Design and implementation of an adaptive antenna for mobile communications (ADAM)

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Abstract

This paper describes the implementation of a simplified version of an adaptive antenna that can be applied to standard UMTS Node-B, both in the up and down links. The prototype includes the radiating elements, the RF and IF subsystem, the digital MODEM and the adaptive array algorithms.

The smart antenna concept is wide, in the sense, that several kinds of arrays are included under this idea. Phased arrays, switched multi-beam antennas and adaptive array antennas are usually included in the same smart antenna concept. Great advantages have been reported for the smart antenna implementation in base stations for cellular telephone communications. But this kind of antenna has not been applied extensively to those systems.

Adaptive arrays, not only can improve antenna gain in the user direction, but it can also cancel interferences. That capability implies an increase in the carrier to interference ratio (C/I) for each user. For CDMA systems an increase of cell or sector capacity is obtained for those sites where a smart antenna is placed.

1 Introduction

Smart antennas in CDMA systems provide a capacity and cell range increase. This capacity increase is greater as long as the interference level from high bit rate users becomes important in the cell.

Adaptive antenna systems can be implemented with time or space reference algorithm. In time reference adaptive arrays, incoming signals at each array element are adaptively processed to form the array vector of weights. The array factor synthesized for each user allows a C/I increment in order to improve Eb/No and reduce bit error rate. This strategy is appropriate for CDMA signals where the time reference is obtained correlating the input signal with each user spreading code. In space reference adaptive arrays, interference directions of arrival must be computed to calculate array weights.

This paper details a practical implementation of a smart antenna with an adaptive beam for a 3rd generation cellular mobile communication system based on W-CDMA (UMTS) [1]. Moreover, the system must be implemented in an easy way to any existing base station, non specifically developed to be used with a smart antenna. ADAM stands for “ADaptive Antenna for Multioperator scenarios” [2], as it can be connected to any base station site, with a total independence of the operator that controls the corresponding node B.

2 UMTS and Smart Antennas

Physical layer of W-CDMA systems has been designed to work with adaptive antennas both in up-link and down-link. The use of two kinds of adaptive antennas has been planned depending on the beamforming of the secondary common pilot channel (S-CPICH). Adaptive algorithm must be applied using dedicated pilot signal in DPCCH received in the base station antenna. Table 1 shows which physical channels are processed by the adaptive antenna [3]. Our implementation does not beamform CPICH, but it needs to listen to the access procedure in CPCH channel in order to obtain user scrambling codes.

Channel	with S-CPICH	without S-CPICH
P-CCPCH	No	No
SCH	No	No
S-CCPCH	No	No
DPCH	Yes	Yes
PICH	No	No
PDSCH(DPCH)	Yes	Yes
AICH	No	No
CSICH	No	No
PRACH	Yes	Yes

Table 1. Relationship between smart antennas and physical channels [4].

3 Antenna array subsystem

The implemented prototype produces a 120º sector coverage and it is built with an array of four standard sectored antennas for mobile telephony in UMTS band. Each element is a commercial dual-polarized sectored antenna [5]. Horizontal and vertical beam-widths are 65º and 7º, respectively, with a gain of 18 dBi. The width of each element is 15 cm, which is equivalent to one wavelength in the UMTS band (2 GHz). The array prototype is shown in Figure 1.

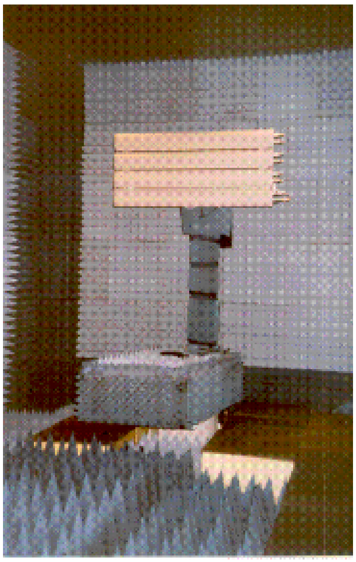

Figure 1. Antenna array prototype.

4 RF/FI subsystem

The RF subsystem connects the 4 antennas array with the modem and adaptive beamformer subsystem, and this one with the standard Node B RF input. The input and output signals are in UMTS frequency band and the intermediate frequency of the interface with modem and adaptive beamformer is 44 MHz, implementing a Software Defined Radio (SDR) system (Figure 2).

RF subsystem incorporates duplexors, low noise amplifiers for receiver sections, high power amplifiers for transmitter sections and conversion sections from the central frequency of each UMTS channel to 44 MHz. The central frequency of the oscillators is controlled through a frequency synthesizer based on PLL. The system allows up to 4 FDD carriers, in order to share the smart antenna by different cellular network operators. The system is duplicated for each polarization, so the Node B implements polarization diversity algorithm.

