SIMULATION OF A SMART ANTENNA SYSTEM

NUR ALINA ZUREEN BT ROSLI

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Universiti Teknologi Malaysia

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ABSTRACT

Smart Antenna technologies will change the economics of 3G radio networks. They provide either a major data capacity gain or a significant reduction in the number of base stations required to achieve a base level of service. When deployed optimally, Smart Antennas can increase the capacity of a network by more than 100% or reduce the required number of base stations to less than 50%. It is not surprising that Smart Antennas are more expensive than conventional technologies. These costs are a fraction on the gain achieved, but they mean that smart deployment will produce the most cost-effective result. This thesis is an overview of Smart Antenna technology, their benefits, how they work and how they can be deployed to best advantage. Implementation that revolves around the Least Mean Square (LMS) adaptive algorithm, chosen for its computational simplicity and high stability algorithm into the MATLAB® simulation of an adaptive array of a smart antenna base station system, is to investigate its performance in the presence of multipath components and multiple users. The simulations illustrate that adaptive array antenna systems are able to adjust their antenna pattern to enhance desired signals, and reduce interference.

ABSTRAK

Ekonomi rangkaian radio 3G berubah dengan adanya Teknologi Antena Pintar. Teknologi ini menyumbang kepada gandaan kapasiti data yang tinggi, ini secara tidak langsung akan mengurangkan bilangan station tapak yang berkadaran dengan perkhidmatan yang diberi. Apabila teknologi ini digunakan secara optima, ia mampu menaikkan kapasiti rangkaian lebih daripada 100% dan mengurangkan bilagan station tapak sebanyak 50%. Tidak hairanlah sekiranya teknologi antena pintar ini lebih mahal berbanding dengan system sedia ada. Tetapi perbelanjaan yang tinggi ini tidak boleh dibanding-beza dengan keberkesanan yang ketara yang diperolehi. Tesis ini merupakan pendedahan kepada Teknologi Antena Pintar ini, keuntungannya dan bagaimana ia beroperasi bagi memperolehi keadaan yang terbaik. Implementasi terhadap algoritma pelengkap kuasa dua, yang dipilih kerana pengiraan yang mudah dan stabil untuk disimulasi menggunakan MATLAB® . Simulasi ini adalah untuk menyiasat kemampuannya dalam mengendali pengguna dan komponen yang berbilang. Simulasi ini juga akan mengambarkan bagaimana adaptive array antenna mampu menyerasikan paten isyarat antena bagi merangsang isyarat yang tinggi dengan mengurangkan gangguan isyarat.

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CHAPTER 1

GENERAL OVERVIEW

1.1 Introduction

Smart antennas have promised to provide significant increases in system capacity and performance in wireless communication systems [2]. In turn, this leads to increased revenue for the telecommunications companies and also a reduction in dropped and blocked calls. Other benefits include greater coverage, meaning less base stations are needed to cover the same area compared to conventional antennas. For these reasons, smart antennas have gained greater interest over the recent years.

Smart antennas have been around for about 40 years which were first used in RADAR applications in the form of phased array. Research on application of smart antennas has paved the way for their use in commercial wireless systems [1]. Smart antennas are currently used in wireless communication systems to provide interference reduction and enhance user capacity, data rates. Current applications of the smart antennas are predominantly at the cellular base stations due to area and processing power requirements.

However, recent propagation measurements for smart antennas and the development of faster and low-power processors have enabled the use of this technology at the access points in a WLAN system in the form of dual diversity reception. Mobile terminal based smart antennas are still in the research stage for large network and ad-hoc network scenarios where they have been touted to improve average network capacity [17]. In future one can expect smart antenna technology to be present at base stations and mobile terminals. The goal of this thesis is to present in a simple yet comprehensive manner the smart antenna technology to the non-specialists.

1.2 Outline of a Smart Antenna

The definition of a *Smart antenna* is an antenna array system that is aided by a processing system that processes the signals received by the array or transmitted by the array using suitable array algorithms to improve wireless system performance. An antenna array consists of a set of distributed antenna elements (dipoles, monopoles or directional antenna elements) arranged in certain geometry (e.g., linear, circular or rectangular grid) where the spacing between the elements can vary. The signals collected by individual elements are coherently combined in a manner that increases the desired signal strength and reduces the interference from other signals.

Hence a smart antenna can be viewed as a combination of “regular or conventional” antenna elements whose transmit or received signals are processed using “smart” algorithms. In the next page Figure 1.1 Generic implementation of Smart Antenna System [18], shows a generic implementation smart antenna system.

