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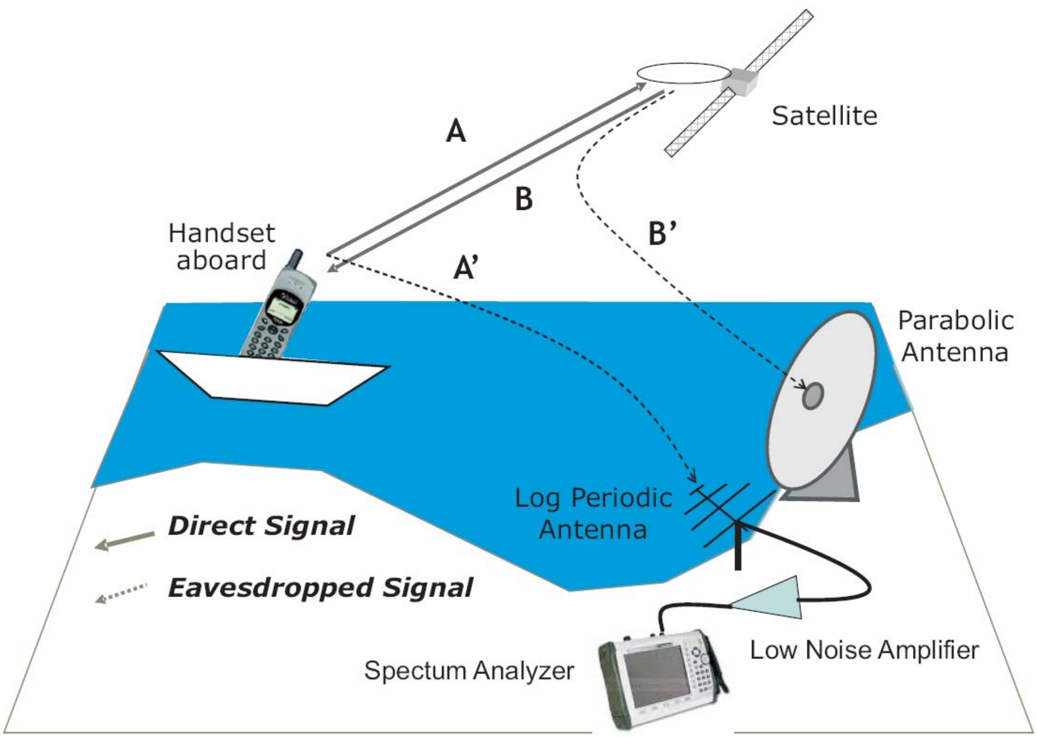
Detection of satellite telephones for maritime security

Franc Dimc, Gianmarco Baldini, David Shaw, Harm Greidanus



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Abstract

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In this technical report, we present a monitoring system to detect mobile satellite terminals in the open sea. The monitoring system is based on high gain antennas and amplifiers and the correlation of the known spectrum responses. The monitoring system can be implemented using low-cost component and it can be deployed in the patrolling boats.

The prototype can be improved and deployed on the vessels of the coast guard or the navy, which have the responsibility to patrol the sea for illegal immigrants and piracy activities. A similar monitoring system can also be installed on Unmanned Air Vehicles (UAV) used for the same purpose.

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Abstract

The technological progress on the digital processing has an impact on the approach to the detection and localization of electromagnetic sources.

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The prototype can be improved and deployed on the vessels of the coast guard or the navy, which have the responsibility to patrol the sea for illegal immigrants and piracy activities. A similar monitoring system can also be installed on Unmanned Air Vehicles (UAV) used for the same purpose.

1. Maritime security and mobile satellite communications

1.1. Awareness of the maritime domain

Two main threats to today's maritime security are immigration and piracy. An essential capability to address these threats is the Awareness of the Maritime Domain (MDA). Availability of data related to Automatic Identification System (AIS), Vessel Monitoring System (VMS), coastal radar tracks and satellite Vessel Detection System (VDS) reports are reliable MDA sources. A number of technologies have been proposed to locate and identify vessels used for criminal activities in the open sea. Data fusion from each of these sources can be integrated with accessible data from Vessel Traffic Surveillance (VTS) networks and GIS data to improve the overall detection threshold as described in [1]. The DECLIMS project (see [2]) used detection of widespread satellite GSM handsets beside satellite AIS and satellite imaging to provide MDA.

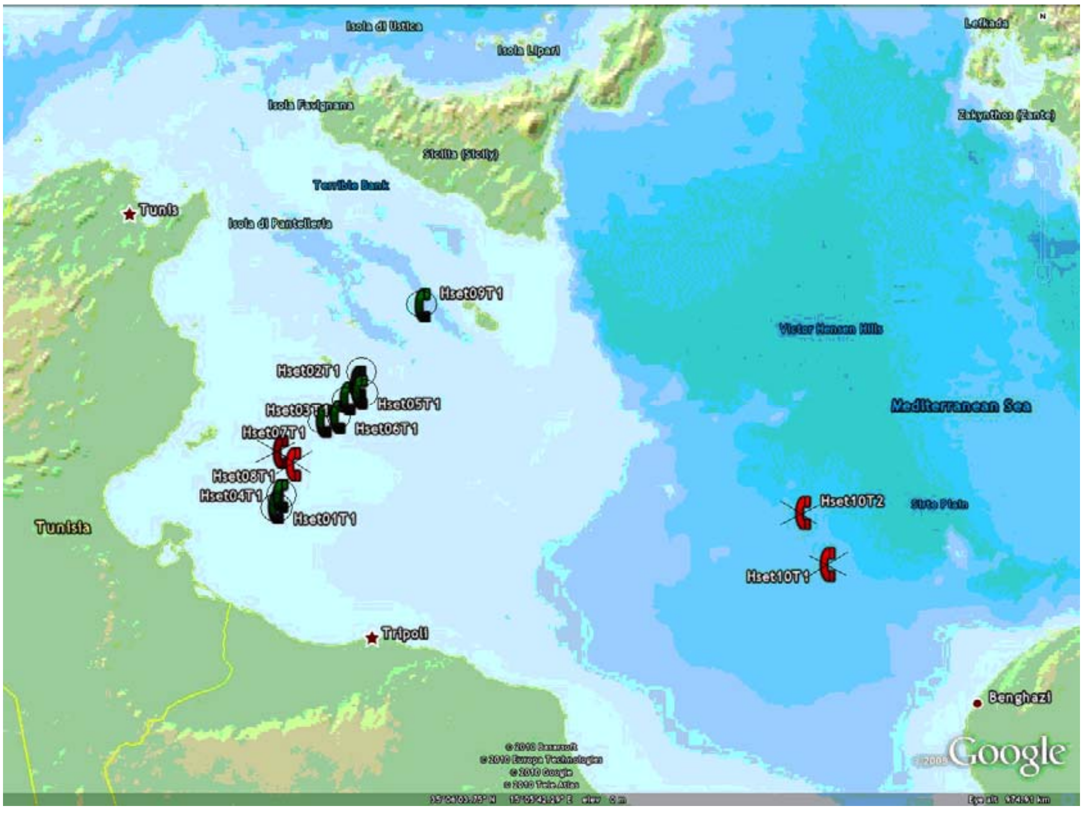

Figure 1 Last accessible positions of telephone handsets used by illegal immigrants in the Mediterranean area

A number of commercial systems are available including Iridium, Globalstar, Thuraya, Inmarsat and others. Each mobile satellite system has various levels of coverage. For example, Iridium has a world-wide coverage while Thuraya-2 has coverage of the Middle East as well as major parts of Africa and Europe (see [3]). The Mumbai terrorists of 26/11/2008 used Thuraya for calls from their fishing boat prior to the attacks [4]. The use of mobile satellite systems by pirates in the Red Sea has been reported by a number of sources such as [5] and [14]. Illegal immigrants in the Mediterranean also use mobile satellite terminals as reported in [6].