Figure 3 shows the general scheme of the transmitter. The combiner allows the usage of several block frequencies. The receiver is a dual scheme. The RF specifications for the prototype are described in Table 2.

Transmission Band	2110 - 2170 MHz
Reception Band	1970 - 2030 MHz
Carrier separation	4.6 to 5.6 MHz
Minimum step between carrier values	200 KHz
Sensibility	-112 dBm
Maximum power of each sectored antenna	1 W

Table 2. Basic specifications of transmitter/receiver section [4].

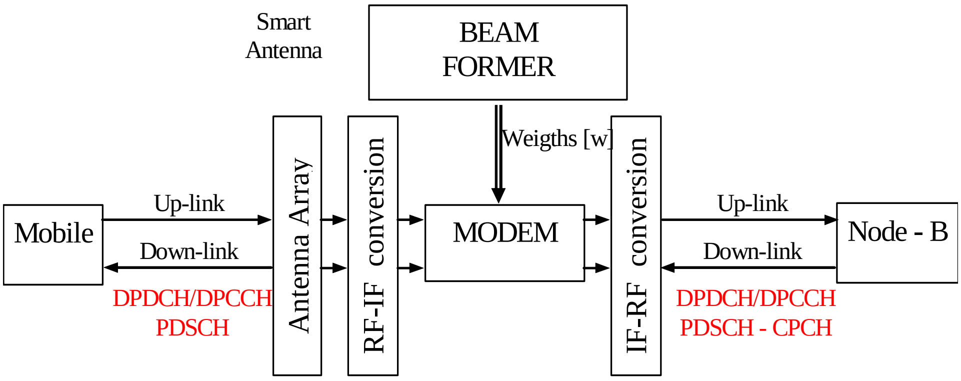

Figure 2. Implementation architecture of this smart antenna to be deployed with a standard Node-B.

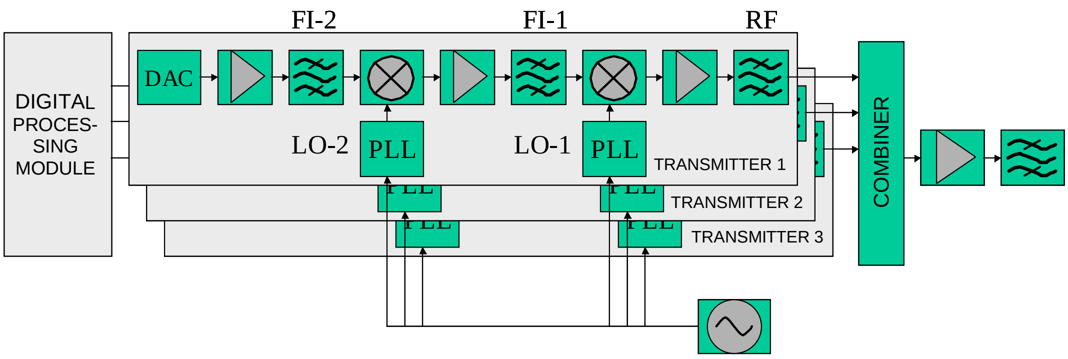

Figure 3. General block scheme of RF-IF stages of transmitter antenna

5 Modem and beamformer subsystem

In order to realize a SDR based platform, RF and modem section interfaces in a 44 MHz. Two main tasks must be fulfilled by this subsystem: code acquisition and tracking, and adaptive beamforming.

Figure 4 shows the hardware implementation of the modem and beamformer subsystem. The first element in the modem and beamformer subsystem is a wideband receiver board with a A/D converter, which samples IF input signals. For each polarization, four synchronized receivers must be used. The core part of the subsystem is the Digital Signal Processing block. It is formed of six boards with four DSPs each. The computational capacity of the system allows for processing upto three users. One of the main tasks within the software implementation is the code optimization and load distribution between DSP. These boards are interconnected through a high speed bus (Raceway Interlink), in order to transfer data between modules.
As it can be seen, both polarizations are processed independently.

