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Small Mobile Ground Terminal Design for a Microsatellite Data Collection System

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Many developing countries with the help of developed ones have gained space technologies experience by building and launching microsatellites which involve affordable costs. Apart from technology transfer, different applications could be achieved using a LEO (low earth orbit) microsatellite over large areas where other communication systems are lacking. The use of a single LEO microsatellite for data collection implies a complex hardware and software architectures of the ground terminals especially when they are designed to be small, lightweight and economical. The ground terminal proposed in this paper is a small, assembled device that incorporates a microcontroller, RAM, Flash memory, Real Time Clock, OEM GPS board, AFSK modem, backup lithium battery, and a transceiver. Its built-in software handles all functions involved in collecting, packaging, and transmitting the various data to the microsatellite. A satellite visibility calculation algorithm, developed in assembly language, makes the terminal intelligent without the need of a PC which makes other available commercial terminals heavy and difficult to carry. The small terminal can be mounted on any mobile or fixed platform to accomplish missions such as data collection from remote sites or mobile automatic position reporting. The connected sensors or GPS are sampled at regular time intervals and data stored in memory. Once the satellite comes into range, the gathered data is packetized and transmitted. The terminal can even be connected to any text editing device for messaging. This paper describes the hardware and software solutions achieved to develop a small, very low cost and automatic ground terminal for use with a single microsatellite data collection system.

I. Introduction

THE use of a single microsatellite in a low earth orbit combined with low cost ground terminals allows developing countries to have a very economical space communications system. Sharing the launch opportunity with other satellites cuts down the overall system cost. Today, the store-and-forward communication payload of a microsatellite is simple and easy to build within a minimum timeframe.[1] the ground terminals and stations could be built using the terrestrial communications equipments. Large rural areas could be covered by the satellite and provide them with missions including messaging, data collection and mobile localization. A central ground station could gather via the microsatellite various data from remote sites. The store-and-forward communication payload allows taking advantage of the global coverage of the satellite in a low earth orbit by reducing the ground infrastructure. By making the ground terminals autonomous and intelligent, the ground station receives data regularly from inaccessible zones where human presence is expensive and difficult to support.

Due to frequent launch opportunities, global coverage and sun-synchronous advantages, the polar orbit is considered with much more interest. Using store-and-forward techniques a message can be delivered anywhere on

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the Earth's surface within a maximum of 12 h. The average message delivery period would be around 4 h. Particular figures for the polar orbit are dependent upon geographical location of source and destination. For data transfer with source and destination along the same line of longitude the message delivery can be almost immediate.

The ground terminals in charge of collecting and sending data to the satellite are more complex due to the non-permanent visibility of the single satellite. The terminal has to predict the satellite passes by means of orbit calculation. Existing ground terminals like for Orbcomm and Argos systems do not need to know the satellite position to begin transmitting data.[2-4] In the first case Orbcomm constellation have numerous satellites so there is (approximately) always one satellite in the visibility cone of the terminal. In the second case, Argos terminals do not care about the satellites visibility and transmit their data in a repetitive manner.

II. Store-And-Forward Communication System Description

Digital Store-and-forward communication via LEO (Low Earth Orbit) satellites is a method for non- real-time communication of digital information. The originating ground terminal sends the collected data message to the LEO satellite, the satellite stores the message in its on-board memory, and the destination ground station later retrieves the message. Between the storage and the retrieval of the message, the LEO satellite moves around its orbit and the Earth rotates on its axis. These movements change the satellite's communications footprint, bringing it to different areas of the Earth. Thus, the satellite physically carries the message from one ground station to the other, and the destination ground station is not necessarily in the satellite footprint at the same time as the originating ground station. The Store-and-forward communication concept has been used with much success in different missions including health and education applications where the microsatellite ties together medical centers and schools within rural and developing areas with those in developed areas.[7]