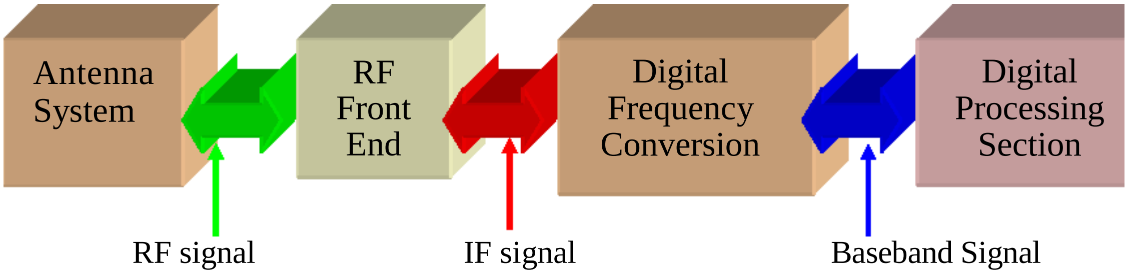

Figure 1.1 Generic implementation of Smart Antenna System.

The antenna arrays have input or output as RF signals in the analog domain. These signals are passed to/from the RF analog front end which usually consists of low noise amplifiers, mixers and analog filters. In the receive mode, the RF signals are converted to digital domain by analog to digital converters (ADCs) and in transmit mode, the base band digital signals are converted to RF using digital to analog converters (DACs). The down-conversion from RF to base band or up-conversion from base band to RF can involve the use of IF signals. The base band signals received from each antenna is then combined using the “smart” algorithms in a digital processing section. Each antenna element hence has a RF chain going from the antenna element to RF front end to digital conversion for receiver and vice-versa for transmitter. The digital processing section can be implemented on a microprocessor or a DSP or FPGA.

Hence the “smart” algorithm implementation usually is a software code unless implemented in an ASIC or FPGA. An example of the array processing in the digital domain is shown in Figure 1.2.

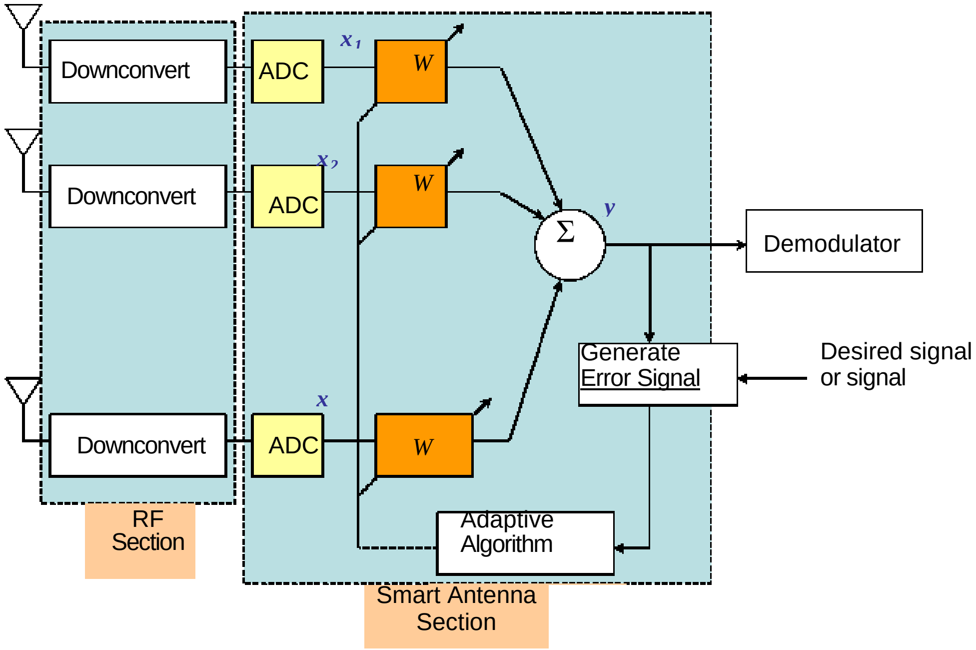

Figure 1.2 Block diagram representation of antenna array processing.

