

Frequency Dependent Quality of HF-Communication Channels Estimated by Superresolution Direction Finding

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ABSTRACT

While Very High Frequency (VHF) communication systems develop rapidly, but nonetheless high frequency (HF) links remain important, particularly for military communication. Their efficiency depends strongly on the ionospheric conditions, especially during the passage of ionospheric disturbances. Usually networks of ionosondes are used to control the ionospheric state. But nonetheless the occurrence of Traveling Ionospheric Disturbances (TIDs) has attracted much less attention in frequency management. In this study a super-resolution HF direction finding (DF) system has been used to estimate the quality of HF-communication channels by the variation of the direction of arrival (DOA) of the waves impinging onto an array antenna. As another source for signal degradation the interference of different propagation modes has been found.

1.0 INTRODUCTION

HF communication uses frequencies from 3 to 30 MHz. By reflection at the layers of the ionosphere, long distance communication links are possible. The calculation of the reliability of a HF communication circuit is often done by updating climatological monthly median ionospheric models with ionosonde data and actual geophysical information. Input parameters to run the model are such as the sunspot number, the date and time of day and the critical frequency f_{oF2} as deduced from ionosonde data and the K-index of geomagnetic activity. This methodology relies on the classical picture of the ionosphere. Reflection may occur on the E, F1 and/or F2 layer, possibly leading to multipath propagation. Each of these paths interfere at the antenna at the receiving site. By the use of an array antenna and suitable super-resolution direction finding algorithms, each single path can be separated from the others. But within each path, the wave splits up into two complementary propagation modes, the ordinary (O) and extraordinary (X) mode. Both modes have only slightly different propagation paths and are thus difficult to separate by their directions.. The waves of each existent mode interfere at the receiving antenna giving raise to a specific form of fading. Surveillance systems are usually designed to use one polarization only. With polarimetry the modes could be discriminated. From recent research [2,4] it is known that interaction between unresolved O and X components in a given propagation path will cause the received energy to fluctuate on a scale of about 5 seconds to several tens of seconds. As the resulting interference field will travel along the antenna field, the angle of arrival will vary on that time scale [2]. When O and X components are resolved this fluctuation does not occur.

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The resulting fading is a prevalent phenomenon as well as the passage of traveling ionospheric disturbances. Both have the potential to reduce the signal strength and the quality of the signal. The deviation of the propagation of the HF-waves from great circle propagation can be measured by a direction finding (DF) system [5]. By the use of super-resolution algorithms like MUSIC [6] or Maximum Likelihood [7] the accuracy of the estimated DOA is strongly enhanced. Thus the signatures of TIDs can be derived with a direction finder. The deviation of the azimuth has been compared to the power of the received signal.

2.0 MEASUREMENT SYSTEM

The experimental broadband super-resolution DF system BRAHMS [1] has been operated as a single station locator. The system has ten active antennas which are grouped on two concentric circles with five antennas respectively. This assures omni-directional sensitivity of the antenna array. The inner circle has a radius of 30.5 m, the outer radius is 65 m. The signals of the ten antennas are fed through a bandpass filter of 4-6 MHz bandwidth to analog digital converter. They are digitized and stored on a mass storage device for later offline evaluation.

The implemented algorithm includes super-resolution DF algorithms as well as spatial filtering. The spatial filtering algorithm enables, even in the case of multipath propagation or cochannel interferers [3], the selective reception of a specific signal,.

3.0 MEASUREMENTS AND RESULTS

In order to study the effects of wave-like TIDs onto the attenuation of a HF-signal, selected long time recordings of the radio stations DLF/Berlin at 6.005 MHz have been evaluated. In the simplest picture, the effect of a TID onto the ionosphere can be described as the distortion of the ionospheric mirror. Some examples for the signatures of TIDs are shown below. It will be investigated, if the passage of a TID is correlated to a decrease in the received power of the signal.

