AN EXPERIMENTAL INVESTIGATION INTO THE FEASIBILITY OF MIMO TECHNIQUES WITHIN THE HF BAND

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Abstract

To date, MIMO research has concentrated primarily on communications within the UHF band (and above). Environments such as those associated with indoor wireless systems are ideal for the implementation of MIMO systems because of the rich multipath environment. Moreover, the small wavelengths involved permit the use of physically small antenna arrays. So far, however, very little experimental research has been conducted in the area of exploiting MIMO techniques within the HF band. Some limited modelling work in this area has been reported. The authors have recently embarked on an experimental investigation into the applicability of MIMO techniques within the HF band. State of the art digital techniques will be employed in radio links established within the UK, between the UK and France, and over a more northerly path to estimate the MIMO channel capacity from measurements. The investigation will include consideration of operational frequencies (including the effect of different mode content), antenna configurations (e.g. spaced arrays and heterogeneous co-located arrays), and geographical effects (e.g. the different nature of the ionosphere between the mid and high latitudes). A theoretical background to HF-MIMO and introductory aspects to the specific project have been presented in this paper, in addition to a preliminary analysis using data from a previous (unrelated) study.

1. Introduction

A multiple-input multiple-output (MIMO) system utilises antenna arrays at the transmitter as well as receiver ends of a communications link. For MIMO systems to be successful, a rich fading or scattering environment is required which, in effect, facilitates the creation of multiple paths for the parallel transmission of data. The use of multiple transmitter and multiple receiver antennas in such an environment enables a substantial increase in data rates to be achieved within the same frequency band, thereby improving the spectral efficiency of the system. Furthermore, the more de-correlated the signals between the antennas, the greater is the advantage obtained. Thus, instead of simply trying to mitigate the effects of fading (as is the aim of standard diversity reception systems), MIMO systems, in contrast, exploit the presence of multipath in the propagation channel to increase data rates. To date, MIMO research has focussed primarily on communications within the UHF band (and above) [1, 2, 3]. Environments such as those associated with indoor wireless systems are ideal for the implementation of MIMO systems because of the rich multipath environment.

At HF, radio waves are capable of travelling well beyond line of sight by means of reflections from the ionosphere. These paths may be either single hop or multiple hop reflections from the different ionospheric regions (the E-region and/or the F-region). Additionally, due to the presence of the earth's magnetic field, each incident radio wave splits into two electromagnetic components known as the *ordinary* (*O*) and the *extraordinary* (*X*) modes. Each magneto-ionic component takes a different path through the ionosphere and arrives at the receiver as elliptically polarised signals with opposite rotational sense. The actual number of multipath components connecting a transmitter to a receiver depends on the geometry of the radio link, the frequency of operation, the time of day, season, geomagnetic activity and sunspot number. Therefore, as illustrated in Figure 1, an HF propagation path through the ionosphere is prone to extensive fading as a consequence of multipath propagation. As such, it would seem that the use of HF signals in a multi-element transmitter-receiver system would be an ideal candidate for a MIMO system. So far, however, apart from the research of Brine *et al* [4], very little experimental research has been conducted in the area of exploiting MIMO techniques within the HF band. Some limited modelling work in this area has been reported [5, 6].

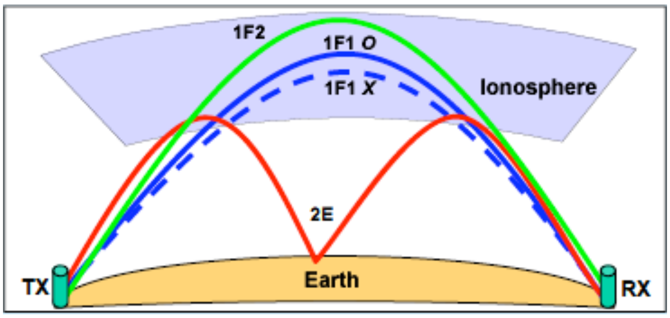

Figure 1: *Multipath and multimode propagation of HF radio waves in the ionosphere.*

In order to realise enhanced channel capacities, it is essential that there is sufficient de-correlation between the antenna elements at each end of the MIMO link. There are a number of factors that could influence inter-element correlation in MIMO systems such as antenna geometry, inter-element spacing and the number of multipath components present. When there are constraints on space requirements, instead of relying on traditional spaced antenna arrays, the use of compact, co-located antenna systems would seem advantageous.

