Paper

Building distributed ground station system with radio amateurs

Marcin Stolarski and Wiesław Winiecki

Abstract— The paper concerns radio amateur satellites that are built by international student teams. For contacting a satellite, a single ground station is usually used. In this configuration and with the satellite on the low Earth orbit (LEO), teams have contact only for about 40 minutes per day. If the satellite has service for radio amateurs, they use it for 20 hours per day. A lot of them have connection to Internet. This is a big difference. In this paper, is shown how they can use the radio amateur transceivers and antenna systems in order to build ground stations network named distributed ground station system (DGSS). Frequencies, types of modulations, calculation of power budge, and the ways to control amateur stations by the Internet are also shown. These are essential procedures, because radio amateurs have their standards and habits. Finally a proposal of implementation dedicated DGSS system for radio amateurs with and without use of APRS network is put forward. Distributed ground station is one of the experiments on PW-Sat satellite, which is being build on the Warsaw University of Technology.

Keywords— space technology, satellite communications, radio amateurs.

1. Introduction

The connection between Earth and the satellite is usually made via one ground station. Only in special situations and for a particular mission, stations situated all around Earth are being used. But this solution is much more expensive, which is not acceptable in amateur space missions, for example in AMSAT [1] programme. On the other hand, a single ground station has restricted range, which depends on the position of ground station and a satellite's orbit. Because of this the greater part of the mission does not have contact with the satellite, which in turn causes the reduction of the amount of data transmission between Earth and the satellite. A lot of radio amateurs have proper devices for radio amateur satellite communication and Internet connection. If they would like to cooperate, the communication through most of the orbit would be possible. In this article, the results of mathematical analysis carried out with author's software named distributed ground station system (DGSS) calculator will be shown. This software simulates optical visibility between the satellite and a ground station [2–5], and calculates parameters like free space loss (FSL) [3, 4] or bit error rate (BER) [3]. It can also calculate position of a satellite due to Keplerian elements [2–5].

2. Single ground station analysis

In Figs. 1 and 2 one can see an analysis of a single ground station radio-wave range for International Space Station (the orbit of 370 km has been chosen to emphasise the differences shown later in the paper).

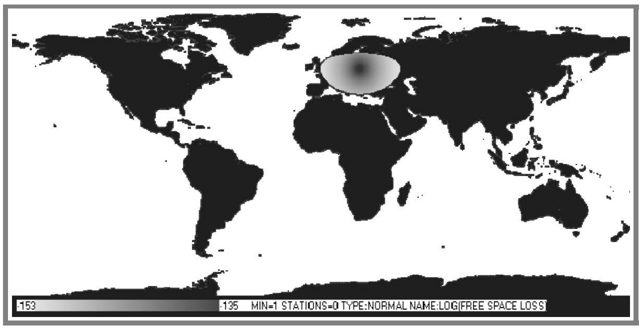

Fig. 1. Free space loss [dB].

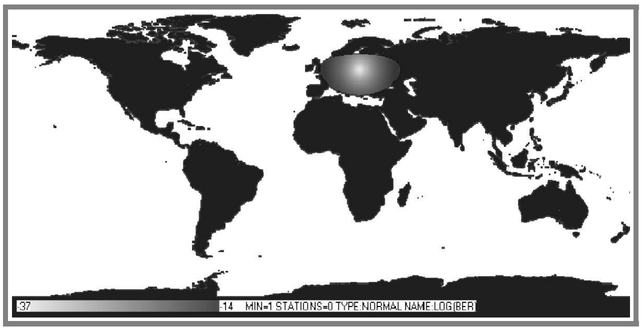

Fig. 2. Bit error rate.

Figure 1 shows FSL (Eq. (1)) in relation to distance between the satellite and a ground station for frequency $f = 433$ MHz in the optical horizon:

$$FSL\ [\mathrm{dB}] = 10 \log \left(\frac{4\pi R}{\lambda}\right)^2, \tag{1}$$

$$\lambda = \frac{c}{f}, \tag{2}$$

where: R – distance, c – speed of light.