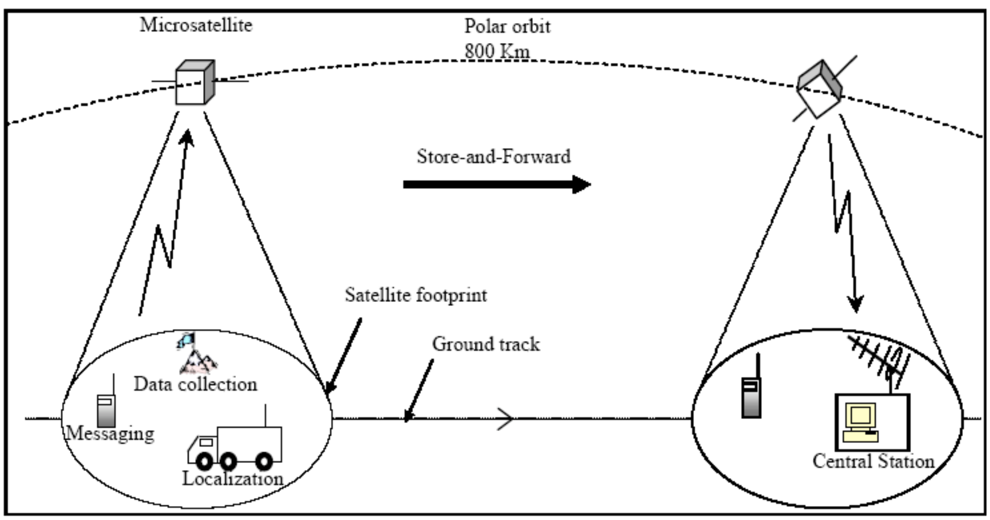

Fig. 1 Store-and-forward applications for a microsatellite.

The drawback of a single-satellite LEO system is the delay in the message transfer from the ground terminal to the central station due to the nonpermanent visibility of the satellite. The originating ground terminal must wait for the satellite to come into range before it can upload a message, and then the message must be stored on-board the satellite until the destination ground station comes into the footprint. These combined delays are not suitable for telephone communication but other applications such as messaging or data-platform monitoring with limited financial budget them.

The main missions achieved by the system are data collection, localization (position reporting), and messaging (see Fig. 1). The data collection mission consists of collecting various data from remote sites. Examples include drifting buoys for oceanography and autonomous weather stations in inaccessible sites. The messaging mission allows message exchange between two ground terminals or between a terminal and a central station. This is useful in the areas not covered by any other communication system: examples include latitudes above 80 deg where the GEO satellites coverage is no longer available.[5] Any mobile with a localization ground terminal can be tracked by the central station witch plots its path on a map using data received from the terminal. Ground terminals for all the three missions have the same hardware, except the message source which is a keyboard for messaging, sensors for data collection and a GPS (Global Positioning System) receiver for mobile localization.

During the nonvisibility of the satellite, the ground terminals collect data (position or sensor value) at regular intervals and store it in its memory. When the satellite comes into range the whole data stored is packetized and transmitted. The amount of data that a ground terminal is allowed to transmit depends on the capacity of the satellite RF channel and the number of terminals we want to operate.

An orbit calculation algorithm is implemented inside the ground terminal to predict the satellite passes. At any time the terminal knows the elevation angle of the satellite relative to its current position. This feature has many advantages. First, the terminal can operate in an automatic manner without any human operator. Second, there is no need for a PC or laptop which makes the terminal heavy and difficult to carry. Third, a power saving method is achieved: the terminal transmitter is keyed only when the satellite is in good visibility range. Fourth, since each terminal calculates the satellite elevation angle, a certain priority in the transmission can be implemented for the terminals in order to increase the system capacity in terms of number of terminals processed.

The ground terminals are made small and lightweight in order to be used on any bearing platform. The hardware composition of the ground terminals as well as the software that controls their behavior is described in the following paragraphs.