Figure 1 shows the automatic self reported GPS positions of Thuraya terminals in the Mediterranean. Handset icons with a circle show the last position of the eight different terminals, while the handset icons with a cross show the last two positions of one terminal of the same boats.

1.2. Maritime security aspects in the use of mobile satellite communications

Criminals use mobile satellite communications to communicate among themselves and coordinate an attack or to communicate with other agents on the land. While, normal GSM/UMTS terminals can be used only near the coast, in the open sea only low frequency bands (e.g. HF/VHF) or satellite communications can be used. HF/VHF communications are already well monitored by government organizations like the coastal guard and most of the radio bands are anyway reserved. The same rationale can be used for LF/MF which may not be practical for small boats. Satellite communications is the other form of communication used in the open sea. Small boats or yachts usually adopt mobile satellite terminals for communication.

Mobile satellite terminals can be detected through radio frequency spectrum monitoring. The detection of radio frequency emissions to identify and locate a potential enemy is well known in the military domain and is one of the elements of electronic warfare (EW) or SIGINT. The main tasks of Electronic Warfare (EW) are to detect a transmission from an enemy unit, locate the source of the emission and eventually extract information from the radio frequency emissions to support understanding of the enemy strategy or operations.

In a similar way, the authors have applied radio frequency spectrum monitoring to the detection and localization of a mobile satellite terminal in the open sea. This detection technique can be an additional source of information for the augmentation of the Maritime Situational Awareness (MSA) and locate criminals in the sea. The same capability can be used for rescue operations to shorten the response time in emergencies (e.g., bad weather conditions).

1.3. Thuraya systems and terminals

Thuraya is a company, based in the United Arab Emirates with a global market of their telephone service [7] and the coverage of Middle East and Southern Europe. A list of the available dual mode (satellite, terrestrial) handsets (product family/producers) includes: Thuraya / Boeing Satellite Systems, Hughes / HNS - still on market, and Ascom

/discontinued, Ascom, Switzerland. The provision of 260,000 units was published by March 2006, with the network capacity of 13,750 communication channels, but no open data are publicly available about local network capacities (e.g. Mediterranean area). The actual identity of the prepaid Thuraya SIM card holder through shipping address is not reliable, so it is thus hard to expect any reliable information of the handset user identity without intelligence data.

The GSM Thuraya handset operates in the L-band with uplink channels on frequencies from 1626.5-1660.5 MHz, and for the downlink channel at frequencies from 1525 MHz to 1559 MHz, where the handset emits a maximum power of 2 W, modulated according to π/4-CQPSK, with channel spacing of 31.2 kHz, and with gross data rates of 195.6 kbits/s (see Technical Specifications at [7]). The handset's capability of self-geolocation due to the integrated GPS receiver offers the system operator the possibility to charge the SIM card owner according to the handset's temporary position.

1.4. Software radio to support related security research

Technological progress on the digital processing has opened the way to a novel implementation approach for wireless communication platforms where most of the digital signal processing is done in software rather than in hardware. Such systems have been known as Software Defined Radio (SDR).

A typical SDR is able to execute all the radio frequency and base-band processing though software components rather then hardware components as in conventional radio communication systems. This capability provides a high level of reconfigurability and the possibility to implement a number of different algorithms for digital processing.

Reference [8] describes software-defined radio as:
"A software-defined radio (SDR) is one that has the capability – through use of programmable hardware (handsets) controlled by software - to tune to any frequency band and receive any modulation across a large frequency spectrum".

In the "Ideal Software Radio" the Digitalization starts right after the antenna (using D/A and A/D Converter with high dynamic range) and the elaboration is implemented by DSP/FPGAs with very high throughput using different software for different waveforms.

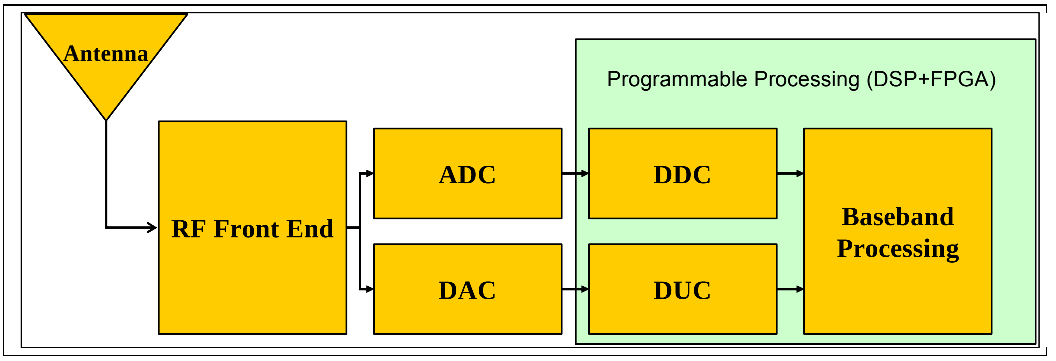

Figure 2 Diagram of a Software Radio

Theoretically, the hardware is able to identify the software with which it is being asked to interface and then to perform multiple tasks at the same time – in a similar way to a mobile telephone being able to act as a Global Positioning System (GPS), telephone and text sender simultaneously.

In other words, a SDR can receive and transmit a new form of radio protocol just by running new software. In this way, a SDR can reconfigure itself appropriately for its environment and can be quickly and easily upgraded over-the-air.

A specific capability which can be implemented in a SDR is spectrum sensing, where the SDR implements algorithms to detect the spectrum environment and the presence of wireless signals and services.
This SDR capability has been adapted to detect GSM Thuraya signals in the Mediterranean sea.

2. Detection of Mobile Satellite terminals

There are two main possibilities to geo-locate a specific GSM handset in the area of interest: 1) by getting the information through the service provider or 2) by the on-site multi-node detection and characterization of transmitted electromagnetic waves.

2.1. Satellite GSM service provider's data access

In the satellite telephone service providers databases the geographical positions of the handset in use are refreshed since the handsets send their GPS positions regularly via network. But since it is against the law which protects the users personal data (i.e., Privacy), even for the law enforcement organizations, the access to these data bases is restricted. Only in the situation of high risk (such as case of rescuing from the high sea), the service provider can send the data as described in Figure 1.

2.2. Locationing by Radio spectrum monitoring

An alternative way to detect mobile satellite communications is through radio frequency spectrum monitoring. The detection of radio frequency emissions to identify and locate a potential enemy, is well known in the military domain and is one of the elements of Electronic Warfare (EW) or Signal Intelligence (SIGINT) - intelligence derived from electromagnetic radiations.

The main tasks of EW are to detect a transmission from an enemy unit, locate the source of the emission and eventually extract information from the radio frequency emissions to support understanding of the enemy strategy or operations.

After the detection a beamforming by a grid of antennae on known locations could take place, which makes base for the triangulation. Another approach for geolocation is by measuring the time difference of arrival (TDOA) from the known locations and solving the system of equations in order to get the handset's position by trilateration.

For both methods all the possibly involved SDRs have to rely on stable and phase synchronized oscillators, a requirement which is very restrictive for the expected low priced equipment at the L1 frequency band. The clocks could be synchronized by access to the GPS time and remain in constant connection in order to exchange the relevant location data. A similar system is also suggested but not described in [9].

2.3. Detection techniques

In recent time, different approaches for spectrum sensing for cognitive radio applications have been proposed. The commonly considered approaches are based on power spectrum estimation, energy detection, and cyclostationary feature detection. Power spectrum estimation may not work reliably in the low Signal-to-Noise ratio (SNR) regime. Energy detection, on the other hand, is subject to uncertainty in noise and interference statistics. In addition, neither power spectrum estimation nor energy detection are able to distinguish among the primary user signals, secondary user signals, or interference. Cyclostationary detection allows classifying co-existing signals exhibiting cyclostationarity at different cyclic frequencies, relaxing assumptions on noise statistics and has reliable performance even in the very low SNR regime. In this report, we describe the application of cyclostationary spectrum sensing to detect the signal of GSM Thuraya communication systems.