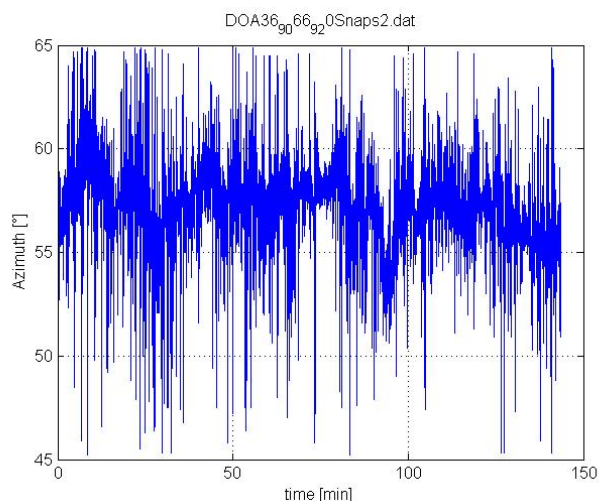


Figure 1: Time series of azimuth angles for the short wave radio station DLF / Berlin with 6.005 MHz. Short term deviations are well visible as well as the signatures of TIDs. True bearing is 58°.

In Fig. 1 the temporal profile of the azimuth from our receiving site in Niedermendig near Bonn to the emitter of DLF / Berlin is shown. Some typical medium-scale TIDs (MSTIDs) [5] can be seen through the observation that the bearing oscillates with a period of about 15 to 20 minutes around the true bearing of 58° . The related standard deviation and the relative received power is shown in Fig. 2. It is interesting to note that the standard deviation of the bearing raises to higher values when the received power is low. The relation between the passage of TIDs and the received power is displayed in Fig. 3. One can see that especially at the beginning of the recording when the TIDs are well pronounced that the power of the signal is in antiphase. It seems as if the TID is introducing an additional source of absorption.

In Fig. 4 the first two minutes of the temporal profile of Fig.1 are shown. One can see some fine structure on the temporal profile of the bearing. This is most probably due to interference of different propagation paths and fast fluctuations in the ionosphere. Additionally in Fig. 5 the power fluctuations are shown. There is no obvious correlation between the received power and the fluctuations of the bearing. The received power shows an oscillation with a period of approximately 20 seconds which is typical for the interference of O and X propagation mode [1,2]. But in our data no effect onto the estimation of the bearing can be seen.

Effects were found to be significant at lower frequencies as well at higher frequencies of the HF waves. At higher frequencies the signatures of TIDs are as well pronounced as at lower frequencies.

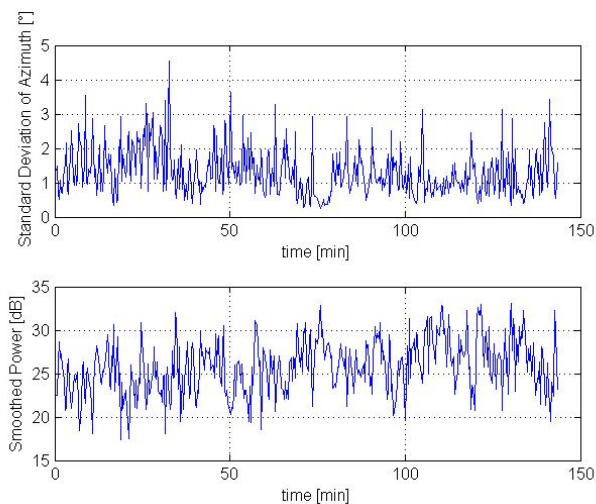


Figure 2: Standard deviation of the azimuth of the azimuth angles shown in Figure 1. Obviously the standard deviation of the azimuth angles raises when the received power is low.