III. Hardware Architecture of the Ground Terminal

The hardware of the satellite ground terminal is composed of three main parts: a control unit built around a powerful microcontroller, a GPS receiver and a VHF transceiver (Fig. 2) with associated antennas. The assembled terminal is a small device which measures approximately twelve-by-seven-by-three centimeters. External connectors of the terminal is, BNC connector for the transceiver antenna, SMA connector for the GPS antenna and a 9-pins connector which supplies power to the terminal and allows connection to a PC over a 9600 baud RS232 interface. Its compact design facilitates easy mounting to a variety of payloads, including cars, cargo containers, buoys, pipelines and boats.

The internal microcontroller has two serial ports and eight A/D channels (analogue to digital). Serial port (2) is internal and allocated to the integrated GPS board, whereas the available serial port (1) is used to connect the terminal to a PC or laptop for booting application programs and reconfiguration. It can also be used for interfacing with other applications which provide serial data on an RS-232 compatible channel. Example is given in Ref. 6 where the operational ground terminal is interfaced with a weather station to transmit meteorological data from a remote site via the Moroccan microsatellite. The terminal can even be used with a laptop or any text editing device to transmit short messages from remote sites. These input options make the terminal a highly-flexible component because its basic core design is independent of its specific application.

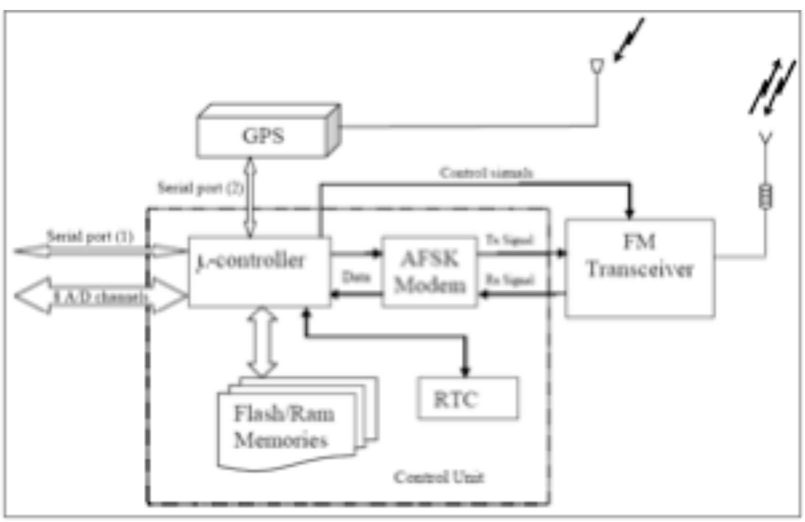

Fig. 2 Ground terminal hardware architecture.

For the data collection mission, any sensor with voltage output can be connected to the terminal which has eight available analog to digital converters. Sensor signal is sampled with a resolution of 10 bits and a reference voltage of 5V yielding a sampling step of 4.88mV.

The design illustrated by Fig. 2 makes the terminal a multi-mission device that can be used for position reporting, data collection or messaging. The three missions can be implemented separately or in the same time. The hardware remains the same and the software is application dependent. As the control unit has a Flash memory, the application software can be loaded at any time to change the terminal behavior.

Power can be supplied to the terminal with a nominal 12V battery. When mounted on a vehicle it can be plugged to the main power of the engine. For data collection on remote sites a solar power set comprising a solar panel, a battery and charger can be used in order to make the station autonomous.[6]

A. Control Unit Overview

The control unit as illustrated in Fig. 2 is a logic board built around a 16 bits Hitachi microcontroller (H8 series) which controls the whole operations of the terminal and makes it an autonomous and automatic device. This microcontroller is chosen for its ease of use, processing power, and intrinsic features. The unit consists mainly of RAM and Flash memories, RTC (Real Time Clock) and a modem. The design has the advantage of utilizing a powerful microcontroller therein eliminating the need for many of the external components needed by other systems (analog-to-digital converters, serial communications interfaces, slave microcontrollers, etc.), while remaining simple to program and implement.