3. Experimental setup and method

A general approach for the detection is shown in Figure 3. Antennae eavesdrop exchanging signals between the handset and communication satellite in the line of sight area and lead them through the low noise amplifier to the attached spectrum analyzer.

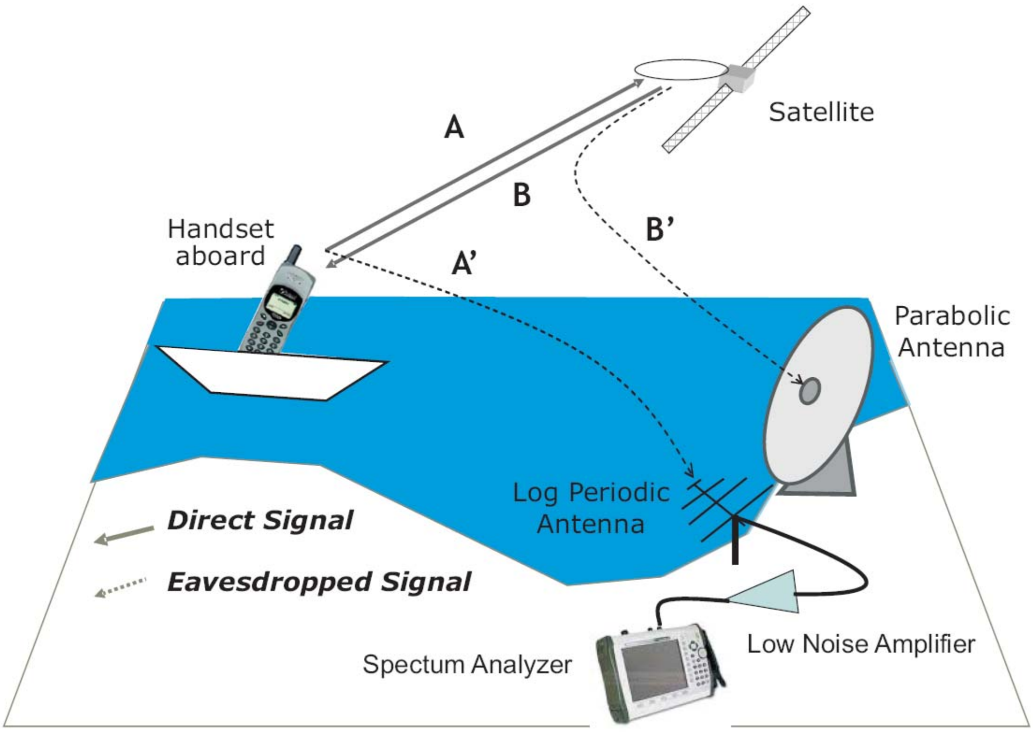

Figure 3 Experimental setup for uplink channel monitoring.

3.1. Downlink channel monitoring

A downlink channel of the Thuraya-2 geostationary satellite was investigated near the Building 72, JRC in late October 2009 by the use of patch active GPS antenna GAACZ by Jinchang with bias tee, parabolic antenna type Eurasis with LNB skew set ability (Metronic), a satellite TV tuner and a RSA Real time Spectrum Analyzer 3408B (Tektronix). Parabolic antenna was pointed to the Thuraya-2 with azimuth 135 deg. and 27 deg. elevation, with LNB skew setting of 25 deg., at the JRC Location in Ispra, Italy.

Polarization shift at reflection from the parabolic antenna was intuitively used to get the right hand circular polarization (RHCP) into the patch antenna from the left HCP signals from the observed satellite. Backscatter noise of the patch antenna was rejected by insertion of the GAACZ antenna into a metal housing which was placed as a reception head of the parabolic antenna and fixed on a robust metal stand.

Figure 4 Downlink antennae: Eurasis, Ø = 60 cm;
GAACZ-D, center frequency 1575.42 MHz ± 3 MHz.

Satellite	INTELSAT 12 (45.0 E)	**THURAYA 2 (44.0 E)**	TÜRKSAT 2A (42.0 E)
Distance	38945 km	**38896 km**	38801 km
Elevation	26.4°	**26.9°**	27.9°
Azimuth	134.2°	**135.3°**	137.5°
LNB skew	- 30°	**- 29.4°**	- 28.1°

Table 1Parameters to get the satellite reception

By aligning the positions of the two TV satellites, received by the SAT TV tuner, we were able to get the Thuraya-2 position.

3.2. Uplink channel monitoring

Using the first generation of the Thuraya's handsets (Hughes 7101) also an uplink channel was tested with two setups, following the scheme described in Figure 5.

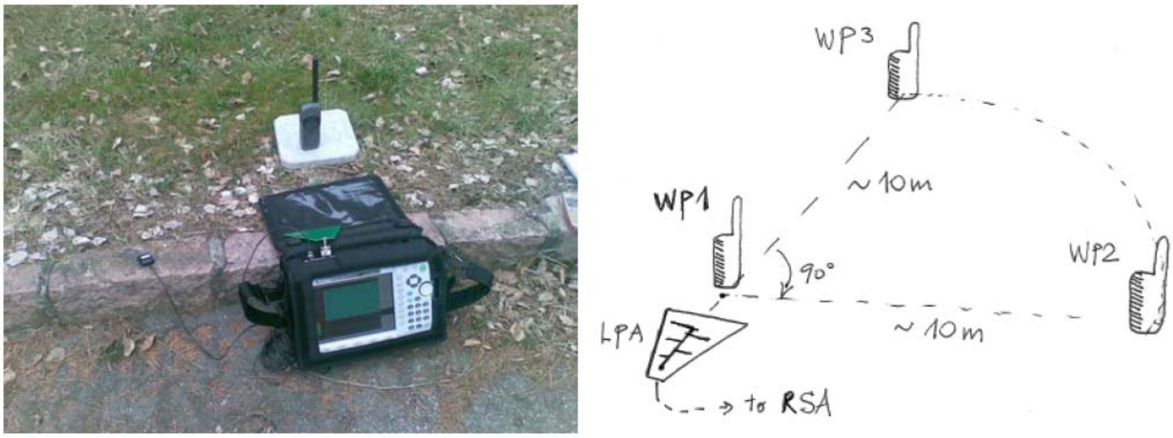

Figure 5 (left) an experiment setup during test at waypoint WP1, (right) a sketch of the tests with handset at three waypoints.

The first field setup (March 2010, 41 measurements) used spectrum analyzer MS2721B (Anritsu) equipped with a 900-2600MHz WA5VJB antenna as described in Figure 5 to investigate the similarity of spectrograms (i.e. power vs. time/frequency patterns) of the signals assigned to the same phase of handset operation. Multipath fading was not considered.

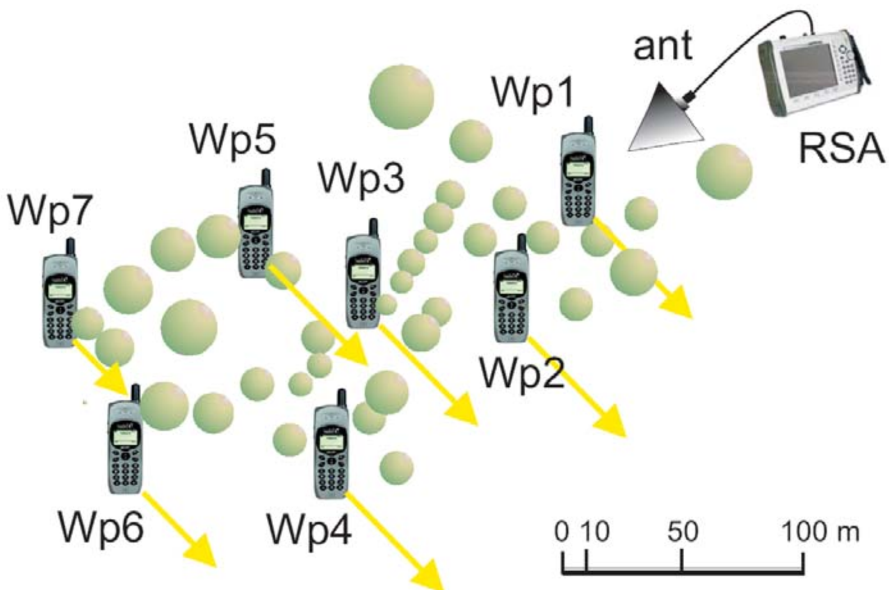

Figure 6 An experiment setup for the second field testing the influence of the distance, antenna orientation and multipath on a signal power.