This paper describes some of the preliminary analysis and background work that has been carried out in order to investigate the feasibility of implementing experimental MIMO techniques within the HF band.

2. Preliminary Data Analysis

In order to realise increased channel capacity by means of a MIMO system, it is essential that there is sufficient de-correlation between the antenna elements at each end of the link. Some preliminary analysis has been undertaken using data from an earlier (unrelated) study [7], and this is outlined below.

The amplitude data from two 7-element antenna arrays in the UK have been examined. Both arrays consisted of vertical monopoles arranged in V configurations. These arrays were: (a) a large 7-element array (Figure 2) with a minimum antenna spacing of 177 m and a maximum spacing of 1526 m (known as the *Forward Look* array) and (b) a small 7-element array (Figure 3) with a minimum antenna spacing of 25 m and a maximum spacing of 294 m (known as the *Verbena* array). Concurrent measurements of amplitude and phase of HF broadcast signals over several paths were made at each of the seven antennas.

As an example, the amplitude fading pattern across the small antenna array for broadcast signals received from Madrid, Spain (bearing: 185.4°; frequency: 9.57 MHz; range: 1259.2 km) for a period of approximately 2.5 minutes (at 16:35 UT on 26 March 1981) is depicted in Figure 4. In general, the fades appear to occur at approximately the same times on each of the seven receiving antennas, indicating high correlation. Clearly, for an HF-MIMO or HF-SIMO system, this is contrary to what is required: that is, adequate de-correlation between the antenna elements. The resultant correlation coefficients computed for various antenna pair spacings in this example are depicted in Figure 5. In order to identify orientation-dependent fading effects, the data have been divided into three parts (indicated by the different symbols) depending on the orientation of the particular antenna arm (orientation-1 (black data): left arm of V-configuration; orientation-2 (blue data): right arm of V-configuration; orientation-3 (red data): E-W pairs). For majority of the data points, the correlation coefficient is seen to drop to 0.5 at an effective antenna separation of approximately 150 m.

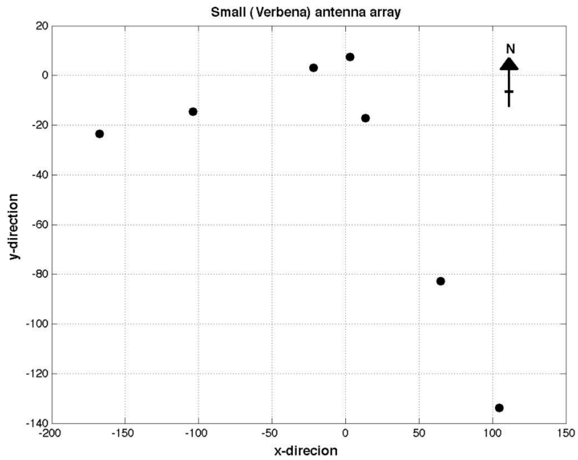

Figure 2: *The relative positions of the vertical monopoles employed in the small receiving antenna array (Verbena) in the UK.*

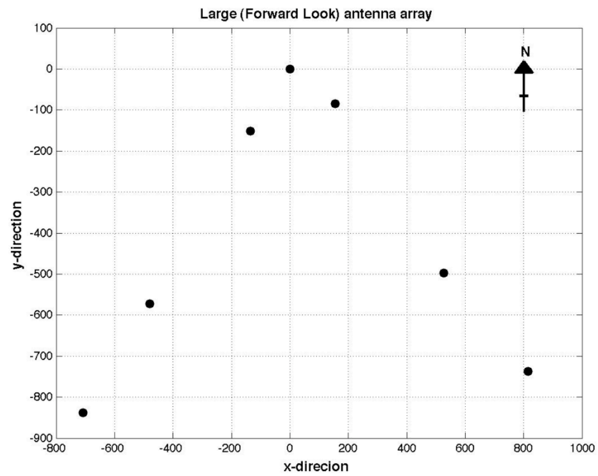

Figure 3: *The relative positions of the vertical monopoles employed in the large receiving antenna array (Forward Look) in the UK.*

