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Calibration Architectures for Use in UTRA Adaptive Antenna Basestations

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Abstract

The ACTS Smart Universal BEAMforming (SUNBEAM) project intends to develop innovative basestation array processing architectures and algorithms for Universal Mobile Telecommunication System (UMTS) that are sufficiently flexible to support a range of different second and third generation air interface standards. This paper will describe the candidate calibration architectures to be studied under the project for use with Adaptive Antenna Basestation Systems (AA-BSS's), with particular reference to the UTRA air interface standards of Wideband-Code Division Multiple Access (W-CDMA) and Time Division-CDMA (TD-CDMA). This paper introduces a semi-transparent calibration scheme for use with the uplink of either a FDD or TDD adaptive antenna basestation.

I The SUNBEAM Project

The SUNBEAM (Smart UNiversal BEAMforming) project has been set up under the EU ACTS research programme and builds on the success of the ACTS TSUNAMI II project [1]. The SUNBEAM project intends to develop innovative basestation array processing architectures, enabling technologies (antenna, digital signal processing, analogue R.F. etc) and algorithms for UMTS that are sufficiently flexible to support a range of different second and third generation air interface standards. Members of the consortium are also addressing the development and evaluation of spatial-temporal channel models.

An adaptive antenna system operates by filtering within the spatial domain, through modification of the transmitted or received antenna array signals with respect to time, frequency and spatial response. This is accomplished by means of amplitude and phase weights applied to the transmitted signals. In the case of both SUNBEAM and TSUNAMI II this is implemented in digital baseband signal processing [2].

The aim of an adaptive antenna basestation is to provide greater spectral efficiency in cellular networks [3]. These systems operate through adaptation of their radiation pattern in response to the environment in which they operate, allowing received and transmitted signals to be manipulated to provide optimal signal combination according to the requirements of the system. For example, adaptive antennas can be used effectively to determine; wanted signal bearing estimation (DOA [4]), interference suppression (SFIR [5]) and, in the case of TDMA systems, the support of more than one user in a single channel (SDMA [6]).

II Adaptive Antenna Array Operational Requirements

Most beamformer algorithms rely on the accuracy of the electrical paths to determine optimal signal combination or interference reduction, in particular when supporting full duplex transmission. As a result, a change in the characteristics of one signal path may drastically affect the operation of the system. Time variant distortions occur in the transceiver chain due to small environmental changes such as: temperature, electrical and mechanical variations and even changes in the channel centre frequency and channel gain. These distortions will effectively alter the transfer function of each adaptive antenna path. These errors in the individual paths can alter the position and depths of the nulls required for accurate steering of the adaptive antenna, which severely degrades the desired antenna pattern. This makes the digital baseband beamforming algorithms useless at these times.

III Adaptive Antenna Calibration System Requirements

Adaptive antenna systems have been proven to significantly expand the capacity of a mobile network. For an adaptive antenna system to operate in a satisfactory manner calibration of the uplink and/or the downlink is generally required. A calibration system should have the following characteristics:

- Transparent to the network and the air interface operation (i.e. does not reduce the network capacity).
- Capable of calibrating the system during initial deployment and in real time during network operation.
- Calibrate the system to the required accuracy and over the operating bandwidth.
- The calibration system may be fitted to an existing UTRA basestation with minimal modification.

A UTRA basestation will be expected to operate in one of two modes either frequency division duplex (FDD) or time division duplex (TDD), these modes of operation cover the W CDMA format and the TD CDMA format. The calibration requirements of these two modes are different due to the different modes of signal transfer and the different frequency requirements of the uplink and the downlink within each system.

A W CDMA Calibration

The W CDMA implementation of UTRA does not separate the users in time but only by the relevant code. The system operates within an FDD format with the uplink and downlink on separate paired channels. This means that the two links are separated in frequency making the transfer functions sufficiently different to make separate calibrations of the uplink and the downlink necessary. Also the hardware for uplink and downlink will be different in form and power handling requirements making separate calibrations necessary.

B TD CDMA Calibration

TD CDMA operates in unpaired bands but the uplink and downlink are separated in time. So theoretically the hardware could have the same transfer function, but in practice the hardware will have differences due to the differing requirements of the transmit and receive chains this is likely to require separate uplink and downlink calibrations.

IV Downlink Calibration

The SUNBEAM downlink calibration system was designed following the methodology used within the TSNUMAI II project [7]. Here the method adopted was the sampling of live data that was then compared with the desired baseband digital data. From this comparison an error signal was generated which was then fed back into the baseband beamformer where corrections were main for non-ideal system behavior. Figure 1 shows an overview of the calibration system.

