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Array Antennas for Third-Generation Network

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ABSTRACT: Wireless operators face increasing network capacity challenges as demand for wireless communications grows and third-generation (3G) voice and wireless internet services become mainstream. Smart antenna technology currently provides a viable solution to capacity-strained networks and lends itself to migrating to 3G networks. For wireless operators, the primary advantages of using smart antennas in wireless networks are increasing the number of voice calls and the amount of data throughput, avoiding interference, and having easy network management. A basic understanding of smart antenna technology and third-generation standards explains the application of smart antennas in 3G networks.

KEYWORDS: 3G, Array Antennas, Mobile Communications, Smart Antennas, Wireless Networks

I. INTRODUCTION

The field of wireless mobile communications is growing at an explosive rate, covering many technical areas. Its sphere of influence is beyond imagination. The worldwide activities in this growth industry indicate its importance. The demand for wireless communications is anticipated to expand steadily, and projections indicate that annual activities will exceed $100 billion by 2000 [1].

Increasing demands for high-speed data rates, excellent quality, comprehensive coverage, and inexpensive communication services have stimulated the rapid development of communication technology for wired and wireless networks. For many years, many investigations to expand the capability of communication networks have continuously taken place. This includes the hardware and software aspects, such as the physical infrastructure, protocol, and billing scenarios. The integration and coordination of these parts is a crucial contribution to communication sector performance. Since the 1980s, wireless communication systems have grown dramatically and applied in many aspects of human life. For instance, the various features offered by cellular mobile phones, the wide applications of wireless LANs (Local Area Networks) and MANs (Metropolitan Area Networks), the fast growth of wireless sensor development, and the significant expansion of wireless access network technologies such as Wi-Fi (Wireless Fidelity) and WiMAX (Worldwide Interoperability for Microwave Access) are some real examples of wireless infrastructures which are part of modern lifestyles. People rely on this technology in their everyday lives. Numerous wireless communication systems have emerged, including cellular telephones, pagers, wireless networks, radio/TV broadcasting transceivers, terrestrial microwave radios, and satellite-based mobile communication systems. These are readily available to the public in most countries worldwide [2]. In the future, wireless technology will gain more essential roles in communication systems. Regardless of its importance, the wireless communication system suffers from traditional problems such as complex multipath propagation effects, noise effects, limited availability and expensive resources of bandwidth spectra, and power limitations. The improper treatment of these factors may create severe impairments in the performance of communication networks. Those problems are the constraints that must be considered to obtain the high standard design and implementation of wireless communication systems. These factors are the most challenging issues to be resolved. For over ten decades after Guglielmo Marconi introduced the wireless communication prototype, various techniques have been investigated to address those constraints. Some of them include multiple access schemes (i.e., CDMA - Code Division Multiple Access, W-CDMA and TDMA - Time Division Multiple Access), bandwidth-efficient source coding and modulation techniques (i.e., turbo coding, STBC – Space-Time Block Code, convolutional coding, and OFDM – Orthogonal Frequency Division Multiplexing), sophisticated signal processing methods, and adaptive antenna technologies called intelligent antenna systems, are potential methods for overcoming the problems in wireless networks. In practice, some examples of intelligent antenna systems include phased arrays, mechanically steered arrays, SPA (switched parasitic antenna), and MIMO (multi-input multi-output). Smart antennas can be divided into switched beam antennas and adaptive array antennas [3-9]. Innovative antenna technology has many applications. It has been used in earth exploration, military operations, radar and navigation systems, sonar and medical imaging equipment, and communications [10]. Smart antennas offer the possibility of enhancing the quality of services (QoS) and providing more efficient bandwidth use. The increased bandwidth suggests the system can support more channel capacity with realistic and high-speed data transport [8-9, 11].

II ARRAY ANTENNA TECHNOLOGY

Typically, this is accomplished through narrow beams at the base site, both on the forward and reverse links. A stamen antenna system combines multiple antenna elements with signal–processing capability to optimize its radiation and reception pattern in response to the signal environment. The transmit and receive patterns are automatically updated as the subscriber moves through the cell or as signal conditions change. The innovative antenna system aims to provide the user with the highest quality uplink and downlink signal [12].