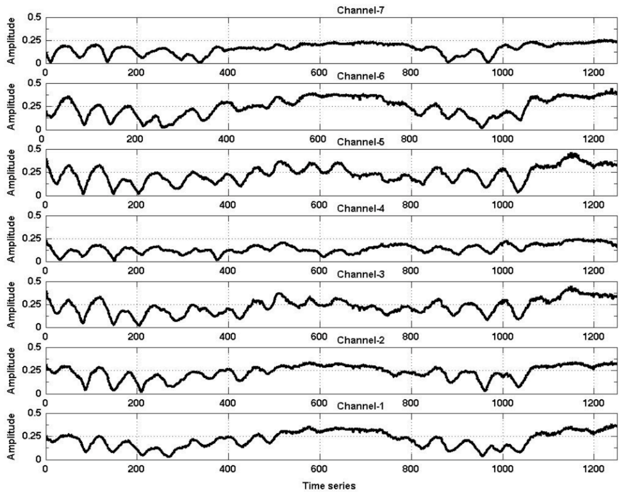

Figure 4: *Amplitude pattern observed on the different channels of the small 7-element antenna array (Verbena) in the UK, for broadcast signals received from Madrid, Spain (bearing: 185.4°; frequency: 9.57 MHz; range: 1259.2 km) for a period of approximately 2.5 minutes (at 16:35 UT on 26 March 1981).*

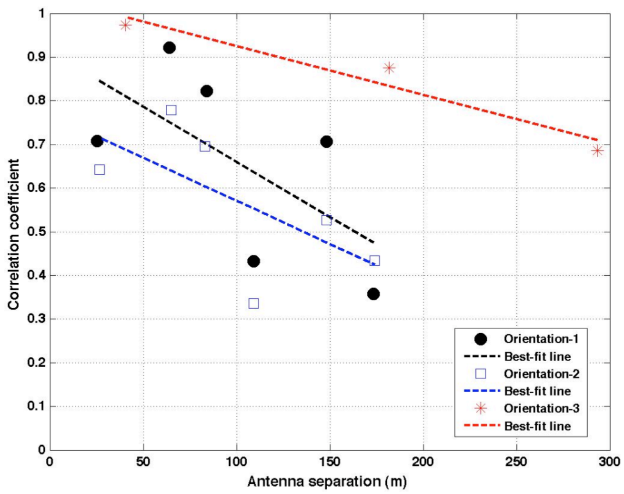

Figure 5: *Amplitude correlation coefficients (corresponding to Figure 4) computed for various antenna pair spacings for the small 7-element antenna array in the UK. The data have been divided into three parts depending on the orientation of the particular antenna arm [orientation-1 (black data): left arm of V- configuration; orientation-2 (blue data): right arm of V-configuration; orientation-3 (red data): E-W pairs].*

With reference to the larger antenna array, when examples of single-moded propagation are considered (over a much shorter path), the correlation coefficients for the various antenna pair spacings are observed to decrease to 0.5 at effective antenna separations of approximately 500 m to a few kilometres. To illustrate, the amplitude fading pattern recorded at the seven channels of the large antenna array for broadcast signals received from Oadby, UK (bearing: 25.1°; frequency: 4.7925 MHz; range: 122.2 km) for a period of approximately 2.5 minutes (at 14:26 UT on 22 January 1980) is depicted in Figure 6. Again, the corresponding correlation coefficients computed for various antenna pair spacings and the different antenna arm orientations are depicted in Figure 7. The data points predominantly lie on a line representing high correlation between the respective antenna pairs, and the correlation coefficient is expected to drop to 0.5 at an effective antenna aperture of approximately 1.4 km. However, when cases of multimoded propagation are considered over the same path and for the same frequency (Figure 8), the correlation coefficients are seen to decrease more rapidly with antenna separation, a correlation coefficient value of 0.5 resulting for antenna spacings of approximately a few hundred metres (Figure 9).

