Bolidozor radio meteor detection network

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Radio meteor detection networks could improve the knowledge about meteors under daylight or inconvenient weather conditions. We present a new approach to the meteor detection system. The hardware described in this paper has unique features for time synchronization of multiple nodes, therefore meteor trajectory calculation is possible in case of appropriate network deployment.

1 Detection method

The general principle of meteor observing by forward scattering of radio waves off their trails is illustrated in *Figure 1*. A lower VHF range radio receiver (30–200MHz) is located at a large distance (about 500–2000 km) from a transmitter that operates at the same frequency. Direct radio contact is impossible due to the curvature of the Earth. When a meteoroid enters the atmosphere, its meteor trail may reflect the radio waves from the transmitter to the receiver. At the receiver, where the signal of the transmitter is normally not received, the signal can then be received for a moment until the ionized material in the meteor trail recombines. Reflections can last from a tenth of a second to a few minutes. The received signal characteristics are related to physical parameters of the meteoric event.

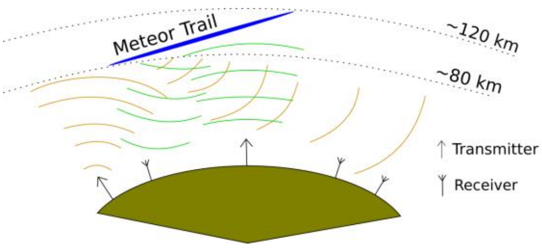

Figure 1 – General principle of meteor observing by forward scattering of radio waves from ionized trails.

Benefits of using this method are obvious – radio meteor detection capability is not dependent on current weather and can work even in daylight or during nights with a full Moon.

The Bolidozor network[1] currently uses the GRAVES transmitter located in France, which transmits a strong almost unmodulated carrier at a frequency of 143.05 MHz. The radiation pattern of the transmitter is beaming mainly to the south, but due to imperfections of the antenna system, the signal from meteor reflections can be observed in almost all European countries. Therefore the transmitter is suitable for testing a network of receivers for the purpose of meteor trail detection and meteor trajectory calculation.

2 Station hardware

The Bolidozor network main objective is the calculation of a meteor trajectory from radio echoes. Therefore, we needed to develop a new receiver with special parameters, especially with a high quality of time synchronization. Tight time synchronization requirements between the nodes increases the complexity of a receiver system. To simplify the development process we used the MLAB open source electronic prototyping platform[2]. Therefore the whole station is an open hardware design.

The use of a modular concept allows on-the-fly modifications and testing of new station's features. After verifying the new hardware features, other stations can be easily updated by adding or replacing MLAB modules. The current station hardware is shown in *Figure 2*.

The station receiver consists of several subsystems. At the input, the RF signal from a low noise amplifier located close to the antenna is conducted by a coaxial cable to the sampling mixer module. The mixer module is

[1] http://bolidozor.cz
[2] http://www.mlab.cz

fed by a frequency precise time-stamped clock. After RF, the signal is mixed with the high frequency clock source, the result of mixing is a low frequency signal which is digitized by SDR-widget[3] compatible hardware. The signal is currently digitized with a resolution of 24bits @ 96kHz.

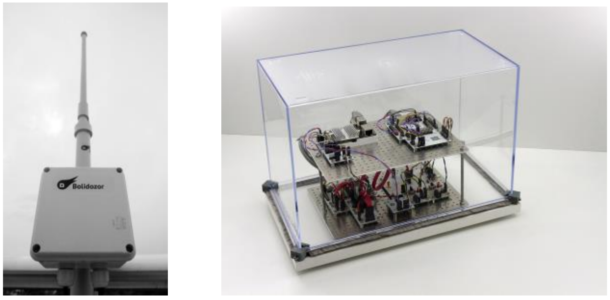

Figure 2 – Ground plane antenna of Bolidozor node (on the left) and the receiver, version RMDS02D (on the right).