The built-in software handles all functions involved in collecting, packaging and transmitting the data to the satellite. During the non visibility of the satellite, the GPS or the sensors are sampled at regular intervals and data is stored in memory. Thanks to the RTC which provides accurate time and date, an implemented orbit calculation algorithm evaluates the orbit position of the satellite. When the satellite comes into range the transceiver is keyed on and the gathered data in memory is transmitted.

A standby mode of the microcontroller is programmed to avoid the waist of energy when the terminal is powered by a standalone battery. Out of the transmission time (no satellite visibility) and between GPS or sensors sampling times the microcontroller powers off everything inside the terminal and enters a sleep mode. This decreases power consumption to an extreme low end achieving a very good power budget.

The H8 microcontroller has an internal memory of 32Ko PROM and an on-chip 2Ko RAM. To make the design flexible the PROM is only used to contain a kernel whereas the application program is loaded in the external Flash memory. The SGS-THOMSON Flash memory M29F040 offers a 512Ko address space. An additional RAM memory on the board offers 512Ko for data storage.

The AFSK modem is an FX469DW purchased from CML. It is a single-chip CMOS LSI circuit which operates as a full-duplex pin-selectable 1200, 2400 or 4800 baud Modem. The mark and space frequencies are 1200/1800, 1200/2400 and 2400/4800 Hz respectively. This modem demonstrates a high sensitivity and good bit-error-rate under adverse signal conditions. This low-power device requires few external components and is available in SMD (surface mounted device) package. All the components on the logic board are chosen with SMD packages for space saving and high density mounting in order to minimize the weight and dimensions of the terminal.

The RTC module offers permanent clock and calendar (date and time) and serial data input/output. The RTC-4553 from EPSON is a very compact real-time clock suitable for use in portable devices. The use of a CMOS circuit make possible low-voltage, low-power, to ensure proper timekeeping also when powered from a backup battery (3Volts lithium). The RTC on the board is used for orbit calculation and time stamping of collected data. The microcontroller reads the RTC registers to get time and date for calculating the satellite ephemeris. On the other hand all the collected data records in memory have a field containing the time stamp. Although this circuit is enough stable, it is adjusted from time to time using the GPS output: RTC registers are updated each time a GPS measure is made.

B. The Integrated GPS

To make the ground terminal small and compact an OEM (original equipment manufacturer) GPS receiver board is integrated inside. The Rockwell "Jupiter" receiver is chosen for its dimensions and performances (see Fig. 3). The board measures 71x41x11mm and weighs 23.8grammes. Its internal architecture with 12 parallel channels provides a rapid TTFF (time to first fix). This receiver has two identical and independent asynchronous serial ports. The first one is interfaced with the control unit microcontroller for input commands and output data. The second port is configured to eventually receive data from a differential GPS. The communication messages between the GPS and the microcontroller are either ASCII or binary coded. The one or the other is hardware selected. The ASCII code complies with NMEA (National Maritime Electronics Association) format whereas the binary format is Rockwell specific and allows more functionality. Since this board is the most power consuming component of the terminal, it is powered on only when a position measure is to be made. A software timeout is also programmed to power off the GPS when it is not possible to get a valid position due to masking or GPS satellites availability.

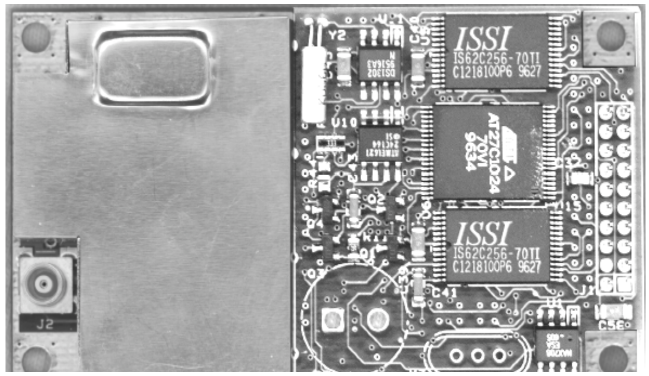

Fig. 3 Rockwell "Jupiter" GPS receiver board.

