Radiocommunication Study Groups

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Automated localisation of electromagnetic emission sources at sites

Introduction

This Report concerns the use of a mobile spectrum monitoring and direction-finding station to examine a given site for the presence of electromagnetic emitters. For this purpose, the mobile station should ideally be fitted out with a high-speed correlation/interferometry direction-finding system capable of providing DF information (azimuth and elevation) for emitters that use narrow-band or broadband modulation, HF consumer and medical equipment, and other sources.
The mobile station should also be fitted with a video camera that can be used to narrow down the emitter's location within the site. Finally, successful operation of such a station requires specialized software to conduct fast, reliable searches.

Identifying emitters in a given area

To identify emitters within a given area ("on-site"), whether it is built-up or uninhabited, using a mobile station located outside the area in question ("off-site"), the two main methods normally used involve measurement of:

1) signal strength

2) bearing.

Signal strength is measured by comparing the signal amplitude spectrum obtained in the immediate vicinity of the site with one obtained at a much greater distance. As a rule, if the source is within the area in question, then the signal amplitude measured at a distance of several tens of metres will be much higher than the amplitude measured at distances of several hundred metres. The signals from off-site sources, by contrast, are hardly affected by such a change in position.

This is illustrated in Figures 1 and 2. Both show emission spectra obtained for a ~60 mW radio source, operating at 300.25 MHz and located inside a building of brick construction. The first spectrum was obtained at a distance of 50 m from the building, while the second was obtained at a distance of approximately 1 000 m.

FIGURE 1

Signal spectrum in vicinity of source

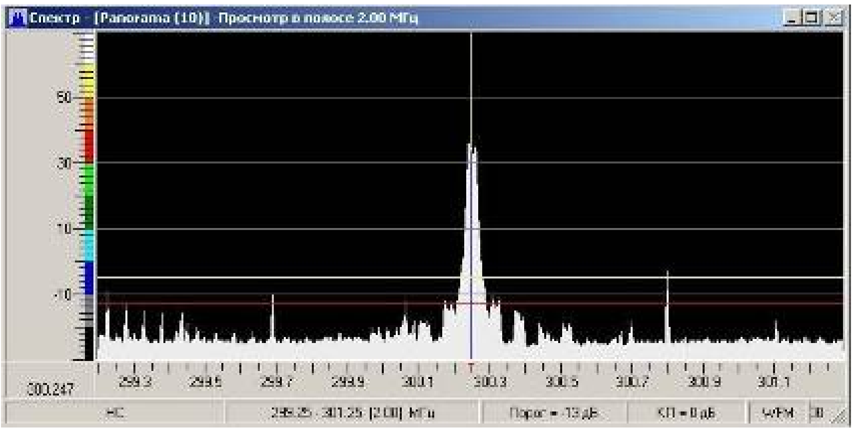
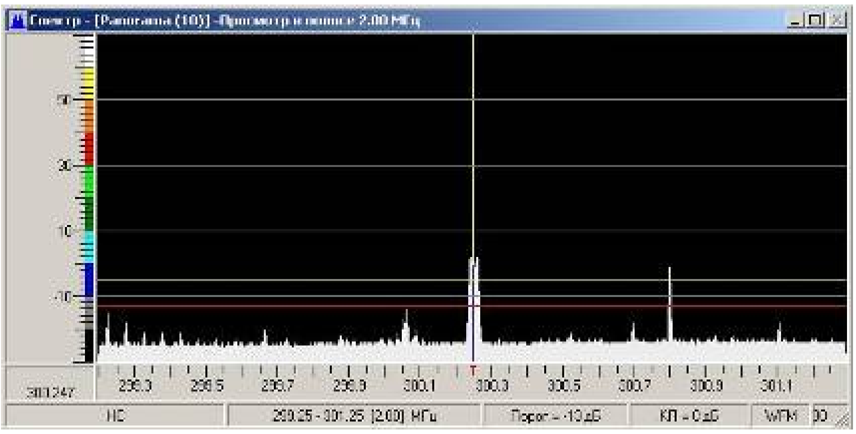


FIGURE 2

Signal spectrum at a distance of 1 000 m from the source



The two figures show how the amplitude of the signal associated with the emitter in the building has dropped by almost 20 dB, while the amplitude of a different signal, at 300.8 MHz, generated by another, remote source, remains practically unchanged.

The bearing method used for searches is based on the same procedure as when determining the location of a source from several bearings, but in reverse. In the ordinary procedure, the source frequency is known, and bearings are taken from several different positions to determine the location of the source. In the present procedure, it is not known whether a source is indeed present; and if one is, what its frequency is. What is known are the spatial boundaries that limit the site for which the search is being conducted. The objective is to determine whether an emitter is operating on that site and what its emission frequency is, and then to locate it more precisely within the site boundaries.