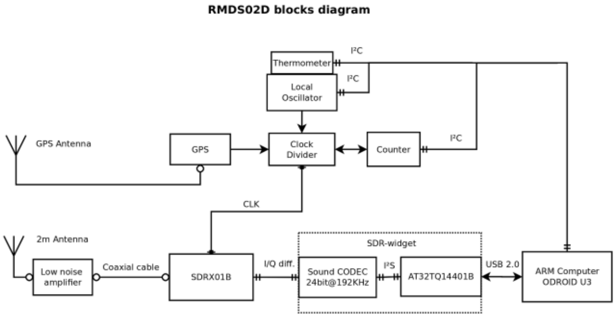

Figure 3 – Simplified interconnection diagram of MLAB modules in a Bolidozor RMDS02D station.

The precise clock signal for the mixer is generated by a GPS-disciplined temperature compensated local oscillator. The accuracy of the oscillator is obtained by a frequency measurement circuit which completes the measurement once every ten seconds in absolute UTC time. The measured oscillator parameters (frequency and temperature) are processed by frequency-guard software running on the station computer. The software determines if any correction of the local oscillator is necessary. Therefore the shape of the local oscillator's Allan variance can be altered by the software. The station clock subsystem is a software defined, GPS disciplined, temperature compensated local oscillator.

The frequency measurement intervals of the local oscillator are controlled by the GPS PPS (pulse per second) output. Because the PPS signal from the GPS receiver triggers a divider connected to the receiver and to the frequency counter, the clock signal to the signal mixer is interrupted by PPS pulses. The interruption of the clock signal generates wide band spikes which appear as a horizontal line in spectrograms of the RF signals. Interruptions of signal can then be used as accurate time stamps in post processing algorithms.

Receiver parameters

The minimum detectable signal at the receiver input is approximately -120 dBm for 143 MHz. However, we have placed a LNA01A low noise amplifier in front of the receiver, directly at the antenna output. The gain of the LNA01A is around 25 dB, therefore the lowest detectable signal is about -145 dBm at the LNA input. Such a sensitivity allows the use of small sizes for the antennas. We currently use a 1/4 λ ground plane antenna for easy deployment at as many stations as possible, but larger types of antennas with better parameters are currently in a development process.

Time marks in the receiver are generated by a GPS which gives PPS pulses with an absolute accuracy of 50 ns (1σ) to UTC. Therefore the inter-station clock accuracy is 100 ns (1σ). These parameters could be further improved by altering the GPS configuration but are considered as adequate for the current stage of the development process.

Station software

Each detection node runs our software on an ODROID-U3 ARM computer under an Ubuntu Linux operating system. The signal from the receiver is captured by a modified SDR-widget server from the GHPSDR3 project. The SDR-widget software accepts socket connections from other processing and display software. The main software component is a radio-observer code whose purpose is to detect the meteor events in the data stream and to create data records as FITS files.

We currently use several types of FITS recordings. A 'snapshot' format continually records the spectrograms for every minute. These spectrograms record only a small part of the spectra where meteor echos appear. The purpose of the snapshots is an illustrative recording of events which are not detected by radio-observer software. This could be useful for a new event type discovery or station debugging. e.g. if noise interference appears.

More detailed format is a ‘met FITS’ which contains the spectrogram of the meteor reflections. The most detailed output file is the ‘raw FITS’ which contains signal samples directly from the analog to digital converter. The RAW FITS data are intended primarily for post-processing.

All the FITS files contain metadata information in their FITS header, but for effective searching in data structure, two metadata files are created in CSV format. First is the meta.csv which contains information about events detected by the radio-observer software e.g. meteor echo duration, frequency of maximal energy etc. Another output is freq.csv which contains the recordings about local oscillator drifts and its corrections.

Network architecture

The Bolidozor network consists of several types of stations: the reception stations, the data servers and the processing stations. Currently all nodes are located in the Czech Republic (*Figure 4*).