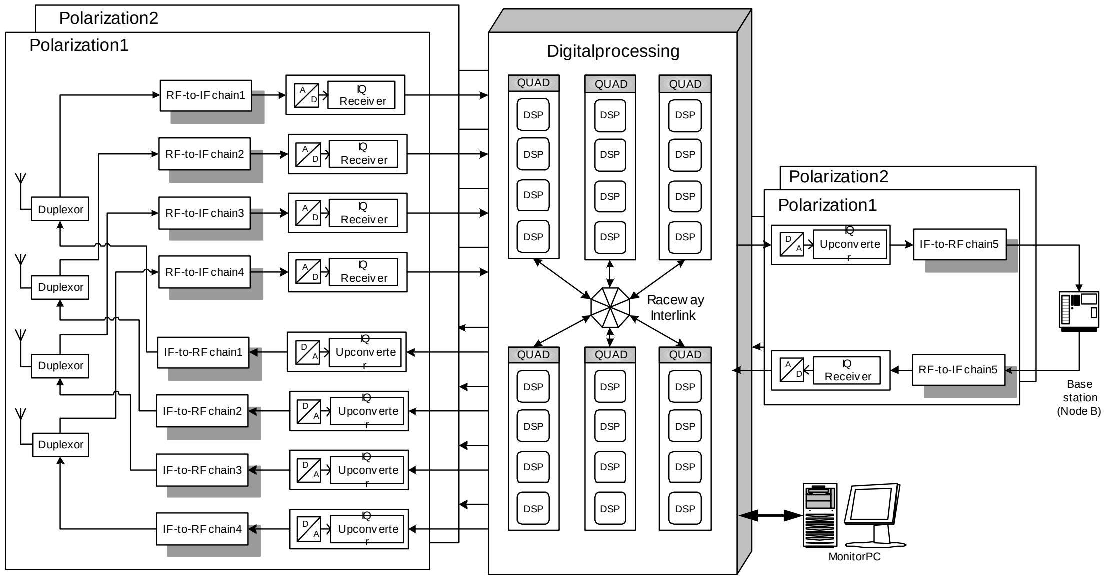

Figure 4. Hardware architecture.

The synchronism issue is solved following a two-step approach [6]. Firstly, coarse synchronization or initial code acquisition accomplishes the synchronization of the received signal and the corresponding code, with an uncertainty of one chip period. Secondly, fine synchronization or code tracking performs and maintains the synchronization between the received signal and the code with a precision always lower than the chip period.

To perform the synchronization the scrambling code properties are used. These codes have an autocorrelation function that is ideally different from zero only when the code and the received signal are aligned. In the coarse synchronization stage, the received matched filter output is correlated with different chip delayed version of the scrambling code, and correlation results are compared with a threshold to track the code alignment.

The code tracking stage is implemented with a loop structure. This stage receives the signal form the coarse synchronization module and then demodulates the DPCCH pilot bits in each antenna element.

The vector of demodulated pilot bits is fed into the adaptive beamforming module. The aim of this module in the uplink is to obtain the optimum weights in order to maximize the signal to interference and noise ratio (SINR) in the array output. Besides, this module performs the weighting and combination of the received signal vector, being the output of this module a spatially filtered W-CDMA signal. The NLMS algorithm is used to compute the adaptive weights [7]. Its reduced computational complexity makes possible a real-time implementation.

As a kind of plug and play functionality is demanded, the UMTS signals from the array output modulated again allowing a direct connection between antenna outputs and base station inputs. Thus, cancelled interferences in the uplink are only those intracellular ones common to the users and the extracellular interferences. The relationship between the extra cellular and intracellular interferences is the intercellular interference factor, F, and it has a value between 0.4 to 1.4 depending on the environment and the service [3]. It implies that more than a 50% of interferences are cancelled in average because common intracellular interferences should be also taken into account.

Therefore, this antenna system will offer good performance in the neighbouring cells of a hot spot, providing an expansion of their coverage and compensating for the "cell breathing" effect of highly loaded cells.

In contrast, in the downlink, a complete user separation can be performed. Because of that, in the proposed downlink structure single-user weight vectors calculated in the uplink are applied as transmit beamforming weights to each user separately. Therefore, downlink beamforming is much simpler than the uplink one, since no adaptive algorithms are needed. However, complete demodulation of DPCH for each user is required, and downlink beamforming is applied at the bit-level. This fact results in a considerable reduction in computational load as far as the multiplier module is concerned, in comparison with the equivalent module for the uplink. Moreover, a total cancellation of interferences is achieved due to user separation. Nonetheless, this scheme increases the complexity of the modulation and demodulation module, as it must be performed for every user in every antenna.
Common broadcast channels are transmitted through one of the arrays elements.

6 Conclusions

A SDR based smart antenna prototype for W-CDMA systems has been designed and implemented. The prototype is ready for being installed in any node B. Currently, measurements in an anechoic chamber are being carried out. Afterwards, the smart antenna prototype will be installed in a node B of the Vodafone Spain UMTS cellular network.

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