Like amplitude comparison, DF based on bearings will require the mobile station to move to several different positions around the site. For each position, the site’s bearing with respect to the mobile station is recorded, and the bearings of all known sources are also calculated and recorded. The bearings obtained from different positions can then be used to determine the frequencies of sources whose angle of arrival lies within the angular boundaries of the site, seen from the station's position. In this way a list is obtained of those frequencies that may be linked to on-site sources. The list frequencies are then used to perform a further iteration with bearings and signal analysis for more accurate results.

Under urban conditions, bearing analysis relies on probabilistic methods, due to the effects of multipath propagation and other local effects. The accuracy of the bearings obtained is heavily influenced by the location of the mobile station. A one or two-metre change of position often results in a different bearing reading. Ideally, the position should be chosen so that the site being surveyed is within line of sight, and there are no high buildings or large metallic structures near the mobile station. It is unfortunately not possible to make more concrete recommendations as to the best position for a station in densely constructed urban settings. In general, however, the more positions are used, the greater will be the likelihood of accurately identifying emitters on the site.

Emitter frequencies can range from several hundred kilohertz to tens of gigahertz. In major urban centres the spectrum tends to be heavily congested; at any one time there may be several thousand sources operating in the range from 25 MHz to 3 000 MHz. The effectiveness of the work of a mobile station will therefore be determined by the speed with which the spectra and bearings can be calculated and the speed of the algorithms used to process the data.

Software suite

The suite of programs used to run the mobile station includes the control module, used to control the spectrum management and DF equipment, and a special analysis module that performs the calculations required to detect and locate emitters within the site.

The software performs the following tasks:

– imports the results of the multi-channel bearing measurements obtained from the control module and saves them in a database;
– displays the spectra and bearing diagrams obtained;
– stores digital camera images of the site;
– combines the available digital images to give a complete image of the site;
– manages and stores sessions and frames for different sites;
– supports on-screen definition of site boundaries for DF purposes;
– generates lists of frequencies to be investigated for possible on-site emitters;
– uses the detected signal bearings and amplitude to find likely frequencies;
– translates the results of the single-channel bearing analysis from the control module in angular coordinates, and superimposes them on an image of the site;
– exports the list of frequencies to the control module for detailed analysis;
– supports the maintenance of a database that contains raw data from the control module as well as the results of emitter identification for different sites.

The raw data consists of spectra and bearing diagrams imported from the control module, along with site images from the digital video camera. The program's output is a list of frequencies for suspected emitters within the site boundaries. The program superimposes the predicted location of the source on the digital site image and supports an export of the frequency list to the control module for detailed analysis.

The analysis module maintains the site database which stores all of the data obtained from the control module, along with the results of emitter searches for each site.

The database consists of a shared database and autonomous DB objects created in a separate folder for each site. The shared database includes a table that shows all sites and another that lists excluded frequencies, which are bracketed out of the analysis.

The site database contains full information on all past spectrum management sessions.

Each monitoring session consists of several “frames”, as shown in Figure 3. A frame corresponds to a particular position of the mobile station with respect to the site being investigated, and contains the raw data (spectrum and bearing diagrams) and digital imagery of the site obtained from that position.

The search for emitters

An investigation session using a mobile station to identify emitters for a particular site consists of several steps:

1) compilation of frames of raw data;

2) analysis of frames and determination of frequencies to be studied more closely;

3) analysis of the frequencies in the list and precise determination of source locations.