For the second field setup (April, July 2010; 49 measurements) a RSA 3408B (Tektronix) with antenna WA5VJB was used. In a later stage, the more powerdul RSA 6114A (Tektronix) spectrum analyzer with Schwarzbeck antenna ESLP 9145 was used. The spectrum analyzer was kept in laboratory of the Building 72, while the handset was moved around (from 5 m up to 250 m).

3.3. *Method 1: Power sensing*

Power sensing is the optimal detector when the noise power threshold is known. The spectrum sensing algorithm determines the presence/absence of primary users on the basis of the energy of the received signal. The sensing is performed by dividing the spectrum into many subsets of frequency bands and computing the energy associated with it within the sub-bands. The computed energy is then compared against a threshold.

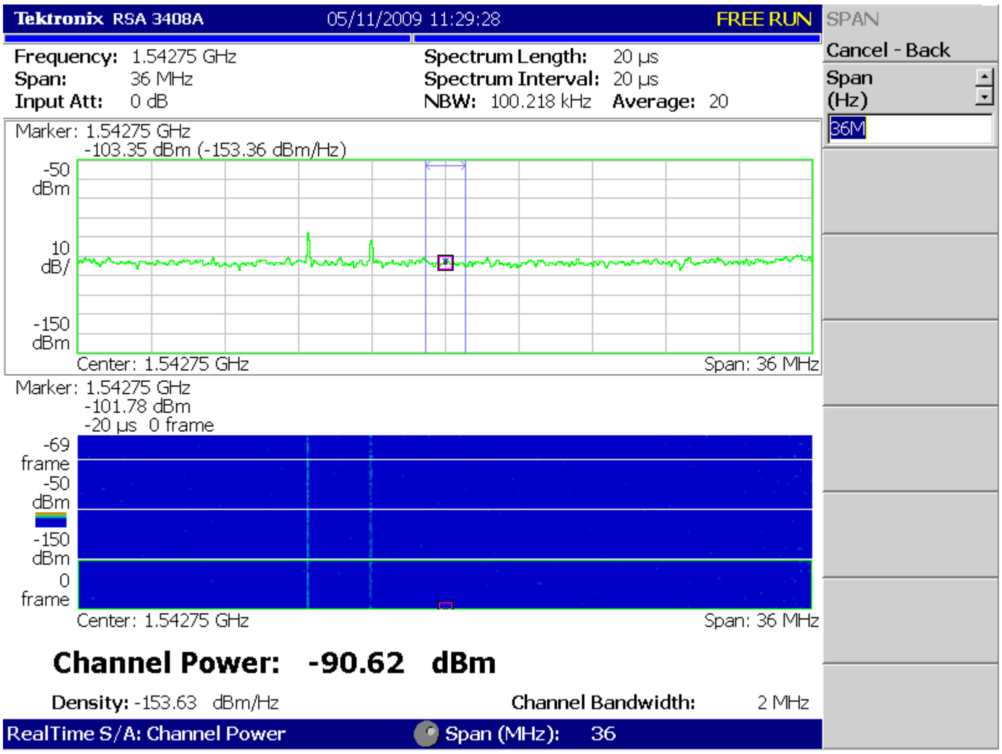

Figure 7 On Thuraya downlink band noise level was established (wide scan).

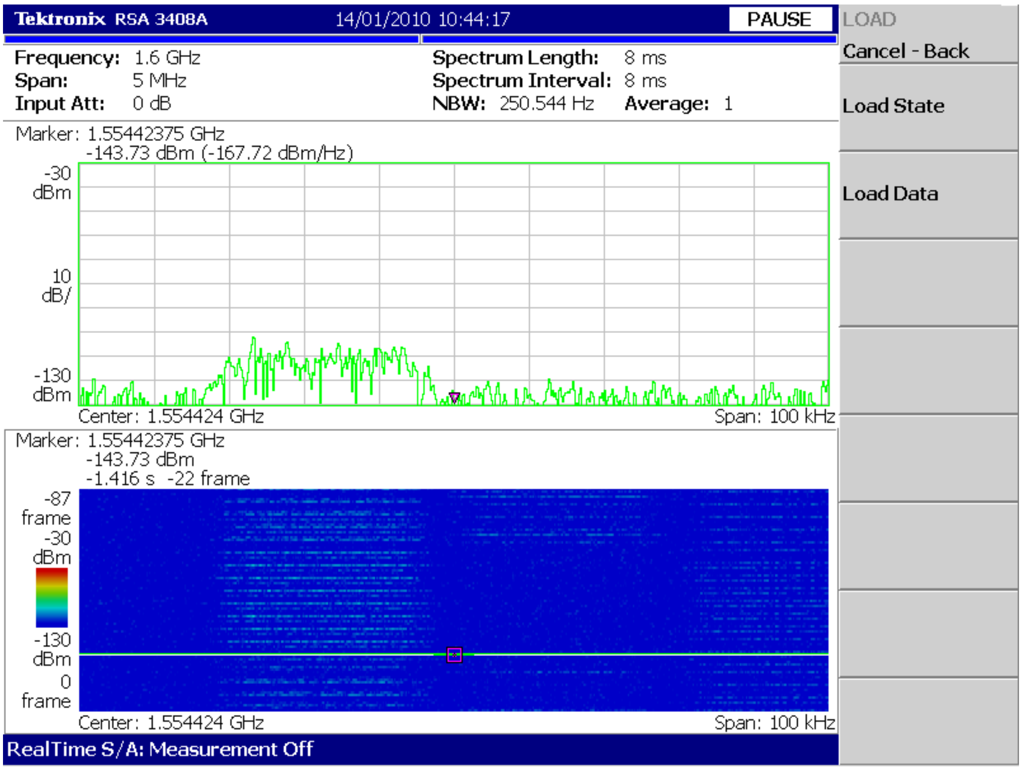

Figure 8 A standard GMR-1 channelization is observed (narrow scan)

In the first step, the noise level was calculated (see Figure 7). In the second step, the standard GMR-1 signal was acquired (see Figure

8).