[3] https://github.com/borgestrand/sdr-widget

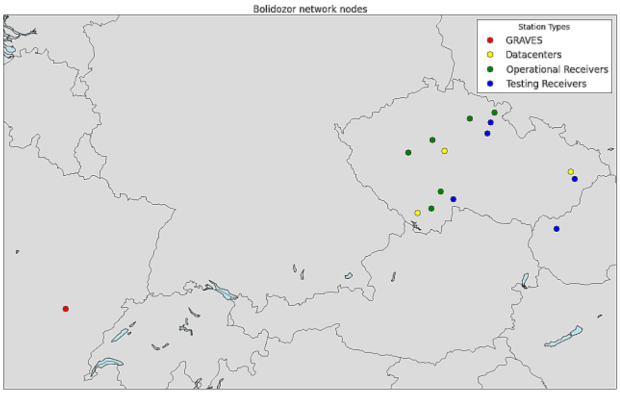

Figure 4 – Deployment of the Bolidozor nodes.

All the reception stations push the data to the central data storage server (space.astro.cz) which currently contains around 7 TB of data, increasing by approximately 1GB of data per station per day. All the data are available to the public via HTTP (*Figure 5*).

Other data handling servers download the data stored on the central server and process them. One example of such data processing is server meteor1.astrozor.cz which downloads metadata files, searches for meteor events and prepares the outputs for the rmob.org site.

Some tools are prepared for retrieving data from the storage. One example is the bzbrowser Python module, which helps with effective data downloading from the server. Therefore anyone can use this utility for Bolidozor data processing.

3 Conclusion

We currently have a large database of meteor reflections from several stations. Some meteors are received on multiple stations as in *Figure 6* for example. Unfortunately, we currently do not have enough stations and suitable network geometry to obtain meteor trail vectors.

To overcome this issue, the Bolidozor network needs more stations outside the Czech Republic.

Acknowledgment

The Bolidozor network depends primarily on volunteers who run and maintain the network nodes, therefore their work should be appreciated accordingly.

We would like to thank the Czech Astronomical society for the maintenance of our central data server space.astro.cz.

Thanks to Center of machine perception of Czech Technical University for financial support of the Bolidozor system.

Thanks to the SDR-widget development team for their open source hardware and related software.