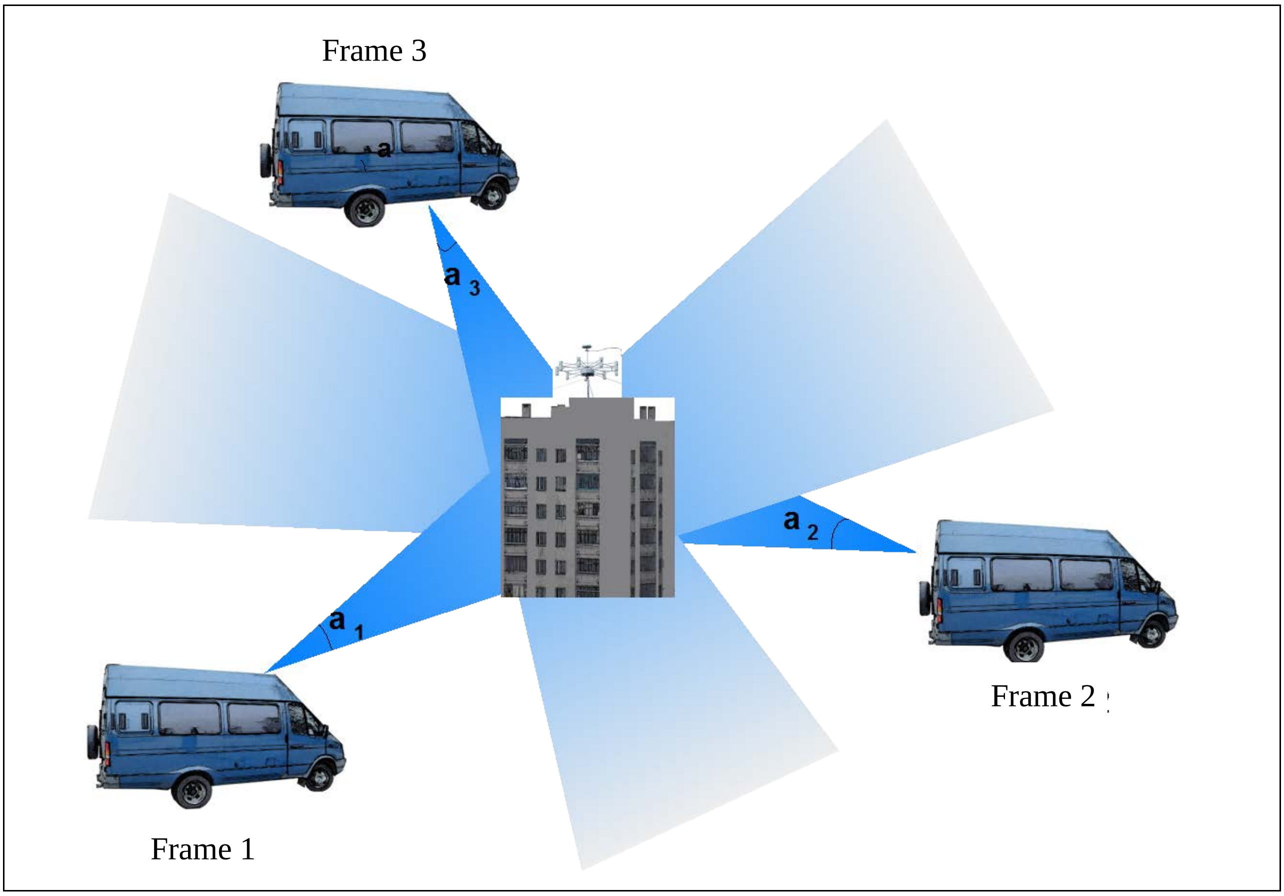
The first step is intended to form a database containing the raw data needed to make a determination.

The mobile station is positioned at several points in the near vicinity of the site under investigation, and others that are at a relatively great distance. For each position, one “frame” of raw data is collected. The positions should be chosen so as to provide site coverage from different angles, if possible.

Multichannel direction-finding (DF) is then used to provide spectra and bearing diagrams. This means, for each tuning frequency of the digital receiver: generating spectra, detecting sources and conducting DF, for the entire digital passband of the digital receiver. Compared with single-channel direction finding, in which the receiver is tuned to the frequencies of detected signals one at a time, multichannel DF is much faster at providing bearing diagrams. With a multichannel speed of 300 MHz/sec, ten seconds is enough time to go over the full spectrum from 25 to 3 000 MHz.

FIGURE 3

One operational session of the mobile station corresponds to several "frames"



After reaching the upper limit of the assigned range, the analyser automatically returns to the lower limit, and the multi-channel DF procedure resumes.

While the spectra and bearing data are being accumulated by the control module, the station operator stores the digital camera imagery of the site using the fixed camera mounted inside the vehicle. A configuration window is used to enter the direction in which the camera is pointing (with respect to the vehicle) and the positions from which recording is done. At this point, the site imagery can be imported into the analysis module's database.

Frames obtained at a great distance from the site are marked with a letter D (for "distant"). These frames are compared with near frames to obtain a list of possible emitter frequencies.

Once the assigned spectrum has been scanned, the operator can transfer the spectrum and the list of identified frequencies from the control module into the analysis module's database. The information in the list includes: centre frequency, bandwidth, amplitude, azimuth and angle of elevation, and the resulting gain pattern for the antenna array.

A separate window in the analysis module displays a digital image of the site, along with the spectrum and the frequency list. The currently selected frequency in the list is indicated in the spectrum diagram by a vertical line; the spectrum zoom window gives a detailed depiction of that part of the spectrum; and a graduated scale shows bearings and angles of elevation, along with the gain pattern for the antenna array. The DF diagram, showing the intersecting lines, is superimposed on the digital image of the site.

