-linked when the satellite passes the desired Gateway Station. From there, data is forwarded as emails via Internet or X.25 to the receiver. Additionally, data from the Internet or other satellite modems may be transmitted via satellite to any “nomadic” ORBCOMM modem.

4. Water-Quality Monitoring Application

Between May 2001 until May 2002, several field-test transmissions of water-monitoring data of the Vordere Rettenbach spring (Upper Austria) were performed successfully, proving high reliability even for a simple test set-up.

This spring is monitored by the Hydrological Survey of Upper Austria within the scope of the National Park Kalkalpen and was chosen by Joanneum Research, Institute of Hydrogeology and Geothermics because of its “worst-case” location – a narrow mountain valley without PLMN-access and no GEO-satellite visibility. Until then, data had to be retrieved manually, which was very expensive and caused delays up to several months (during the winter period) before data was available.
In this prototype application, the ORBCOMM modem controlled the measurement process (Fig. 3). Every 15 minutes it initiated a measurement cycle (gauge height, conductivity, temperature and turbidity) of the data-logger (Logotronic “Gealog”) and transferred the data (approx. 125 Bytes) into the modem input queue. The input queue was set to its maximum 7kByte, enabling buffering of up to 43 data-sets. According to prior tests, a simple λ/2-motorcycle whip-antenna was used. Although flat-panel antennas could perform better at such locations, they can, however, not be used because of snow and ice during the winter period. Power was supplied by a solar-panel with buffer battery and electronic load controller.

![Fig. 3: Block diagram of the implemented LEO satellite water-quality data transmission system](image)

As soon as a satellite came “in view”, the queued data was transmitted and relayed via satellite to the Gateway Earth Station (e.g., GES at Matera/Italy). From there the Gateway Control Center (GCC) forwarded the data via Internet as emails to the receiver. Additionally, data was re-transmitted via satellite to a second remote satellite modem. Both approaches showed similar performance. A graph of the transfer delays of the first basic test-series in May 2001 is shown in Fig. 4.

Although most of the time data was transmitted with 15 – 30 minutes, due to the floating “satellite gap” (caused by different orbit periods of the satellite planes and aggravated by satellites out-of-service or GES interruptions) transmission delay peaks of several hours occurred. In this first test series, the original data-logger format was transmitted, which yielded 133 Bytes of information per 3-channel measurement including ORBCOMM address overhead.
Between October 2001 and May 2002, a further long-term transmission was performed. Among others, data-compression was added to our satellite modem software, which reduced the data-set size to approx. 30 Bytes (data still “intelligible” and easy to decode at the receiver). It reduced transmission costs significantly and also improved the reliability to a very low data-loss rate of less 0.3% within certain periods. In January 2002, a fourth measurement channel (turbidity) was added. Due to temporary problems of the email-account at the Fachhochschule, however, approx. 1.9% data-loss occurred.

<table>
<thead>
<tr>
<th>Measurements 9.-23.5.2001</th>
<th>Satellite-to-Email Transmission</th>
<th>Satellite-Re-Transmission</th>
<th>Measurements 6.10.01 – 29.05.02</th>
<th>Satellite-to-Email Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>1342 Messages a 133 Bytes</td>
<td>1324 (98,6%)</td>
<td>1324 (98,6%)</td>
<td>19 781 Messages a x 25 / 30 Bytes</td>
<td>19 416 (&gt; 98,1%)</td>
</tr>
<tr>
<td>Data-Sets correctly received</td>
<td>1324 (98,6%)</td>
<td>1324 (98,6%)</td>
<td>19 416 (&gt; 98,1%)</td>
<td>not measured</td>
</tr>
<tr>
<td>Misaligned order, etc.</td>
<td>4 (0,3%)</td>
<td>4 (0,3%)</td>
<td>(375) (&lt; 1,9%)</td>
<td></td>
</tr>
<tr>
<td>Lost Messages</td>
<td>13 (0,97%)</td>
<td>13 (0,97%)</td>
<td>(375) (&lt; 1,9%)</td>
<td></td>
</tr>
<tr>
<td>Average Delay</td>
<td>49 Min.</td>
<td>54 Min.</td>
<td>45 Min.</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 5: Summary of quality parameters of the data-transmission.