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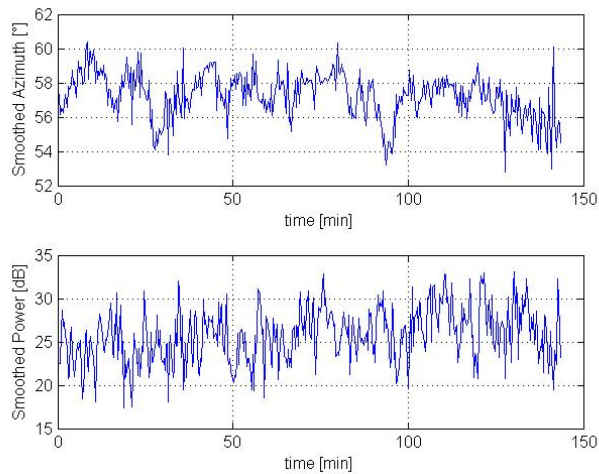


Figure 3: The signature of the TIDs is visible in the received power, too. Deviative absorption reduces the received power of about 6-8 dB.

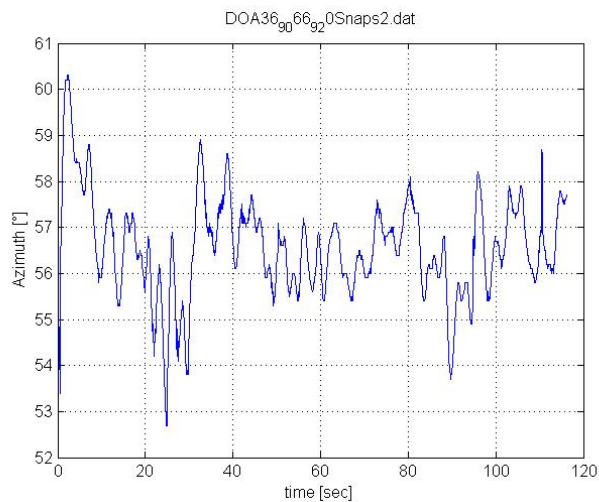


Figure 4: Magnification of the first two minutes of the recording shown in Figure 1.

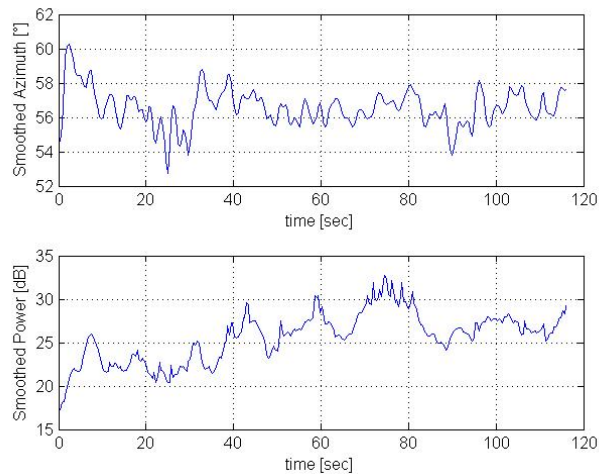


Figure 5: Azimuth and received power of the first two minutes of the recording shown in Figure 1 and Figure 4.

4.0 CONCLUSIONS

The investigations have shown that TIDs and interference of X and O mode influence the received power in a given HF communication link. While TIDs are natural phenomena and their existence has simply to be respected in the power management of the emitter, the fading due to mode interference can be encompassed by suited technical equipment. With the use of polarimetric antennas this problem can be eliminated.

5.0 REFERENCES

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Introduction

Concept

- Calculation of HF radio communication circuits usually relies on the modelling of an „average“ ionosphere only or modelling plus the calculation of correction factors which are estimated by the use of actual observation (ionosonde data)
- The observation of disturbances of the ionosphere may help to more accurately specify actual correction factors