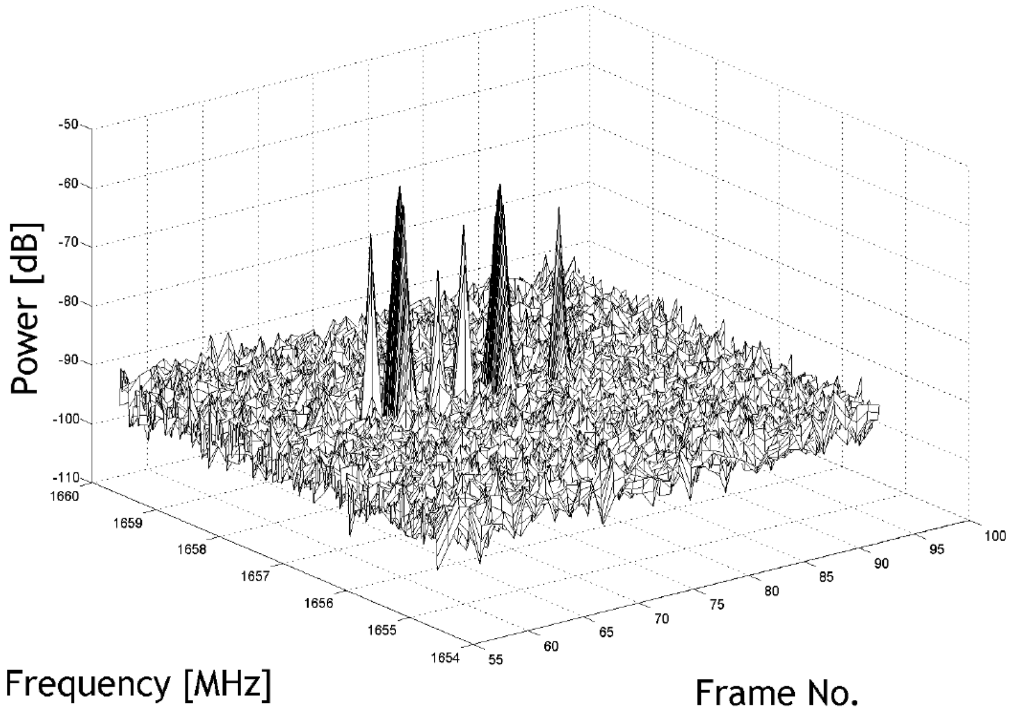

Figure 9 Spectrogram of the uplink power sensing of the GSM Thuraya.

Figure 9 describes the spectrogram during the deactivation phase, when the antenna was moved from WP3 towards WP1 (for the WayPoints refer to Figure 5). The following parameters were used: *GPS position* MS2721B: N 45 48 35, E 8 37 48, time of sweep of frame 0 = 03-19-2010,06:57:43, *time of sweep of frame 155* = 03-19 2010,06:58:35, *frequency span* 5 MHz, *calculated time scale* 52"/155 frames => 0.3355"per frame.

The binary hypothesis test for sensing the spectrum can be obtained by comparing the decision metric with a detection threshold λ. The detection probability (PD) and the probability of false alarm (PFA) are dependent on the signal/noise ratio, which can be higher or lower than λ. This type of detection algorithm is easy to implement and it is has low complexity but it has strong limitations. The decision threshold can be chosen by optimizing the value of PD and PFA. For the theoretical calculus of PD and PFA, refer to [10].

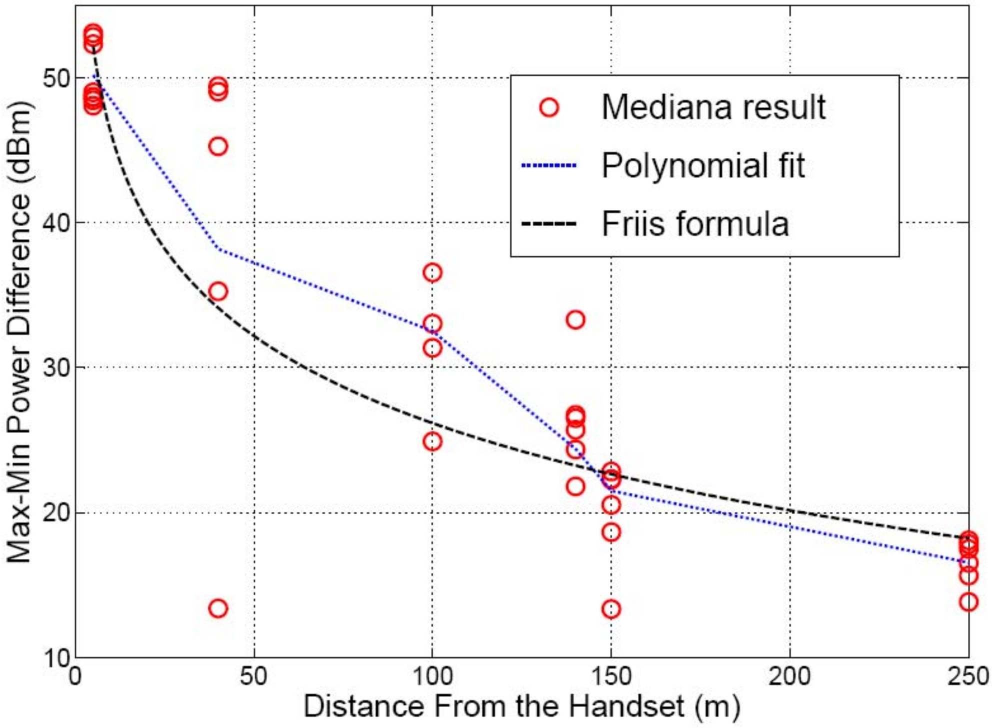

Figure 10 Uplink: median power levels get during 49 attempts on different locations and under different signal propagation conditions.

The influence on faded propagation conditions is clearly shown in Figure 11, where the handset's transmitted signals during deactivation phase are presented. Activation data sequences typically take cca. 200 Time Division Multiple Access (TDMA) frames while deactivation a half of it. A typical data deactivation sequence consists of 7 TDMA 40 ms frames, (e.g. high power. 5 ms + low power 35 ms) ending by variable number of low power TDMA frames.

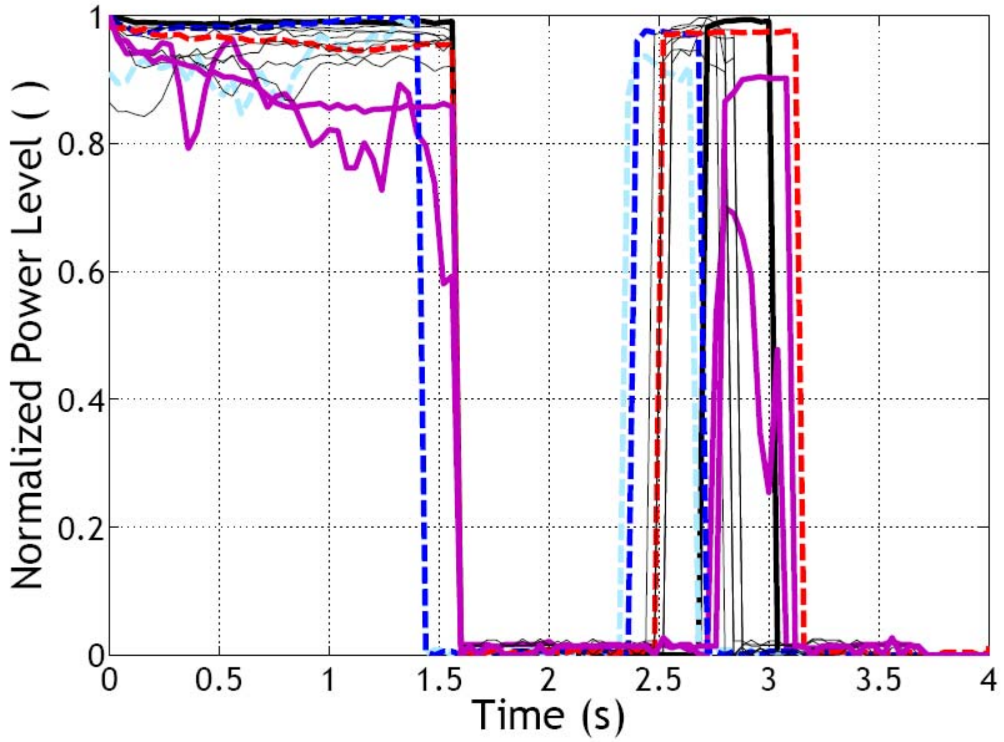

Figure 11 Uplink: Changing the power level during the deactivation phase under different conditions of signal propagation.

3.4. Method 2: Cyclostationarity

Cyclostationary feature detection has a very high computational complexity, because the algorithm has to estimate the correlation between spectral components of signals. In most operational scenarios, spectrum sensing algorithms must execute in real time on terminals or computing platforms with limited power. Consequently, it is important that the detection algorithms are very efficient. In comparison to classical cyclostationary analysis, computationally efficient cyclostationary detection algorithms have been defined (see [11]).