The diagram illustrates the operation of an M-element antenna array system in the receive mode. The signals collected by the antenna elements are down converted, sampled and digitized to generate the beamformer inputs (*x*1, *x2*,.. *xM).* These signals contain both the desired signal and the interfering signals and these are appropriately scaled by complex gain vectors, also known as weight vectors (*w*1, *w2*,.. *wM)* and combined to generate the array output *y* as:

$$yt = \mathbf{w} \quad t \, \mathbf{x} \, t \qquad (1.1)$$

The array output is then compared with some reference signal in the 'Generate Error Signal' block to generate an error signal which is then adaptively minimized by an adaptive algorithm. This adaptation process involves changing the weight vector according to some minimization criteria. For example, for stochastic gradient based Least Mean Square (LMS) algorithm, the weight update equation has the following form:

$$\mathbf{w}\; k + 1 = \;\mathbf{w}\; k + \mu\; e\; k\, \mathbf{x}\; k \qquad (1.2)$$

where **w**(*k*), *e*(*k)* and **x**(*k*) are the weight vector, error signal and input signal vector at the *k*-th instant and ‘*’ denotes complex conjugate operation. In most cases, the weight vector is updated during some training sequence when some known or pilot symbols are transmitted and at the end of the training sequence, the array output is fed to the demodulator and subsequently to the upper layers of the system.

REFERENCE

[1] L. C. Godara, ***Application of Antenna Arrays to Mobile Communications, Part I: Performance Improvement, Feasibility, and System Considerations***, Proceedings of the IEEE, Vol. 85, No. 7, July 1997, pp. 1029-1060.

[2] Wong, K.K., Murch, R.D. & Letaief, K.B. 2001. Optimizing Time and Space MIMO Antenna System for Frequency Selective Fading Channels. *IEEE* ***Journal on Selected Areas in Communications,*** July, pp.1395-1406.

[3] Rappaport, T.S. 1996 ***Wireless Communications: Principles & Practice,*** Prentice Hall Communications Engineering and Emerging Technology Series.

[4] Oeting, J. 1983. Cellular Mobile Radio — An Emerging Technology. *IEEE* ***Communications Magazine,*** November, pp. 10-15.

[5] Rosol, G. 1995. Base Station Antennas: Part 1, Part 2, Part 3. ***Microwaves & RF,*** August, pp. 117-123, September, pp. 127-131, October, pp. 116-124.

[6] Brickhouse, R.A., and Rappaport, T.S. 1997. A Simulation Study of Urban In-Building Frequency Reuse. ***IEEE Personal Communications Magazine,*** February, pp. 19-23.

[7] Liberti, J. C. & Rappaport, T.S. 1999. ***Smart Antennas for Wireless Communications: IS-95 and Third Generation CDMA Applications,*** Prentice Hall Communications Engineering and Emerging Technology Series, NJ.

[10] Haykin, S. 1996. ***Adaptive Filter Theory,*** Third Edition, Prentice Hall Inc., pp. 365 — 405. How, L. 2001. Signed LMS Adaptive Filtering with Detection. ***Undergraduate Thesis,*** School of Information Technology and Electrical Engineering, University of Queensland, Brisbane.

[11] Homer, J., Mareels, I., Bitmead, R., Wahlberg, B., & Gustafsson, F. 1998. LMS Estimation via Structural Detection. *IEEE* ***Transactions on Signal Processing,*** Vol. 46, No. 10, pp. 2651-2663.

[12] Pattan, B. 2000. ***Robust Modulation methods and Smart Antennas in Wireless Communications,*** Prentice Hall PTR, NJ.

[13] Zooghby, A. 2001. Potentials of Smart Antennas in CDMA Systems and Uplink Improvements. *IEEE* ***Antennas and Propagation Magazine,*** pp. 172177.

[14] Widrow, B., Mantey, P. E., Griffiths, L. J., and Goode, B. B. 1967. Adaptive Antenna Systems. *Proc. of* ***the*** *IEEE,* December.

[15] Monzingo, R. & Miller, T. 1980. ***Introduction to Adaptive Arrays,*** Wiley and Sons, NY.

[16] Frost, 0. L., III. 1972. ***An Algorithm for Linearly Constrained Adaptive Array Processing,*** Proc. of the IEEE, August.

[17] Jing Jiang, R. Michael Buehrer, and William H. Tranter, ***Antenna Diversity in Multiuser Data Networks***, IEEE Trans. Comm., vol. 52, no. 3, pp. 490-497, Mar. 2004.

[18] Jeffrey H. Reed, ***Software Radio: A modern approach to radio engineering,*** Prentice Hall Communications Engineering and Emerging technology series 2002.

[19] S. Choi and J. H. Reed, “**Smart Antenna API,” a power point presentation submitted to Technical Committee SDRF**, June 15, 2004.