C. The Transceiver

The transceiver integrated inside the ground terminal operates in VHF band and consists of the "guts" of a Yaesu FT-11R, arguably one of the smallest and lightest handhelds on the market. The radio is two stackable double-sided PCBs measuring approximately 5x5cm. Its amplification output stage can be adjusted to more than 5Watts which achieves a positive RF budget link. Current consumption for the receiver and transmitter is 140mA and 1200mA, respectively.

The transceiver is interfaced with the control unit microcontroller by means of AF (audio frequency) and control signals as illustrated by Fig 2. AF signals consist of transmit and receive signals of the AFSK modem which carry data packets, whereas as control signals consist of power and PLL (phase locked loop) command signals. The PLL command signals allow the microcontroller to choose the transmit and receive frequencies of the radio. The radio is only powered when the satellite is in range and there is data to transmit. It is turned off as soon as the last packet stored in the terminal memory is sent to the satellite.

The AFSK/FM signal output from the transceiver is fed to a quarter wave ($\lambda/4$) monopole antenna which is handy and practical to use even though it is not ideal for LEO satellites communications because of its poor performance at higher elevations.[8] in fact, the type of antenna to be used the ground terminal depends on the mission and the platform on which it will be mounted (truck, ship, animal, …etc.). The turnstile antenna is the most suitable for LEO satellites communications because it is horizontally omni directional and provides circular polarization at higher elevations[9,12,13] which compensates for satellite attitude movements. This antenna is better used for geographically fixed ground terminals.

IV. Ground Terminal Automatic Operation

The satellite ground terminal is a standalone device and comes into operation automatically as soon as it is powered on. The RTC and satellite Keplerian elements are home set before the terminal is spread out into the field. Theses are useful for collected data stamping and for orbit calculation. At power-on, timers for sensors or GPS sampling are initialized according to the measure interval. While the satellite is out of range, data from programmed sources is sampled, time-stamped and stored in memory. Each time the microcontroller comes out of stand-by mode (10 seconds) it calculates the satellite elevation angle. When the value of this angle is higher than the preset mask, the microcontroller keys on the transceiver and enters a communication session where the whole gathered data is divided into packets and sent to the satellite. After all the sent packets are acknowledged by the satellite the microcontroller turns off the transceiver and returns back to stand-by mode. The ground terminal operation is illustrated by the algorithm of Fig. 4. The microcontroller comes out of the software stand-by mode when it receives a hardware NMI (Non-Masquable Interrupt) interrupt. This signal is delivered by the 1/10Hz timing pulse output of the RTC. Therefore the microcontroller wakes up each 10 seconds, calculates the satellite elevation angle, executes the communication and data collection tasks then returns to sleep mode.

Whenever a GPS reading is made, the position data is stored for later transmission and the terminal current coordinates variables are updated in memory. This is necessary when the terminal is mobile because it keeps correct satellite orbit calculation which depends on the ground observation point.

For automatic position reporting or data collection missions, the ground terminal is intended to be deployed in remote sites without human control. For fail-safe operation a software watchdog is implemented which resets the terminal after a non-cleared timer count reaches 30 minutes.

Thanks to a lithium battery installed on the microcontroller logic board, data stored in RAM is not lost when the terminal is powered off. This feature is useful because critical data such as terminal coordinates remain in memory and the RTC keeps running providing correct time and calendar without initializing when the terminal is powered on again.