Beyond the horizon FSL is assumed to be equal to ∞. Next, the bit error rate (Eq. (3)) was calculated on the basis of FSL:

$$BER = \frac{1}{2} e^{\frac{SN\ [\mathrm{dB}] B}{-2BR}}, \tag{3}$$

$$\begin{aligned} SN\ [\mathrm{dB}] = \\ + TX\_power\ [\mathrm{dBw}] \\ + TX\_gain\_ant \\ + RX\_gain\_ant\ [\mathrm{dBi}] \\ - FSL\ [\mathrm{dB}]. \end{aligned} \tag{4}$$

For the calculation the following parameters have been established: frequency shift keying (FSK) modulation, bit rate $BR = 1200$ bit/s, canal bandwidth $B = 7$ kHz, power of transmitter 5 W, gain of transmitter antenna 0 dBi, gain of receiver antenna 6 dBi. The calculated BER was between 10^{-14} and 10^{-32}.

3. Distributed ground station system analysis

The automatic position reporting system (APRS) [6, 7] is used by a lot of radio amateurs. Its job is to send the radio station position via radio to the APRS network. A typical APRS station can receive packets from other stations via radio and forward them via radio or the Internet.

In one week the activity of around 14 000 stations may be observed (Fig. 3), and the amount of data transferred by Internet servers is close to 250 MB per day. Most of it is generated in USA and the European countries (Fig. 4). APRS stations function also in other parts of the word. If the range of the satellite at 370 km would be simulated (Fig. 5), it could be seen that a satellite will be able to communicate with the APRS net in most of the areas.

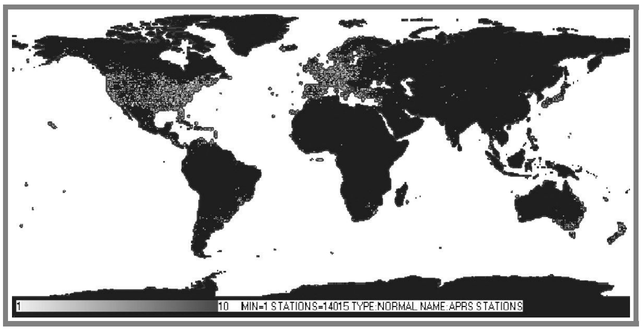

Fig. 3. The APRS stations.

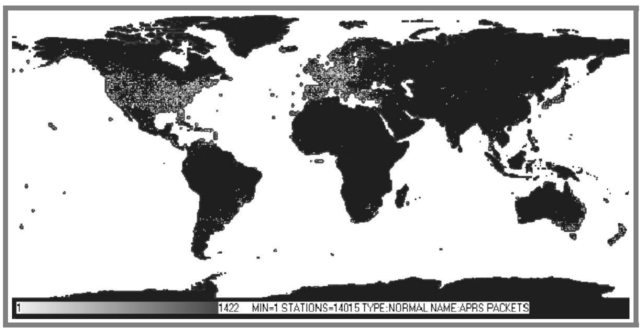

Fig. 4. The APRS packets.

Over USA and the EU the number of APRS stations within the range of the satellite exceeds 600. The results of theoretical FSL (Eq. (5)), assuming that the received energy will be summed, are visible in Fig. 6:

$$FSL_T \text{ [dB]} = 10 \log \left(\sum_{i=1}^{n} 10^{\frac{FSL_i \text{ [dB]}}{10}} \right). \tag{5}$$

In comparison with FSL of a single ground station, the FSL here is lower by about 25 dB.

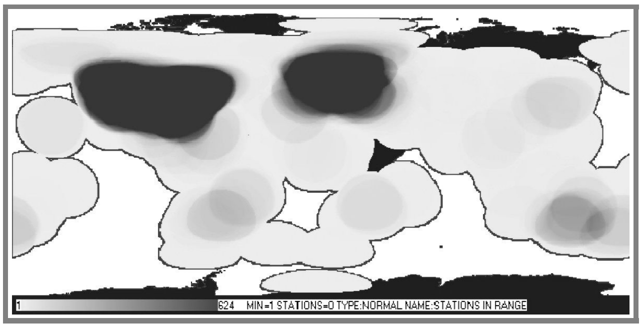

Fig. 5. Stations in range.