Cyclostationarity analysis algorithms generally fall into two classes: those that average in frequency (frequency smoothing) and those that average in time (time smoothing). Although both classes of algorithms produce similar approximations to the cyclic spectrum, time smoothing algorithms are considered to be more computationally efficient for general cyclic spectral analysis.

In present report, we also apply the Strip Spectral Correlation Algorithm (SSCA) to the detection of GSM Thuraya signal. The report makes a comparison among the two spectrum sensing techniques: the cyclostationarity approach and SSCA. The technical details on both approaches are presented in Annex I.

During on-field test, it was observed that the processing time of the SSCA algorithm for the same resolution of the positive alpha plane was significantly faster than the classical cyclostationary time smoothing approach. The extraction of cyclostationary signature from the received QPSK signal was based on the known GMR-1 uplink channel parameters [12], however the approach is suitable for the short signal observation times and does not require any frequency nor the phase synchronization as described in [13].

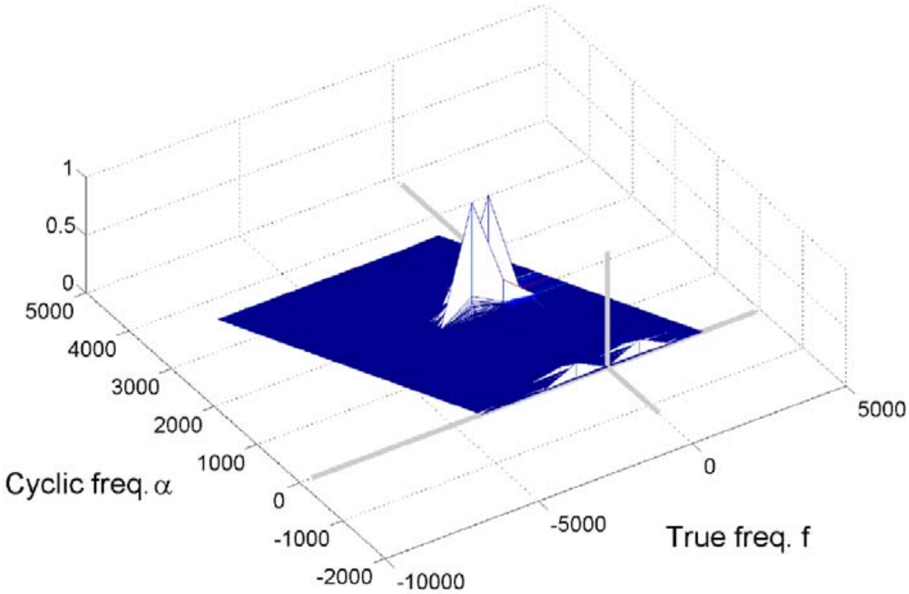

Figure 12 SSCA plane for the uplink channel

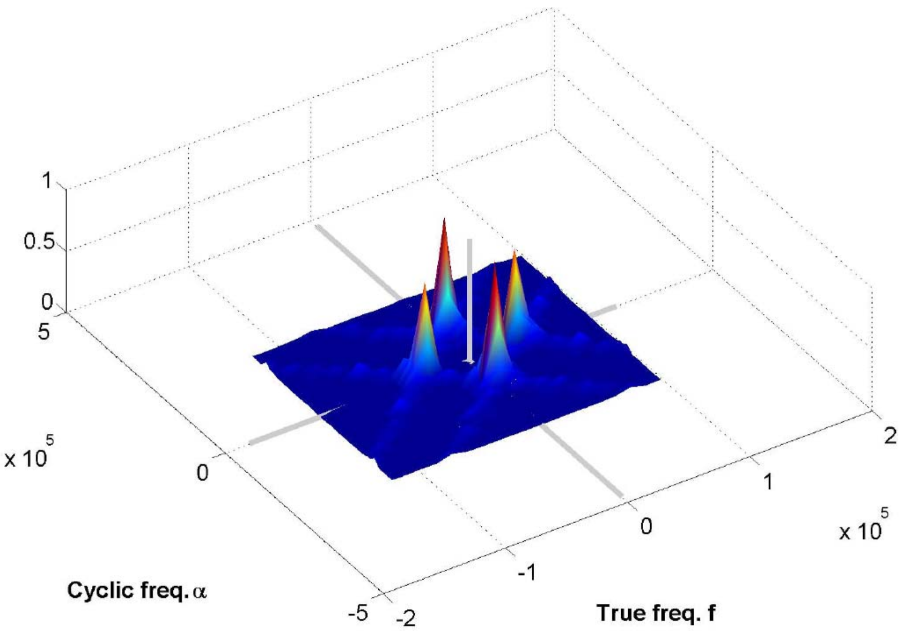

Figure 13 **Cyclic Power Spectral Density (CPS) of the Uplink GSM Thuraya signal in the absence of distortion**

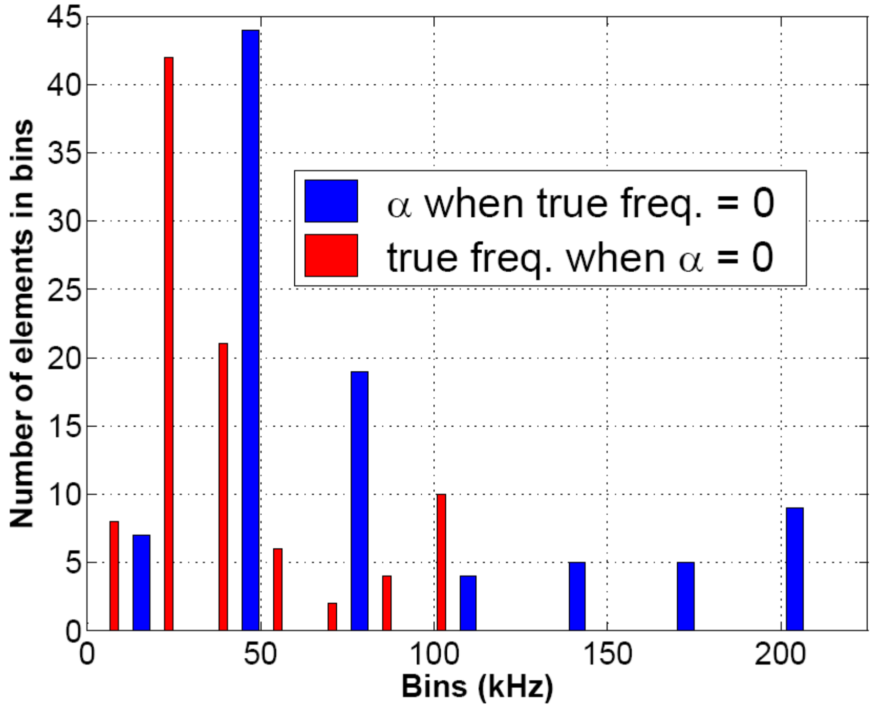

Figure 14 Statistics for cyclostationarity peaks in the deactivation of the downlink channel