Instrumentation

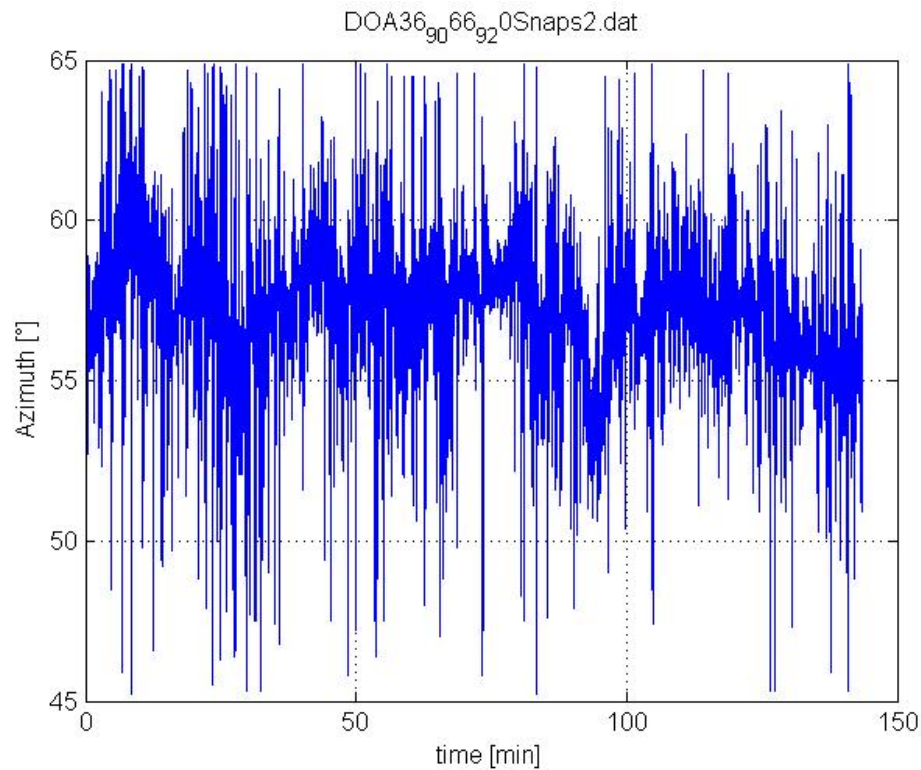
- Super-resolution direction finding system
- Signals of ten antennas are fed into ten synchronized receivers
- Covariance matrices are stored
- Direction of reception calculated offline
- Analysis of the variation of the bearing and its time spectrum

Sensing of the ionosphere with a super-resolution DF system

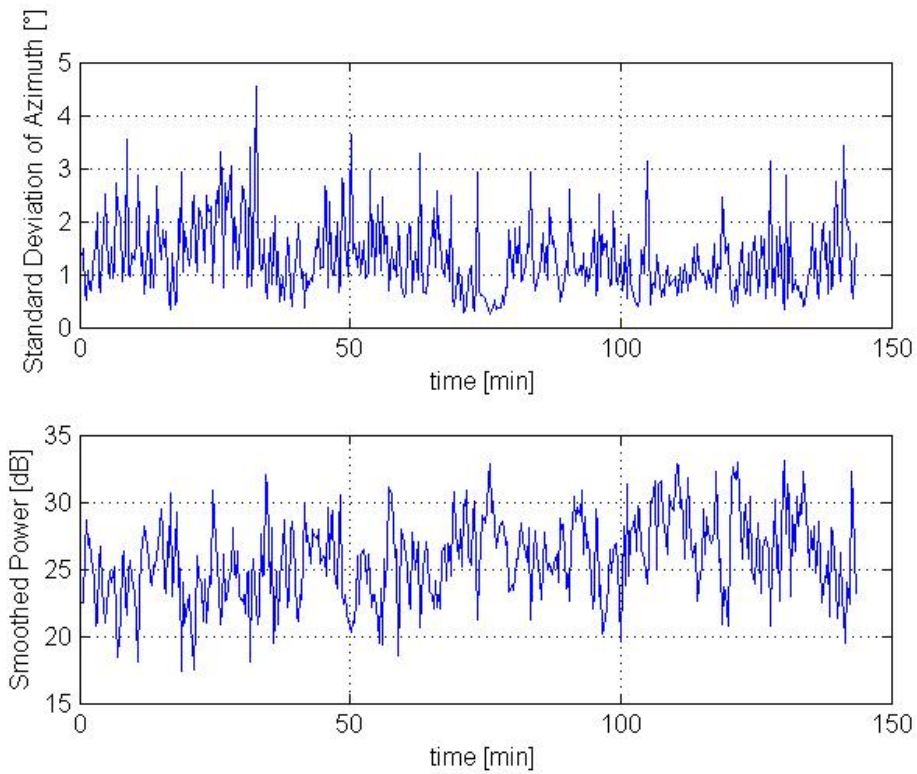
- Reflection of HF waves at the layers of the ionosphere
- Traveling Ionospheric Disturbances (TIDs) distort the ionospheric mirror
- The received power may fluctuate
- The physical process is density fluctuations of the free electrons
- The critical frequency is modified
- The ionosphere splits a vertical polarized HF wave into two circular polarized waves, the O- and the X-Mode
- Their interference may distort the signal and lead to fluctuations of the received power