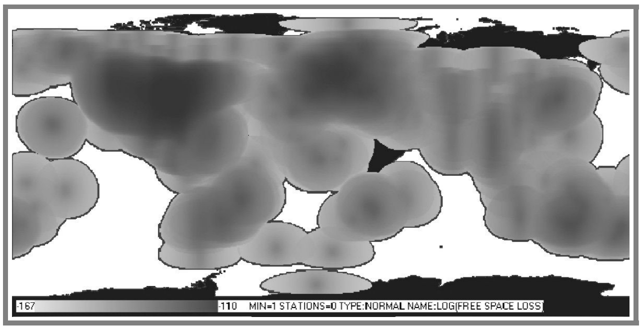

Fig. 6. Theoretical free space loss [dB].

Because it is rather impossible to connect all the antennas to a single receiver, the author proposes to carry out a comparative analysis of the received packets. The first idea is to compare BER of all the stations within a range, and chose the packet for the lowest one. This method will ensure keeping BER (Eq. (6)) between 10^{-4} and 10^{-36} (Fig. 7):

$$BER_{\text{MIN}} = \underset{i=1}{\overset{n}{\text{MIN}}} \left(BER_i \right). \tag{6}$$

A more advanced solution is also possible. The author's second proposition is to send raw data to the server, which would make the comparative analysis through voting between particular bits of particular packets. With the large number of stations we get a large number of

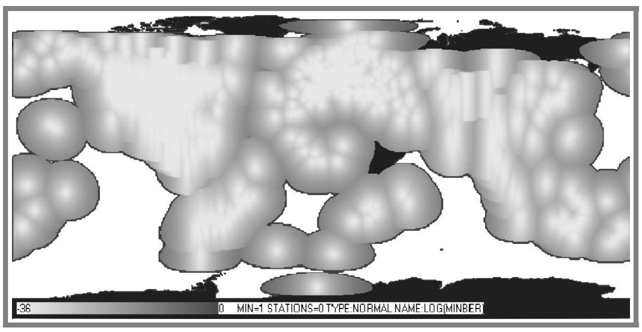

Fig. 7. Minimal bit error rate.

Fig. 8. Bit error rate.

packets to compare, which allows reducing *BER* (Eq. (7)) up to 10^{-30792} (Fig. 8):

$$BER_0 = \prod_{i=1}^{n} BER_i \,. \tag{7}$$

With such low *BER* one can considerably reduce the power of a transmitter, or increase transmission speed to the point where it would be possible to receive the packets with *BER* not higher than 10^{-4} on a given area. This would allow reducing the power on the satellite or increasing the amount of transmitted data.

4. Automatic position reporting system

The empirical verification of the proposed methods of reducing *BER* could be performed in the APRS net. There are different kinds of communications transmitted via this net. The first one contains the geographical situation of a station and some additional information, for instance the speed of the vehicle on which a station in located. The second kind of packets is telemetry. Its main use is transmitting information from weather stations, but any other kind of information can also be transmitted. The third kind of communications is short messages.

The packets of the first two kinds are broadcasted to all units of the APRS net. The amount of packets sent via radio is territorially restricted on account of radio wave link capacity. The full stream of data may be received via Internet.

The messages are being sent in a different manner. The messages are of two kinds. The first one is the bulletins, which are sent to all stations. The second one is private messages, which are sent to specific recipients.

The APRS net sends this kind of messages for re-transmitting to all stations connected to the Internet. If one of the stations hears the station of the addressee on a radio port within a specific period of time (usually 30 min), the re-transmission of the message via the radio port goes through. When the addressee receives the message, he sends a confirmation message to the sender.

This way of communication is not 100% successful, but it is sufficient for radio amateurs. It is also used for communication with radio amateur satellites [1]. However, it has some flaws. While the system enables receiving telemetry from the satellite when it is within the range of the net, sending messages to the satellite via the net is virtually impossible. When the satellite is, for instance, over USA, it is within the range of over 600 stations, and if all of them re-transmit the message to the satellite at once (because they all heard the satellite within the last 30 min) the packets will collide in the radio wave and such packet will not be received correctly. Because of this, transmission to the satellite is possible only when it is directly over the main ground station.