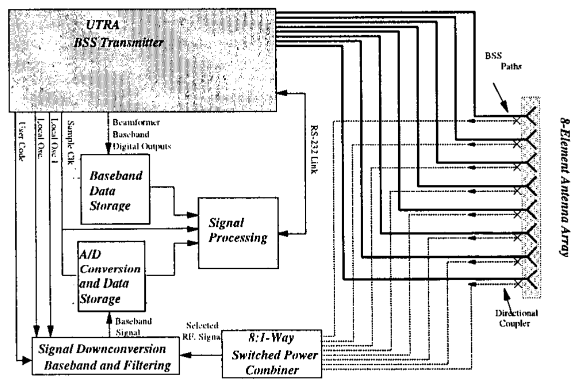

Figure 1 SUNBEAM Downlink Calibration Subsystem

V Uplink Calibration System

Receive calibration by it's very nature is a more complex problem due to the lack of a baseline reference signal. This increases the complexity of the receive calibration system considerably. Essentially the receive calibration system has to generate a suitable calibration signal, monitor the effect the system has on this signal and then pass suitable correction signals to the beam former. In order to calibrate the uplink with minimal interference it has been proposed that a suitable calibration code is used for the uplink calibration [8].

C Spreading Code Techniques

Both the FDD and TDD modes of UTRA separate the individual users via the use of a variable length orthogonal spreading sequence code. This code structure allows for variable data rate users. This code structure is effectively a Walsh code. Walsh codes can be easily despread using a Walsh-Hadamard transform, Walsh codes may be constructed from Equation 1

$$H_0 = [0] \quad H_n = \begin{bmatrix} H_{n-1} & H_{n-1} \\ H_{n-1} & \overline{H}_{n-1} \end{bmatrix}$$

Equation 1

The Walsh codes have an even number of chips and the number of codes is equal to the number of chips so for example if there are 128 codes they will have a length of 128.

Another form of orthogonal variable rate codes is known as tree structure orthogonal codes, these codes were first proposed in [9]. The structure of these codes is illustrated in Figure 2, all codes are orthogonal so long as they are neither a mother code of a subsequent code or are within the same arm of the tree. For example codes $C_{2,1}$ and $C_{4,1}$ are not orthogonal due to their location within the tree. These codes may be generated by using the relationship in Equation 2.

$$C_{2n} = \begin{pmatrix} C_{2n,1} \\ C_{2n,2} \\ \vdots \\ C_{2n,2n} \end{pmatrix} = \begin{pmatrix} \begin{pmatrix} C_{n,1} & C_{n,1} \\ C_{n,1} & -C_{n,1} \end{pmatrix} \\ \vdots \\ \begin{pmatrix} C_{n,n} & C_{n,n} \\ C_{n,n} & -C_{n,n} \end{pmatrix} \end{pmatrix}$$

Equation 2

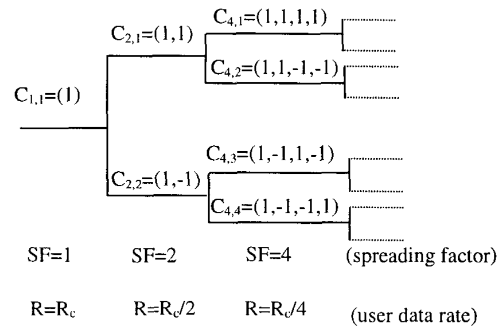

Figure 2 Construction of Orthogonal Spreading Codes for Different Spreading Factors

D Receive Calibration Using Orthogonal Codes

One possible method of calibrating an adaptive antenna system with minimal interference is to use one of the orthogonal codes to carry the calibration information. Basically the calibration information will appear as another user to the system and hence interference will be at a minimum. To test the viability of this approach a simulation was developed to include a second spread signal which would carry the calibration information. The simulator operates by generating two sets of random data, one for user data and one for calibration data. A code is selected for the spreading of user data; another code is then selected for the calibration data. The user data is then despread and checked for errors.

The simulator was used to run a Monte Carlo simulation with a duration of 10000 data bits and the error introduced by the calibration process was recorded. These results are shown in Figure 3.

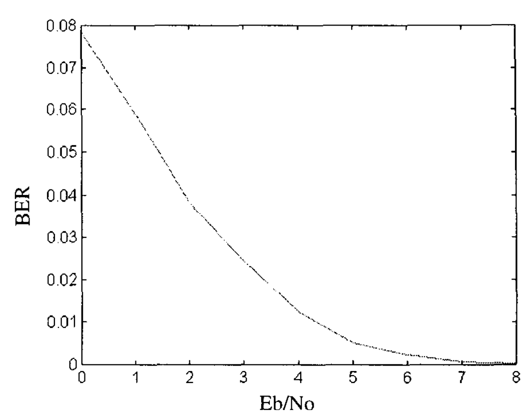

Figure 3 Graph of Signal to Noise vs Error for the Orthogonal Calibration Scheme

Figure 4 shows that the calibration scheme introduces minimal interference to the user data signal. It may also be noted that for a signal to noise ratio of greater than 8dB the introduced error is zero in the presence of additive white Gaussian noise.