Data Analysis

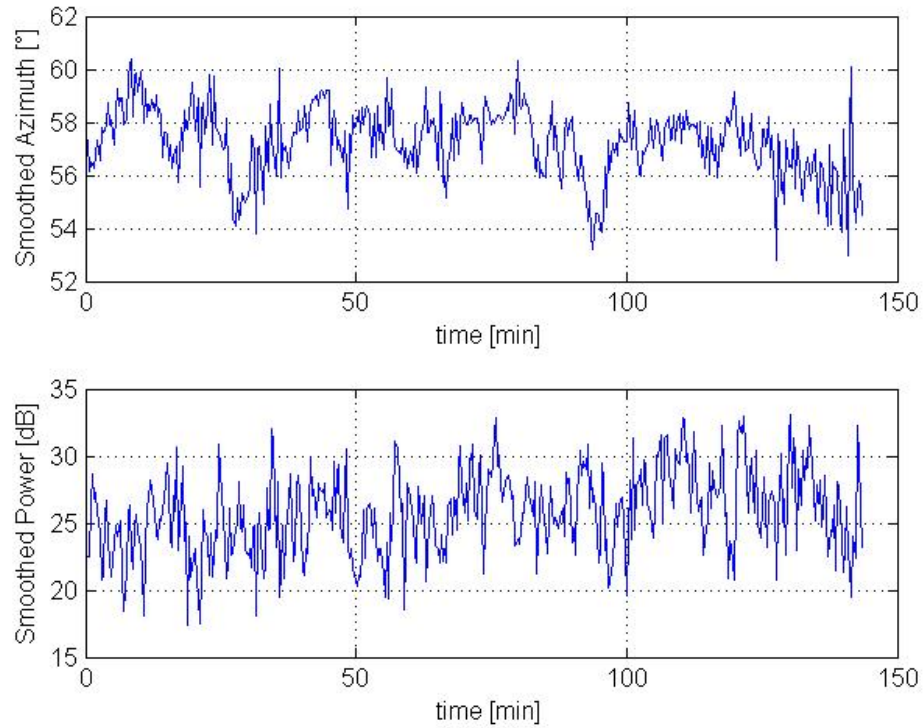
Selected long time recording of DLF/Berlin received at Mendig near Bonn