More then 57% of the data was received within 15 minutes and 76% within less than 1 hour. Single latency peaks of several hours, however, again occurred (Figs. 5, 6). These figures closely agree with predicted values from “LeoSphere”-simulation software [18]. Total average delay was about 45 mins. (certain weekly minima 19 mins.). Those long transmission latencies obviously arouse from the “worst-case” location in a narrow valley: Similar tests at “best-case” conditions (open field, river Danube) yielded e.g. average delays of only less than 3 minutes [11].
5. Cost Comparisons

The basic satellite modem hardware (ORBCOMM smart bidirectional Communicator, whip antenna and mains power supply) is available at approximately 900,- €, which is slightly higher than for a GSM modem (which usually lack data-acquisition functionality).

Similar to GSM-SMS, ORBCOMM is primarily intended for small data-block applications (typically up to 250 Bytes per message). Transmission costs for a monthly data-volume above 30 kByte are roughly 0,25 €-Cent per Byte (charging on a Byte-by-Byte base). Compared with typical GSM-SMS costs (max. 160 Bytes) of 10 €-Cent per SMS (home net) and 30 €-Cent (roaming), one obtains, that satellite transmission is cheaper for data-packets up to approx. 40 Bytes. For "roaming"-applications, satellite transmission is cheaper even up to packet lengths of 120 Bytes (Fig.7).

For the implemented transmission of spring water measurements (acquisition of water level, temperature, conductivity and turbidity in 15 min. intervals; simple data-compression), transmission costs were roughly 200,- € / month. Satellite transmission hence is significantly cheaper than manual retrieval (approx. 750,- € / month) and also less than GSM-SMS transmission costs (estimated 300,- € / month). Applying increased data-compression (giving additional ≈ 50% reduction, but sacrificing...
the human intelligibility of the raw-data) could further drop satellite transmission costs to approx. 100,- € / month.

![Graph showing comparison of transmission costs ORBCOMM vs. GSM-SMS](image)

**Fig. 7.** Comparison of transmission costs ORBCOMM vs. GSM-SMS

### 6. Further Developments and Conclusions

Successful long-term prototype tests of remote water-quality monitoring from “worst-case” topographic locations have successfully proved the applicability of LEO satellites for a broad range of “nomadic data-transmission” in environmental-protection applications. These results extend applications from non-critical coverage areas such as oceans or open fields [3,5]. It allows bi-directional “near real-time” transmission of short data-sets from vast areas and “dead-spots”, where land-based cellular- or GEO transmission systems are inapplicable. This enables world-wide unified installation of data-loggers and data-retrieval “near on-line” via internet at low costs.

In a next step the test-set-up will be transferred to “St. Ilgen”-Spring (Graz water authorities, measurements July – Sept.2002), another karstic spring in the Hochschwab area, where no PLM wireless communication infrastructure is available. Furthermore, a concept for event triggered measurements linking several monitoring stations via LEO satellite modems is under development. Forthcoming implementations will include a specific email-client for automated data-retrieval and – presentation.

**Acknowledgement**

This joint project of Technikum-Wien, Joanneum Research, Alcatel, Logotronic and Via-Donau was sponsored by “Impulsaktion FH-Wirtschaft” of the Federal Ministry of Transport, Innovation and Technology (BMVIT), coordinated by the “Forschungsförderungsfonds der gewerblichen Wirtschaft (FFF)”. The authors are grateful for the coordination of Dr. K.
Woletz and knowledge-retrieval/programming/measurements by the project-students F. Aichmann, W. Bruckner, J. Trögl, R. Glaser, J. Beranek, C. Haydn, C. Heger, K. Scheida, G. Soukup, C. Weiß. Valuable co-operation was provided by ORBCOMM-Czech and –Germany as well as by Panasonic’s Communicator development department.

References