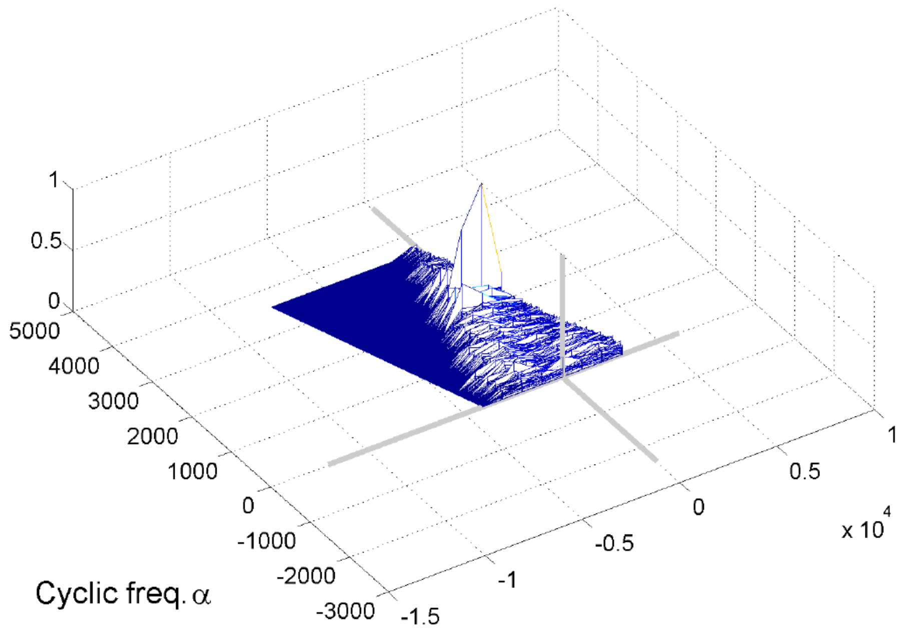

Figure 15 The distortive effect of multipath fading on normalized power results is presented for the positive in the SSCA plane for the uplink channel

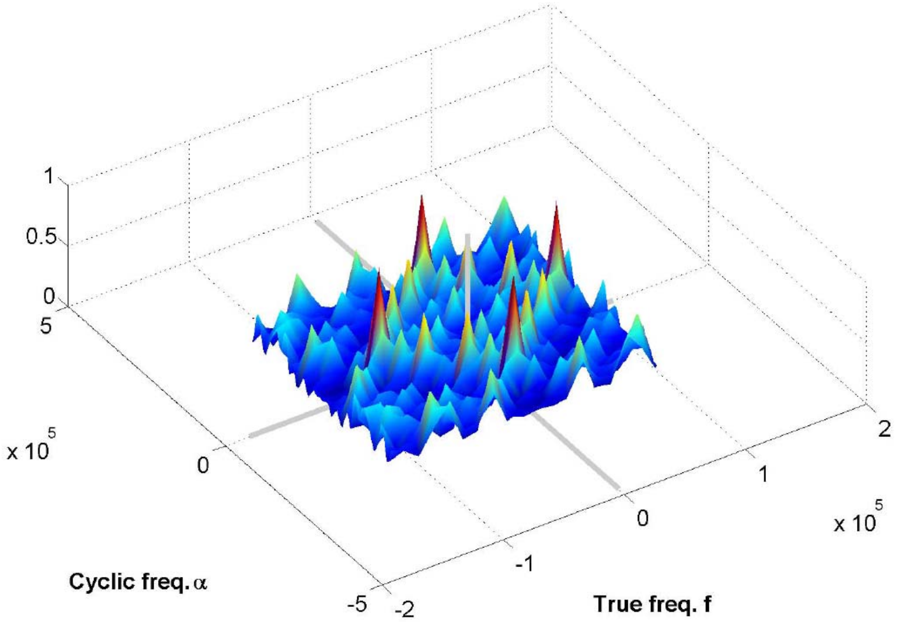

Figure 16 Cyclic Power Spectral Density (CPS) of the Uplink GSM Thuraya signal in presence of disturbances and multipath fading

4. Conclusions

The report presents a monitoring system to detect mobile satellite terminals in the open sea. The monitoring system is based on high gain antennas and amplifiers and the correlation of the known spectrum responses. The monitoring system can be implemented using low-cost component and it can be deployed in the patrolling boats. A description of this solution has also been presented at the ELMAR conference in Croatia [15].

The prototype can be improved and deployed on the vessels of the coast guard or the navy, which have the responsibility to patrol the sea for illegal immigrants and piracy activities. A similar monitoring system can also be installed on Unmanned Air Vehicles (UAV) used for the same purpose.

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Annex I

1. CYCLOSTATIONARITY SENSING

A random process $x(t)$ can be classified as wide sense cyclostationary if its mean and autocorrelation are periodic in time with some period T_0. Mathematically they are given by,

$$E_x(t) = \mu(t + mT_0) \tag{1}$$

and

$$R_x(t, \tau) = \mu(t + mT_0, \tau) \tag{2}$$

where, t is the time index, τ is the lag associated with the autocorrelation function and m is an integer. The periodic autocorrelation function can be expressed in terms of the Fourier series given by,

$$R_x(t, \tau) = \sum_{\alpha=-\infty}^{\infty} R_x^{\alpha}(\tau) \exp(2\pi j \alpha t) \tag{3}$$

where,

$$R_x^{\alpha}(\tau) = \lim_{T_0 \to \infty} \frac{1}{T_0} \int_T x(t - \frac{\tau}{2}) x(t + \frac{\tau}{2}) \exp(-2\pi j \alpha t) dt \tag{4}$$

The expression in (4) is known as the cycle autocorrelation, and for a cyclostationary process with a period T_0, the function $R_x^{\alpha}(\tau)$ will have component at $\alpha = 1/T_0$. Using the Wiener relationship, the Cyclic Power Spectrum (CPS) or the spectral correlation function can be defined as,

$$S_x^{\alpha}(f) = \int_{-\infty}^{\infty} R_x^{\alpha}(\tau) \exp(-j2\pi f \tau) d\tau \tag{5}$$

The CPS in (5) is a function of the frequency f and the cycle frequency α, and any cyclostationarity features can be detected in the cycle frequency domain. An alternative expression for (5), for the ease of computing the CPS, is given by,

$$S_x^{\alpha}(f) = \lim_{T \to \infty} \lim_{T_0 \to \infty} \frac{1}{T_0 T} \int_{-T/2}^{T/2} X_{T_0}(t, f + \frac{1}{\alpha}) \tilde{X}_{T_0}(t, f - \frac{1}{\alpha}) dt \tag{6}$$

where, $\tilde{X}_{T_0}(t, u)$ is the complex conjugate of $X_{T_0}(t, u)$, and $X_{T_0}(t, u)$ is given by,

$$X_{T_0}(t, u) = \int_{t-T_0/2}^{t+T_0/2} x(v) \exp(-2j\pi f v) dv \tag{7}$$

Expression in (6) is also known as the time smoothed CPS which theoretically achieves the true CPS for $T >> T_0$ and for larger T. In the following section we present the detector based on the CPS considering the cyclostationarity features of the signal.

Cyclostationarity analysis algorithms generally fall into two classes: those that average in frequency (frequency smoothing) and those that average in time (time smoothing). Although both classes of algorithms produce similar approximations to the cyclic spectrum, time smoothing algorithms are considered to be more computationally efficient for general cyclic spectral analysis.

We use the cyclostationarity feature to detect the presence of GSM Thuraya systems in the radio environment. Based on the sensed noisy signal, the binary hypothesis test to perform the decision is given by,

$$\begin{aligned} H_0^u &: r_u(t) = \nu_u(t) : \text{when signal is not present} \\ H_1^u &: r_u(t) = hs(t) + \nu_u(t) : \text{when signal is present} \end{aligned} \quad (8)$$

where, $r_u(t)$ is the signal sensed in the u^{th} frequency cluster, $\nu_u(t)$ is the zero mean bandlimited Gaussian noise at the receiver front end with a noise power of σ_u^2, and $s(t)$ is the GSM Thuraya signal. The signal to noise ratio (SNR) can be defined as

$$\text{SNR} \triangleq P_s^u / \sigma_u^2 \quad (9)$$

where P_s^u is the received signal power. We consider the channel h to be slowly varying and hence ignore its statistics in our modeling process below, we also assume that $h \approx 1$ in order to make valid comparisons between different experiments and techniques. Since we use the CPS function to detect the signal, we can re-write () in terms of the CPS as,

$$\begin{aligned} H_0^u &: S_r^\alpha(f) = S_\nu^\alpha(f) \\ H_1^u &: S_r^\alpha(f) = S_s^\alpha(f) + S_\nu^\alpha(f) \end{aligned} \quad (10)$$