This approach has the advantage of introducing minimal error to the user data it does however reduce system capacity by removing a user code from the system. For low data rate use this reduction in system capacity may not be significant when it is remembered that the calibration system will remove 1 code of 255 possible usable codes. However for high data rate services where there are only 3 available codes the removal of one code significantly reduces system capacity. This makes this approach very unattractive for high data rate service provision.

E The Use of PN Sequences for Calibration Purposes

The use of a user code for calibration purposes has the disadvantage of significantly reducing system capacity for high data rate purposes. A possible method of reducing the impact on capacity of the calibration process is the use of a PN sequence to spread the calibration sequence rather than using one of the user orthogonal codes.

The simulation was then modified to investigate the possibility of using a pn sequence to spread the calibration data sequence. The simulator was modified to incorporate these changes and another Monte Carlo simulation was run over a 10000-bit data sequence.

The results of this simulation are shown in Figure 5, it may be observed from the graph that this method of calibration introduces more interference than the orthogonal code scheme. This is not surprising when it is remembered that a pn sequence will not be truly orthogonal to a user code. This is due to the fact that if the pn sequence were orthogonal then it would be one of the orthogonal codes. If we compare Figure 4 and Figure 5 in terms of the point in Figure 4 were the error is zero i.e. the point where the signal to noise ratio is 8dB, we can see that the error when a pn sequence is used to spread the calibration signal is 1%. We can see however that if we increase the signal to noise ratio to 12dB or greater then the error reduces to 0.3% which is an acceptable error rate when it is borne in mind that the simulations have been run with no account taken for any error correction coding scheme.

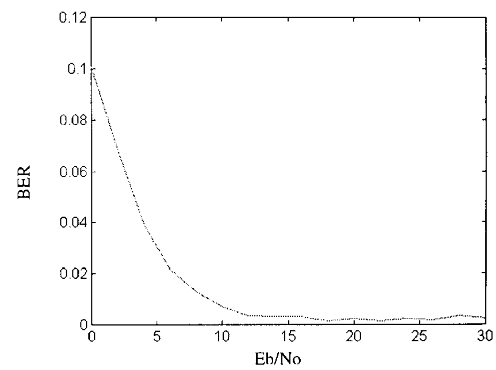

Figure 5 Graph of Signal to Noise vs Error for the PN Sequence Calibration Scheme

F Proposed Calibration Scheme for Uplink Calibration

These simulations have shown that either the use of an orthogonal code or the use of a PN sequence to spread the calibration data is a viable approach for calibration of an adaptive antenna system in terms of acceptable levels of interference. In terms of a realistic scheme for use in an operational system then the pn sequence scheme would be the best alternative due to the minimal impact that the use of this would have on system capacity. It is envisaged that the error introduced by this scheme would be reduced within a real system due to the inclusion of error correction codes that would certainly exist within an operational system.

So to calibrate the uplink the calibration subsystem hardware would have to consist of a CDMA transmitter operating at 3.840Mchips (this assumes a 1^{st} phase system chipping rate, a higher chipping rate would be required for higher bit rate iterations) and a comparator to monitor any differences between the downconverted data and the originally transmitted calibration data. A block diagram of the proposed architecture is shown in Figure 6.

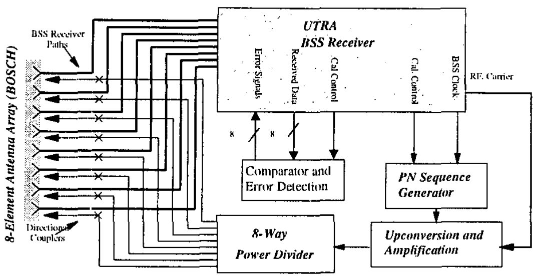

Figure 6 Uplink Calibration Subsystem Architecture

When a calibration is requested a data sequence is spread by the pn sequence generator and then upconverted and amplified, this signal is then power divided and transmitted to all the elements of the antenna. This signal is then downconverted by the UTRA receiver and fed to the comparators. Any error signal is then fed back into the beamformer where error correction is carried out. If required the hardware could be simplified by using a multiplexer to apply the signal to one antenna at a time, this would remove the need for multiple comparators and error detectors. However this would have the effect of increasing the calibration time by a factor of eight.

VI Conclusions

This paper has shown how the uplink and downlink of an adaptive antenna system may be calibrated. Downlink calibration is a much simpler problem than uplink calibration due the availability of a reference signal.

It has been shown that the uplink may be calibrated by the use of a spreading code. It has been also shown that a PN sequence with the same chipping rate as the system may be used to spread the calibration data with minimal interference to the system.

VII Acknowledgements

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