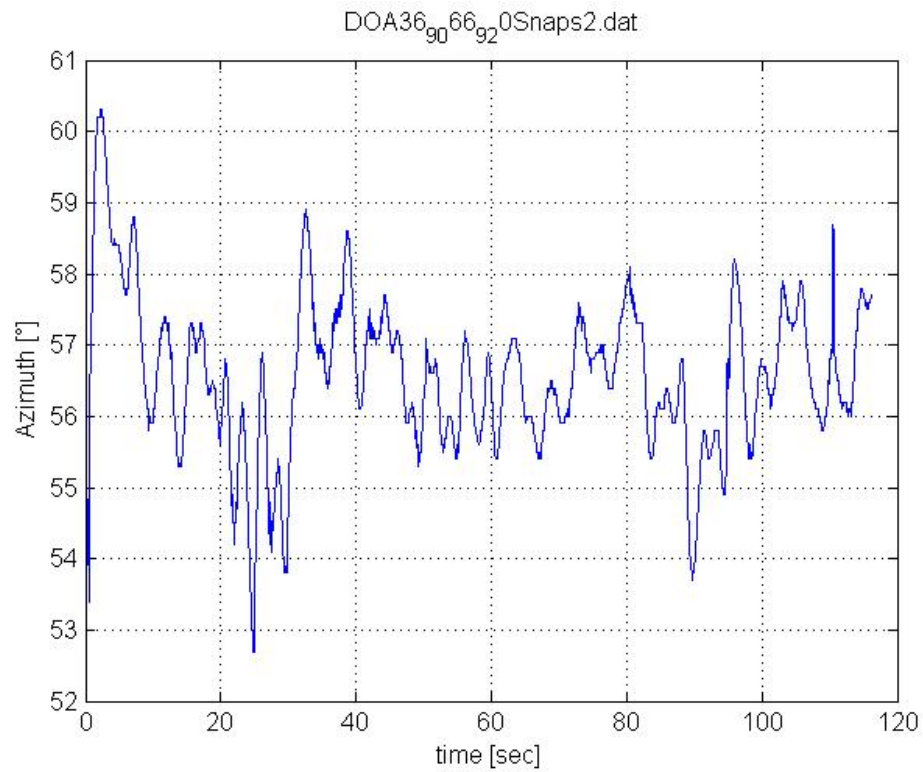
Data Analysis



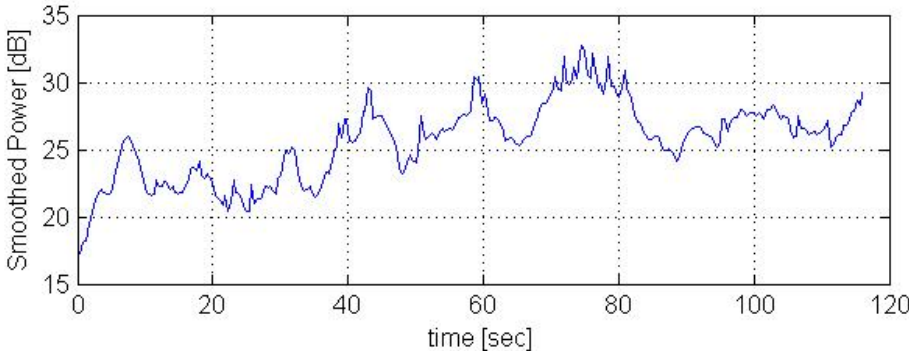
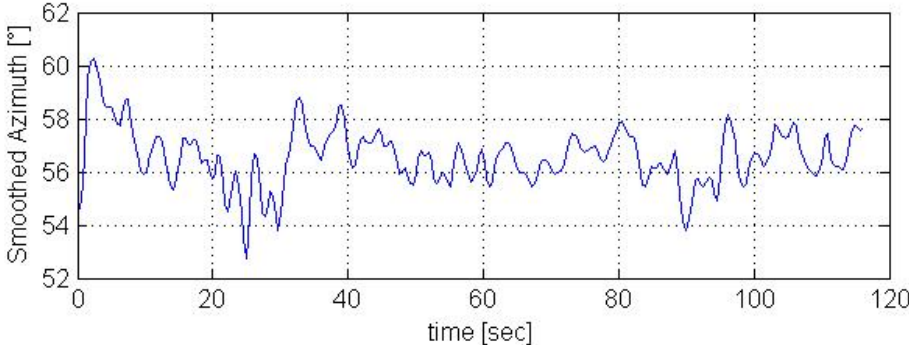
Data Analysis



Data Analysis



Data Analysis



Conclusions

- TIDs and X- and O-mode interference affect the quality of an HF communication link
- These can be detected by a super-resolution DF system
- TIDs are a natural phenomenon who affect the received power
- Reduce frequency when TID activity is strong
- X- and O-mode interference can be eliminated by the use of polarimetric antennas