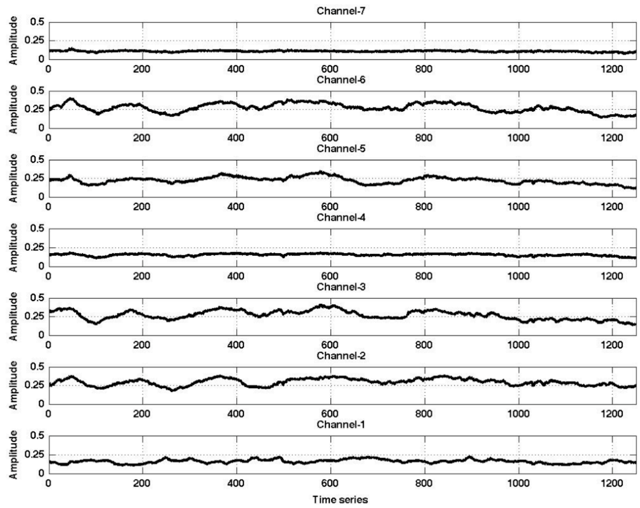

Figure 6: *Single-moded propagation amplitude pattern observed at the large 7-element antenna array (Forward Look) in the UK, for broadcast signals received from Oadby, UK (bearing: 25.1°; frequency: 4.7925 MHz; range: 122.2 km) for a period of 2.5 minutes (at 14:26 UT on 22 January 1980).*

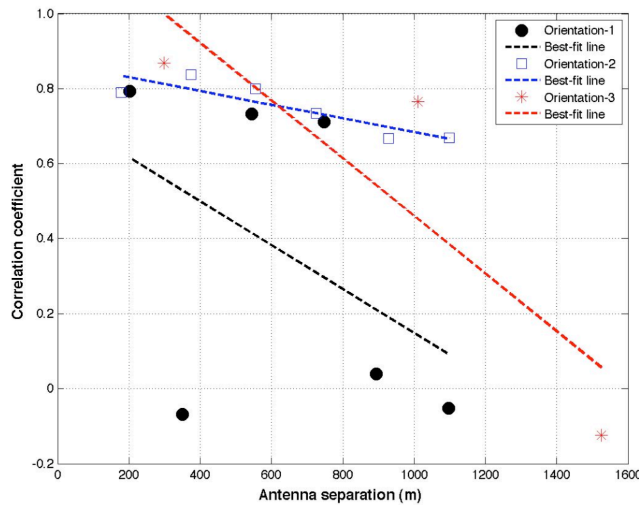

Figure 7: *Amplitude correlation coefficients (corresponding to Figure 6) computed for various antenna pair spacings for the large 7-element antenna array in the UK. The data have been divided into three parts depending on the orientation of antenna arm.*

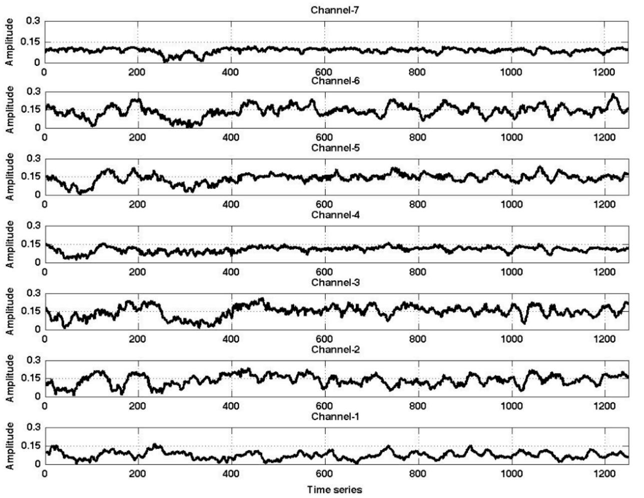

Figure 8: *Multimoded propagation amplitude pattern observed at a large 7-element antenna array (Forward Look) in the UK, for broadcast signals received from Oadby, UK (bearing: 25.1°; frequency: 4.7925 MHz; range: 122.2 km) for a period of 2.5 minutes (at 15:45 UT on 22 January 1980).*