The author proposes to solve this problem by providing radio amateurs with special client software. Such a client would receive the re-transmission packet by a separate channel, which would allow for the message to be transmitted only to the chosen station.

The second problem concerns the legal aspects of working with the APRS net. The national and international regulations demand that transmissions via radio amateur systems be overt (not encoded). This makes a satellite vulnerable to an unauthorised access of other radio amateurs.

The author proposes to carry out the authorisation by means of an electronic signature. Every message to the satellite would be signed electronically by the operation team and the satellite would only accept the commands signed in this way. Still, there is a risk of a signed message being intercepted and re-transmitted again by an unauthorised sender. To eliminate this risk, the addition of an incremented counter to the message is proposed, which would allow eliminating the already used packets.

5. Distributed ground stations system

In order for the experiment to take advantage of all the possibilities of a diffused packet analysis, the author proposes to construct a system of a diffused ground station. Such a system would make use of a couple of subsystems.

The DGSS elements are:

- Local ground station for a direct communication with a satellite in case of unavailability of the distributed system.

- Remote control ground station also known as virtual ground station [8]. The system would allow for a remote managing of a radio amateur station through the remote turning of radio amateur antennas and altering the radio frequency.

- Distributed client server communications system for collecting raw data from the station in order to process it later. The packets to be send to a satellite would be sent in a return channel. This system would assess the quality of data (it would foresee *BER* on the basis of the location of a station and a satellite). It would also decide which station would be most suitable for sending the packets to a satellite (on the basis of the quality of the received packets and theoretical capabilities resulting from a mathematical model).

- Packet voting system (PVS) for comparing many packets (even the damaged ones) received simultaneously by many stations (parallel receiving system). Eventually, the correct packets with the information from a satellite would be received.
- Remote control console is a panel for receiving the decoded telemetry of a satellite with PVS, and creating the packets with commends for a satellite.

6. Summary

The author presented a new method of space communication, which uses a parallel data reception from the satellite and proposed a subsequent analysis in order to reduce *BER* with mathematical methods. The calculation results show a great improvement of transmission when using a parallel reception. A practical verification of the method could be carried out using APRS communication with certain modifications, which would allow further improvement of *BER*. The experiment is planned as a part of space mission PW-Sat [9], which consist in the Warsaw University of Technology sending a small satellite in order to check a possibility of bringing satellites from the orbit by using aerodynamic resistance at the orbit.

References

[1] AMSAT, http://www.amsat.org

[2] "Orbital mechanics with MATLAB". Documents describes an interactive MATLAB script named npoe.m, http://www.cdeagle.com/ommatlab/npoe.pdf

[3] M. O. Kolawole, *Satellite Communication Engineering*. New York: Marcel Dekker, 2002.

[4] D. J. Bem, *Telewizja satelitarna*. Warszawa: Wydawnictwo SIGMA NOT, 1992 (in Polish).

[5] J. A. Magliacane, "PREDICT: a satellite tracking/orbita prediction program", http://www.qsl.net/kd2bd/predict.html

[6] APRS International, www.aprs.org

[7] APRS Poland, www.aprs.pl

[8] S. Bernier and M. Barbeau, "A virtual ground station based on distributed components for satellite communications", in *15th Ann. AIAA Conf. Small Satell.*, Logan, USA, 2001.

[9] G. Niemirowski, "Cubesat microsatellite with balloon", in *56th Int. Astronaut. Congr.*, Fukuoka, Japan, 2005.

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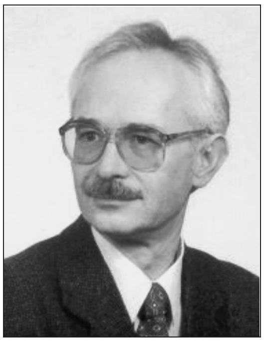

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