Processing frames and building up the frequency list

Once at least three to five frames of raw data have been obtained, the operator can proceed to the next step: in the analysis module, opening the digital images of the site and using point-and-click to draw a coloured border that defines the limits of the site being studied, as shown in Figure 4.
The resulting angular boundaries are used to limit the DF search. The analysis will focus on those signals whose horizontal and vertical angles of arrival fall within the boundaries.

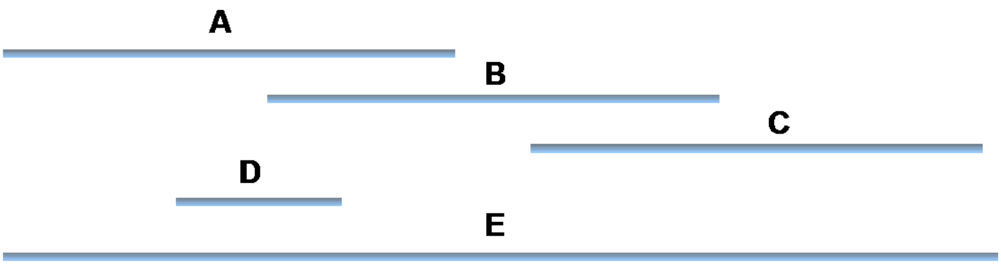
FIGURE 4

Defining the site boundaries

Once the angular boundaries have been entered, the operator starts the emitter detection procedure. In the database for the site, a new list of aggregate frequency bands is set up. The aggregate bands are produced by taking individual emitter bands that are found to be overlapping, and constituting a new band that just covers them; the new centre frequency is then taken from this new band. In the example below, a series of four overlapping emitter bands (A, B, C and D) are represented in the aggregate frame as frequency band E (see Fig. 5).

FIGURE 5

Producing an aggregate frequency band



As a check, the final table with the complete list includes such information as the number of originally detected frequencies included in each aggregate frequency band and the number of raw-data frames in which each frequency was detected. The operator can filter the results to rank the aggregate frequencies by the number of frames in which they appear. It is also possible to view all the originally detected frequencies.

Overlapping frequencies – even if they were detected in different frames – are combined to form a single contiguous band, covering the same range of spectrum.

Once the individual frequencies have been aggregated, a list of frequencies of interest is displayed, covering all those signals that were detected in at least two frames, with angles of arrival falling within the defined angular boundaries for the site.

The list is initially created without reference to the frames that are marked “D” (for “distant”). Once the list has been obtained (on the basis of “near” frames, marked “N”), the amplitude of each frequency in the list is compared with the corresponding one in the “D” frames. If the difference exceeds a certain threshold value, then that frequency is flagged to show that it probably belongs to an emitter within the site, on the basis of positive results using bearings and amplitude comparison.

With the detection procedure completed, the final frame shows a list of identified frequencies for signals observed in at least two frames, with angles of arrival falling within the angular boundaries of the site, along with frequencies detected by means of amplitude comparison.

Figure 6 shows a typical screen of the analysis module after the emitter detection procedure has been completed. Detection was performed on a total of six frames of raw data. Three frames were obtained in the immediate proximity of the site, within line of sight, and the program shows the digital images of the site obtained there. The other three frames were taken beyond visual range, at distances of 800 to 1 500 metres. Analysis led to the identification of a signal transmitted at 300.25 MHz, present in all six raw data frames, with an angle of arrival from inside the site’s angular boundaries. As indicated in the figure, the probable location of the emitter has been narrowed down to a second-floor room in the building, corresponding to the fourth and fifth windows from the left side of the building.