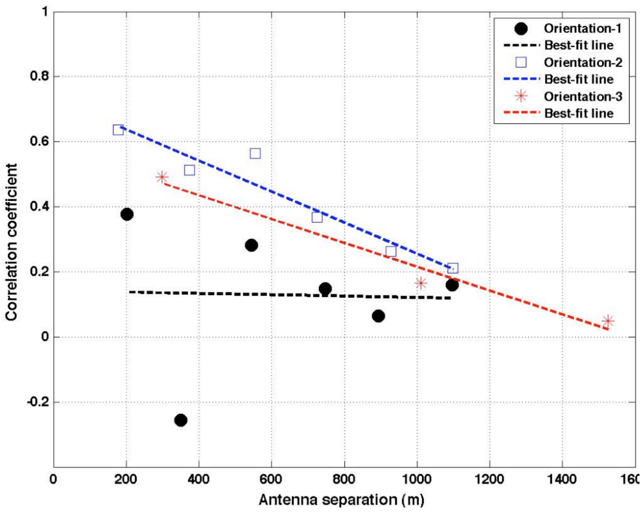

Figure 9: *Amplitude correlation coefficients (corresponding to Figure 8) computed for various antenna pair spacings for a large 7-element antenna array in the UK. The data have been divided into three parts depending on the orientation of antenna arm.*

Thus, for the same antenna separations, by virtue of providing multiple parallel paths, the case of multimoded HF propagation (Figures 8 and 9) results in more de-correlation between the individual antenna elements compared to the case of single-moded propagation (Figures 6 and 7). If the configuration were employed in a MIMO scheme, the multimoded propagation channel matrix would possess a higher rank and should consequently be able to deliver higher capacities.

3. Programme and Methodology

Through this research, it is envisaged that a purpose-built multi-channel transmitter system and multi-channel receiver system will be implemented (maximum: 8 x 8 system). Future investigations will include consideration of operational frequencies (including the effect of different mode content), antenna configurations (e.g. spaced arrays and heterogeneous co-located arrays as shown in Figure 10), and geographical effects (e.g. the different nature of the ionosphere between the mid and high latitudes).

Specifically, the system development work and the majority of operations will be undertaken over a path from the University of Leicester's field site at Bruntingthorpe to a field site at the University of Durham (a path length of approximately 290 km). Both systems will be connected to the internet to enable system control to be undertaken. Since the number of multipath components restricts the number of independent MIMO channels, an oblique ionospheric sounder available at Leicester will be used simultaneously to determine the propagation conditions in parallel with the MIMO measurements. The receiver system will also be deployed in Tromsø, northern Norway in order to obtain measurements over a path with different, more disturbed, propagation characteristics. Finally, IETR, Rennes University specialises in the design of compact, co-located as well as spaced heterogeneous antenna arrays [8, 9, 10]. Joint experiments will be conducted with IETR, Rennes University with the various antenna configurations available at Rennes. For illustration, two such antenna systems are shown in Figures 10a and 10c, along with a third configuration (Figure 10b) that is currently being constructed at the University of Leicester. The latter configuration is based on the design of a unique ground symmetric loop antenna system developed by Massie *et al* [11]. As mentioned previously, the use of collocated antennas enables the compact implementation of a MIMO system, which is particularly advantageous at HF due to the wavelengths involved.

Figure 10: *Examples of antenna arrays envisaged for use in the HF-MIMO investigations.*

4. Concluding Remarks

The users and uses of the HF radio band are many and varied, including defence, broadcast and civilian users with applications including point-to-point and mobile communications, broadcasting, air traffic control over the world's oceans, radiolocation and over-the-horizon (OTH) radar for surveillance, environmental monitoring (e.g. sea state) and ionospheric research. HF radio is a cost effective means of establishing communications in regions where the communications infrastructure is non-existent or not well developed, such as over the oceans, in third world countries and in the high latitude regions. The operators and designers of HF radio communication systems are the principal 'end-user' beneficiaries of this proposed investigation.

Current data transmission rates within the HF band are lower than desired by the users and technological developments are required in order to overcome the limitations. Such developments include, for example, improvements in modem waveforms as well as the development of antenna technologies, such as that proposed here.

Finally, the activities in this investigation are also related to the interests of Working Group 2 (Advanced Terrestrial Systems) of the European COST 296 Action on the Mitigation of Ionospheric Effects on Radio Systems (MIERS).

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