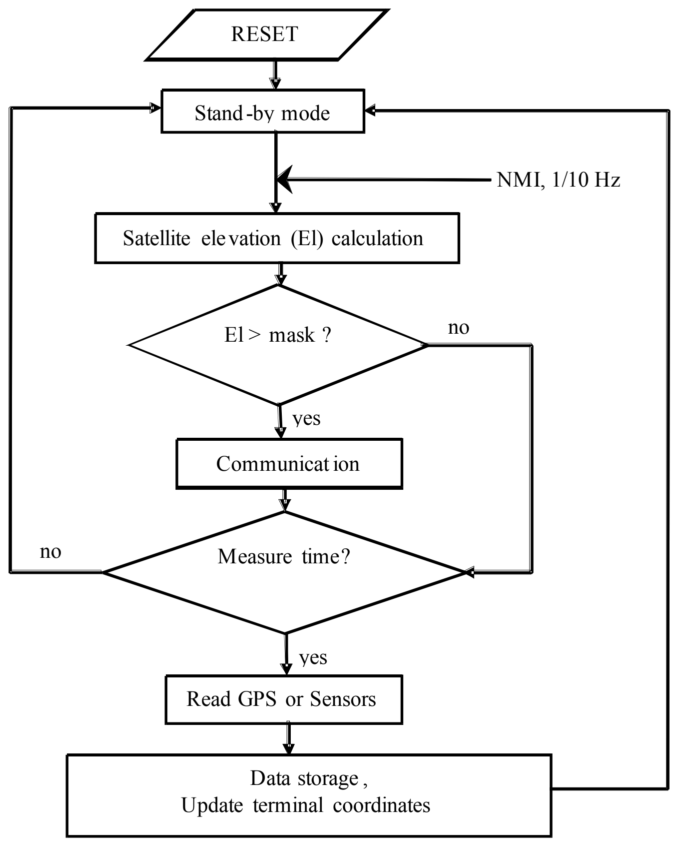

Fig. 4 Ground terminal operation.

A. Orbit Calculation Algorithm

An assembly code module is developed and loaded into the flash memory. This module reads the RTC and the terminal geographical coordinates and outputs the satellite elevation, azimuth and slant range. One subroutine derivates the slant range to give the Doppler shift which is important in LEO satellites communications due to high satellite velocities. A floating point unit has also been developed using the standard 32-bits IEEE format numbers. Prior to releasing the terminal on the field the satellite ephemeris at epoch time are loaded via the serial port. These are available as NORAD two-line elements sets in the NASA prediction bulletin.[10]

The implemented orbit model is a general model valid for low earth orbits with altitudes higher than 500Km to achieve a good prediction precision. The orbit calculation methodology used expresses the satellite coordinates in the terminal relative topocentric coordinate system which easily yield the values of elevation and azimuth angles along with the slant range. This is achieved by means of satellite vector transformations through different coordinate systems.[11] the developed assembly code module undertook several long-time tests and works correctly giving results comparable to those of commercially available orbit calculation software.

B. Satellite Communication Session

Once the satellite comes into range the ground terminal starts a communication session to transmit all the collected data in its memory using a stop-and-wait ARQ (automatic repeat request) protocol (see Fig. 5). Data is segmented into packets with constant length (256 bytes) which are successively sent to the satellite along with a calculated CRC (cyclic redundancy check). The same packet is retransmitted until an ACK (acknowledge) is received. Each time any packet is to be transmitted, the microcontroller calculates satellite elevation to check if it is still visible. The communication session ends when all previously stored packets are acknowledged by the satellite. The ground terminal then returns to stand-by mode.

The access to the satellite channel is purely random. All the ground terminals using the satellite transmit their packets without caring about the other terminals. When a collision occurs the packet is retransmitted after a random interval time. The random number of seconds representing the interval time is taken from the least significant byte of the floating point value of the calculated elevation angle. The Aloha multiple access is chosen for its simplicity in implementing the hardware and software of ground terminals as well as the satellite payload, keeping in mind that for developing countries the overall system cost is of major concern.