Verification of list frequencies and precise determination of emitter location

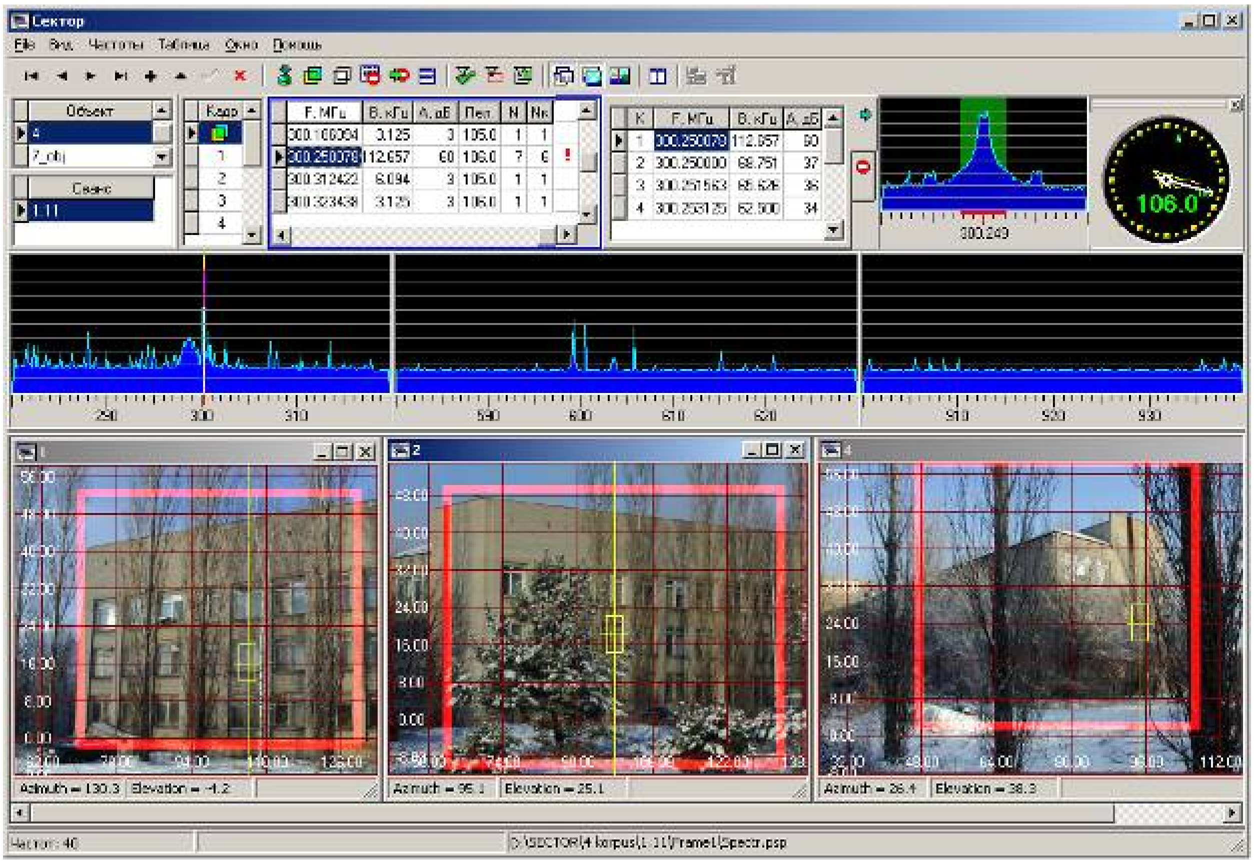
In an urban environment, radio reception and DF are often subject to interference, with an attendant risk that significant errors may creep into the list of identified frequencies. For this reason, every frequency listed needs to be verified to ensure that it is in fact originating from an emitter on the site.

To verify, the operator goes to an aggregate frame and selects the necessary frequencies, and then invokes the export command that puts them into a separate table, for single-channel DF and detailed analysis.

For single-channel DF, the signal bearings are transferred from the control module to the analysis module, where they are superimposed on the digital image of the site. In this way, the probable location of the emitter can be visually identified. To reduce the effect of interference, the mobile station is moved so as to obtain single-channel DF results from different locations. The detailed signal spectrum can also be used to detect sideband components, providing further confirmation of the proximity of the emitter. If the angle of elevation is also calculated, then the yellow crosshairs marking the location can be accurately positioned along the horizontal (azimuth) and vertical (elevation) axis, as shown in Figure 6.

FIGURE 6

View of analysis module screen showing detection results



Once it has been determined that the emitter is located inside the site and its approximate position has been determined, a search can be made to find the emitter itself. Knowledge of its general location and the emitter frequency makes the final search, which may cover the inside of the building or the roof, a relatively straightforward affair.

Conclusion

The use of a mobile station for spectrum monitoring and direction-finding in order to detect emitters located within a given site offers a number of clear advantages. Mobility, of course, is one; the station can be rapidly moved from one suspicious site to another and full-perimeter detection carried out without any further preparations. The mobile station is a highly versatile facility, which is suitable not only for finding electromagnetic emitters in sites, but also for a variety of other tasks related to spectrum monitoring.

Finally, the practical experience obtained with such stations in urban settings confirms their effectiveness in finding emitters inside identified sites.

Bibliography

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2) *Radiomonitoring: zadachi, metody, sredstva.* A.M. Rembovsky, A.V. Ashikhmin, V.A. Kozmin. Moscow, 2006, Goriachaya Liniya-Telekom press. (Russian only)