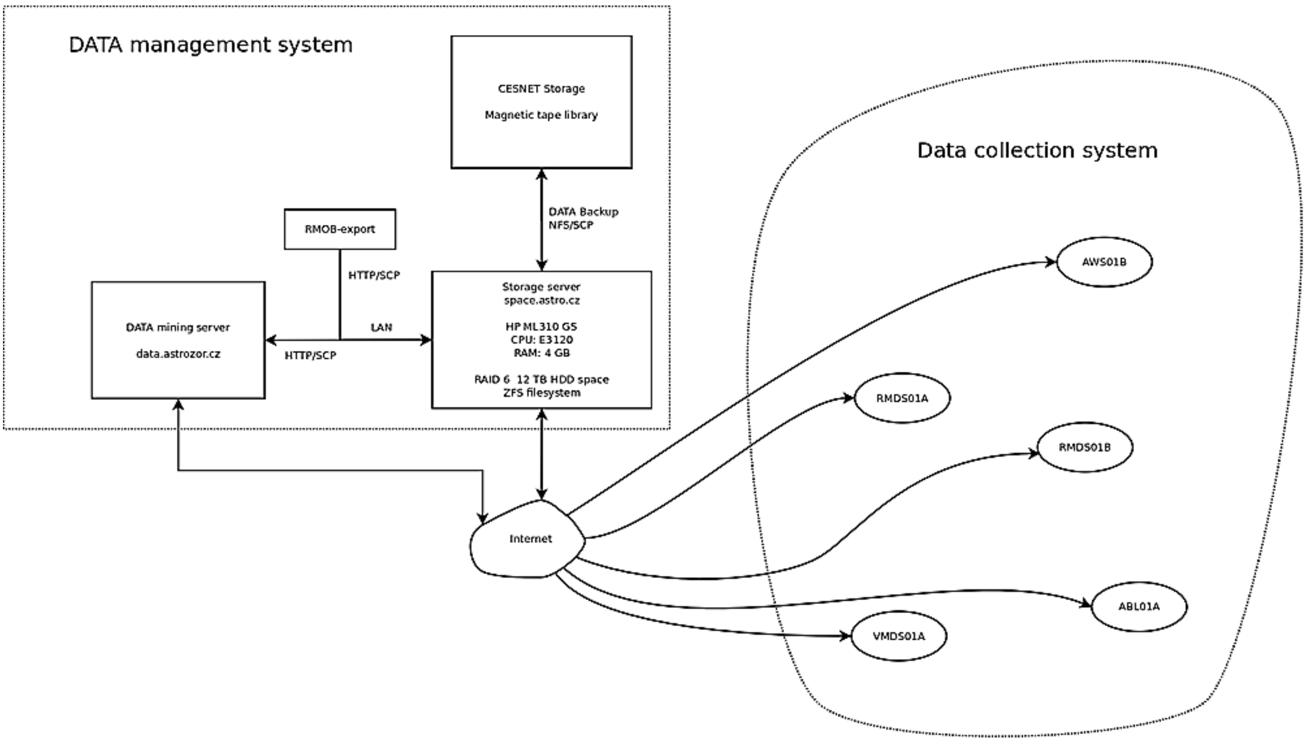

Figure 5 – Diagram of the measuring network.

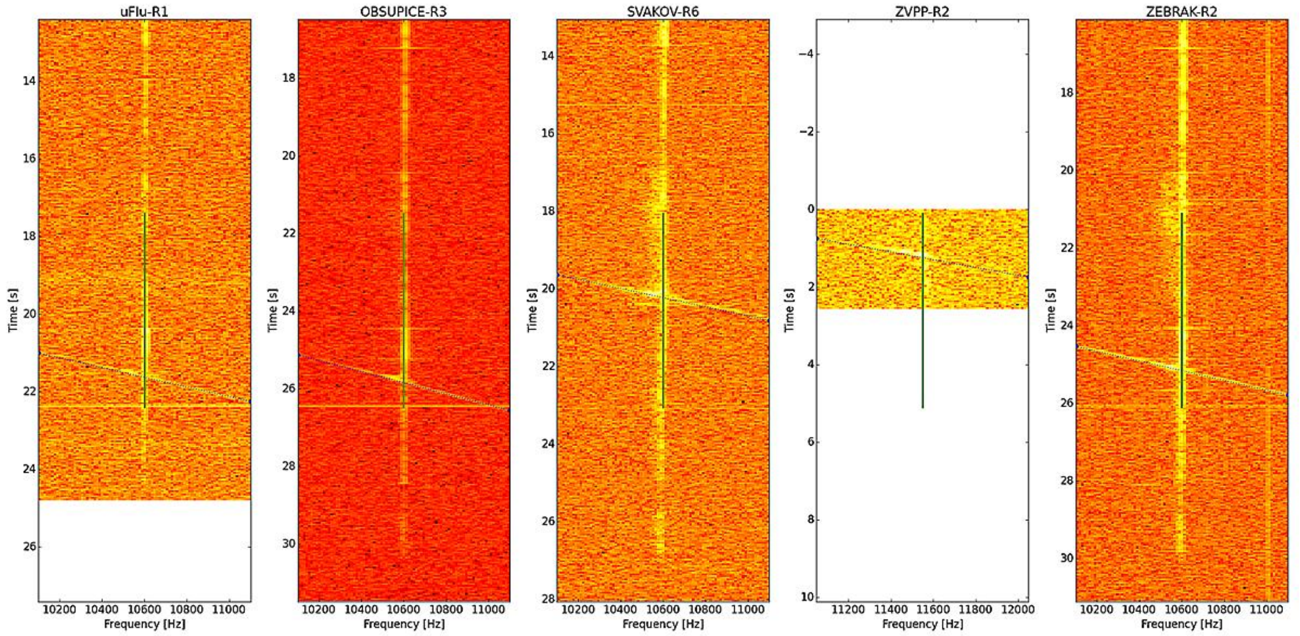

Figure 6 – Example of an head echo from a radio bolide received by multiple stations. Pictures are aligned by time (the vertical time scale axis is reversed).

The author, *Jakub Kákona* at right, explaining during the poster session (Photo by *Axel Haas*).