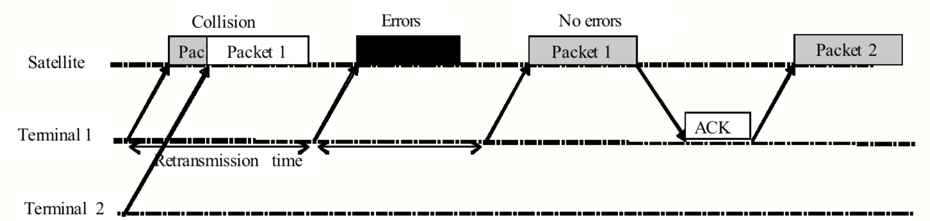

Fig. 5 Satellite-terminal communication session.

C. Power Saving Method

A power saving method is implemented to ensure long life to the ground terminal when it is deployed for a long term mission and powered only with a standalone battery. This is achieved by software in three steps. First, since the data is collected from GPS or sensors at regular intervals, these are only powered on when a measure is to be made. Second, thanks to the orbit calculation software module the transceiver is keyed on only when a satellite is visible and there is data to transmit. In the same satellite pass, it is powered off as soon as the last data packet in memory is successfully sent to the satellite and its acknowledgment is received. Third, to keep the microcontroller off running all the time, a stand-by mode is entered whenever the satellite is out of visibility and time to make a new data acquisition is not reached yet. In this way the microcontroller functioning is cycled on and off. If there is any task to accomplish, the microcontroller remains active until the task is finished. It then resumes the cycling.

D. Overall System Capacity Consideration

The ground terminal is designed to operate inside a network comprising multiple nodes including a satellite, a central ground station and numerous terminals. Therefore the system performance depends on various parameters including the terminal data collection and transmission parameters. Indeed, the system capacity in terms of number of terminals processed by the satellite depends on communication time (duration of satellite pass), data length of transmitted packet, number of packets stored in the terminal waiting for transmission, channel multiple access protocol and finally the link transmission data rate. To derive much benefit from the network the number of terminals intended to use the satellite is to be maximized. To carry out the system capacity evaluation, a network simulation tool is needed (example: OPNET).

V. Field Tests And Results

A ground terminal respecting the design shown in this article had been realized and built at CRERS.[*] It ensures a data collection mission using the Moroccan microsatellite "Zarkaa Al Yamama" launched in December 2001. The small low cost ground terminal installed in a remote site is interfaced to a weather station and transmits meteorological data (wind speed and direction, temperatures, humidity, solar illumination, rain and atmospheric pressure). The data received by the central ground station is used by the DMN (Direction de la Météorologie Nationale) to study the site region weather.

Since its deployment on the field in April 2002, the terminal shows excellent results.[6] As a mutual agreement with the DMN, the data flow consists in transmitting one packet of 256Bytes each satellite pass, thus providing 1KByte of data each day. The communication payload of the microsatellite consists of only one VHF channel with a data rate of 1200bps. The ground terminal feeds 5Watts RF power to a turnstile antenna. Electrical power is drawn from a solar set (battery and solar panel). For the two years of operation, we had no lack of data and the terminal operates in an autonomous, automatic, non-stop and fail-safe mode. The only action we needed to take is to update

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the satellite ephemeris in order to keep correct orbit calculation. A solution to this constraint is to update the terminal orbit parameters via the satellite downlink which can be supported with the current terminal design.

VI. Conclusion

Large rural areas in developing countries where other communication systems are lacking could be covered by an economical solution of satellite data collection system. Associating low cost ground terminals with a single LEO microsatellite allows developing countries to access space communications with a very economical system. The present work dealing with the design of the ground terminals shows hardware and software solutions adopted to cut down the system cost. The hardware architecture of the compact ground terminals utilizes commercial low cost components and the software for data collection and orbit calculation which make them intelligent is locally developed. The ground terminals are automatic small devices that can be mounted on any fixed or mobile platform to serve applications such as data collection, mobile localization and messaging. The design described in this paper has already been implemented and field tested giving out good application results.

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