where, $S_\nu^\alpha(f)$ is the CPS of the AWGN noise ν, and $S_s^\alpha(f)$ is the CPS of the signal s. In theory, since ν is not a cyclostationary process, the CPS of ν for $\alpha \neq 0$ is zero. Therefore, by using the CPS one can detect s when it is present. However, for a finite time duration T, or equivalently a finite length of data in the discrete domain with length $N = T/T_s$, where $f_s = 1/T_s$ is the sampling frequency, noise can be present in $S_r^\alpha(f)$ for $\alpha \neq 0$. Based on these arguments, we derive the test statistic for the detector as,

$$Z = \sum_\alpha \int_{-f_s/2}^{f_s/2} S_r^\alpha(f) \tilde{S}_r^\alpha(f) df \quad (11)$$

where, $\tilde{S}_r^\alpha(f)$ is the conjugate of $S_r^\alpha(f)$. The detector is then given by,

$$\begin{aligned} H_0^u &: Z < \lambda \\ H_1^u &: Z \geq \lambda \end{aligned} \quad (12)$$

where, λ is the detection threshold. Finding the optimum threshold is the most crucial aspect of the detector and is generally used to target a particular performance criteria for the false alarm probability and the miss detection probability. In general, knowing the noise variance will allow us to have better threshold values and is also feasible in many practical situations.

In Figure , is presented the bifrequency plan and the concept of the CSA cell. The area included in Δa and $\Delta\alpha$ represents an idealized CSA cell located at f_0 and α_0. In reality a CSA cell may have sidelobes or skirts. To avoid sidelobes, the cycle frequency resolution must be small enough to resolve the cyclic features of $S_x^\alpha(f)$ and the frequency resolution must be small enough to resolve $S_x^\alpha(f)$ in frequency.

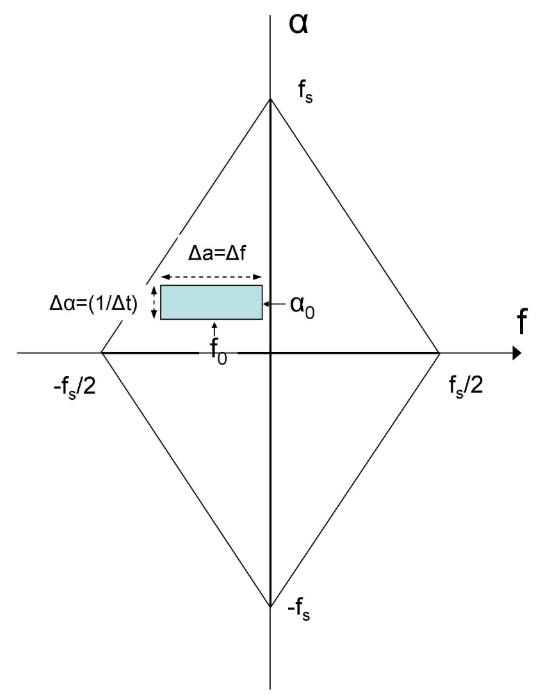

Figure 1. Cyclic Spectrum Analyzer (CSA) cell in the bifrequency plane

The features of the signal within a CSA cell are transmitted to the output while features outside of the region are suppressed. Thus, the width of a CSA cell determines the cycle frequency resolution, $\Delta\alpha$ and the length of the cell determines the frequency resolution. f_0 and α_0 identifies the location of the CSA cell. For a proper measurement the cycle frequency resolution must be small enough to resolve the cyclic features of $S_x^\alpha(f)$ and the frequency resolution must be small enough to resolve $S_x^\alpha(f)$ in frequency.

The sidelobes of the domain's support region, called Cyclic Spectrum Analyzer cell are generally smaller than those of its main lobe. The area of each CSA cell and thus the resolution of the final SCD estimate in the bi-frequency plane, centered in (f_0, α_0) is determined by the $1/\Delta t$ along the cyclic frequency α axis and 1/T along the true frequency axis.

The detection algorithm based on cyclostationary detection has an high computational complexity in comparison to detection algorithm based on power sensing. There is need to identify more efficient algorithms, which are still based on the CPS features, but they require less computational effort.

Reference [0] describes time smoothing algorithms for cyclic spectral analysis, which are quite efficient: Time smoothing with a Fourier Transform (FAM) and Strip spectral correlation algorithm (SSCA).

In this report, we have used SSCA.

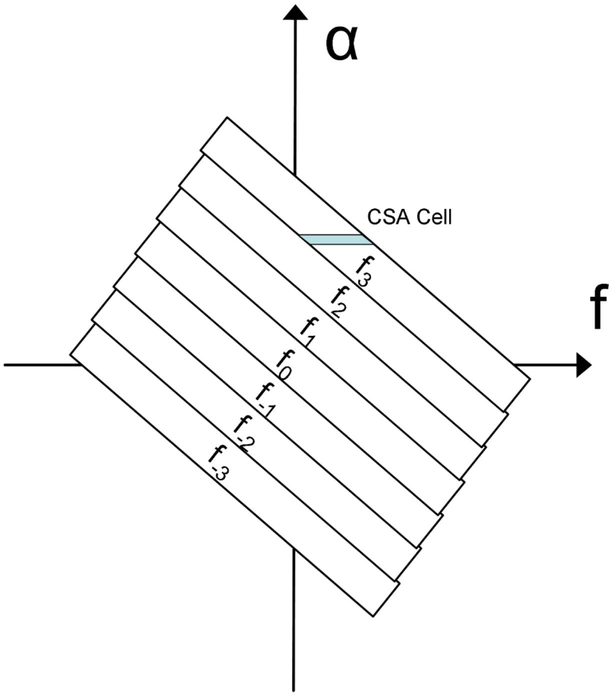

Figure 2. Cyclic Spectrum Analyzer (CSA) cell in the bifrequency plane

In the SSCA, the complex demodulates in frequency directly multiply the conjugate signal in time. From the mathematical point of view, this is expressed with the following equation:

$$S_x^{f_k+q\Delta\alpha}(\frac{f_k}{2} - q\frac{\Delta\alpha}{2}) = \frac{1}{T_0 T}\int_{-T/2}^{T/2} X_{T_0}(v, f_k) \tilde{x}(v)\exp(-2j\pi f v)dv \quad (13)$$

The point estimates produced by the SSCA lie along the frequency skewed family of lines $\alpha = 2f_k - 2f$ as described in figure .

The constraint is that the sampling rate of $X_{T_0}(v, f_k)$ cannot be decimated: the sampling rate of $\tilde{x}(v)$ and $X_{T_0}(v, f_k)$ must be the same.

CSA cells in SSCA have a constant length of $\Delta\alpha$, see figure , which implies that the SSCA has a constant frequency resolution of Δ f= Δa, which implies that the SSCA has a constant frequency resolution of $\Delta f = \Delta a$. The width of the CSA cell is $\frac{1}{\Delta t}$. Hence the frequency resolution of the SSCA is $\Delta\alpha = \frac{f_s}{N}$.

If the main characteristics of the signal are well represented in the SSCA cell, the computation complexity of the SSCA algorithm is much lower than the basic cyclostationary algorithm.

As a consequence, the SSCA signal detection is much more efficient that other signal detector algorithms if the features of the signal are well known in advance, as in the case of GSM Thuraya signal.

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Abstract

The technological progress on the digital processing has an impact on the approach to the detection and localization of electromagnetic sources. In this technical report, we present a monitoring system to detect mobile satellite terminals in the open sea. The monitoring system is based on high gain antennas and amplifiers and the correlation of the known spectrum responses. The monitoring system can be implemented using low-cost component and it can be deployed in the patrolling boats. The prototype can be improved and deployed on the vessels of the coast guard or the navy, which have the responsibility to patrol the sea for illegal immigrants and piracy activities. A similar monitoring system can also be installed on Unmanned Air Vehicles (UAV) used for the same purpose.

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