The intelligent antenna uses an array of elements connected to an analog or digital combing network. The size of the array and the number of elements determine the antenna array's maximum gain and minimum beam width. This implies that a trade-off must be made between the antenna array size, the antenna gain, and, to a lesser degree, the antenna sidelobe performance. Smart antennas form beams by adjusting the amplitudes and phases of the signals received from each antenna element so that, when added together, they form the desired beam. This process is called beamforming. Beamformers can create a wide range of beams: scanned beams, multiple beams, shaped beams, and beams with steered nulls.

An application of antenna arrays has been suggested in recent years for mobile communications systems to overcome the problem of limited channel bandwidth, thereby satisfying an ever-growing demand for a large number of mobiles on communication channels. Many studies have shown that when an array is appropriately used in a mobile communications system, it helps improve the system performance by increasing channel capacity and spectrum efficiency, extending range coverage, tailoring beam shapes, steering multiple beams to track many mobiles, and compensating aperture distortion electronically. It also reduces multipath fading, cochannel interferences, system complexity and cost, BER, and outage probability. It has been argued that adaptive antennas and the algorithms to control them are vital to developing high-capacity communications systems [10]. An array of antennas may be used to improve a communications system's performance. Perhaps most important is its capability to cancel co-channel interferences. An array works on the premise that the desired signal and unwanted cochannel interferences arrive from different directions. The beam pattern of the array is adjusted to suit the requirements by combining signals from other antennas with appropriate weighting**.**

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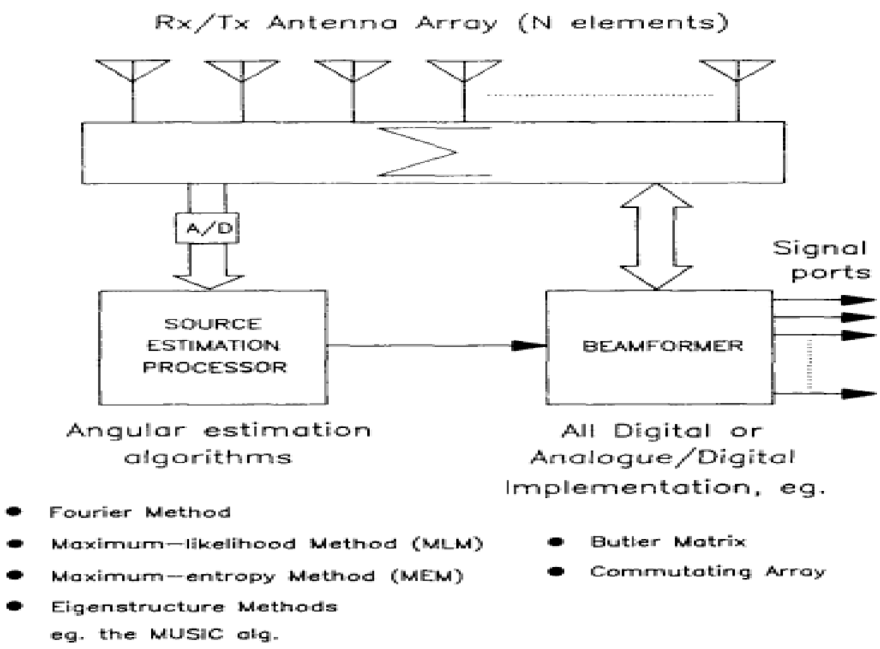

Fig 1. The 'Smart' Antenna Array.

A. **Switched–Beam Array Antenna Systems**

Switched–beam systems consist of multiple narrow beams (15-30 Horizontal beam width), the best of which is used to serve the subscriber as it moves through the coverage of the cell. Adaptive systems can form several patterns adjusted to track the subscriber user. Switched-beam systems are more economical, requiring only a static beamforming network, RF switch, and control. A separate beam selection is continuously made for each subscriber unit as it moves through the cell's coverage area. Commercial deployments of switched–beam systems have demonstrated significant capacity improvements: over 100% capacity gain in analog and GSM networks. For example, in a recent MetaWave Communications field trial, a GSM smart antenna system significantly reduced interference and improved 6 dB carrier-to-interference (C/I). In the same test, the improvement in C/I led to a 50% reduction in dropped calls. Studies have also indicated that network capacity increases of 100% can be achieved with deployments at selected sites representing only 38% of the number of base sites in a network.

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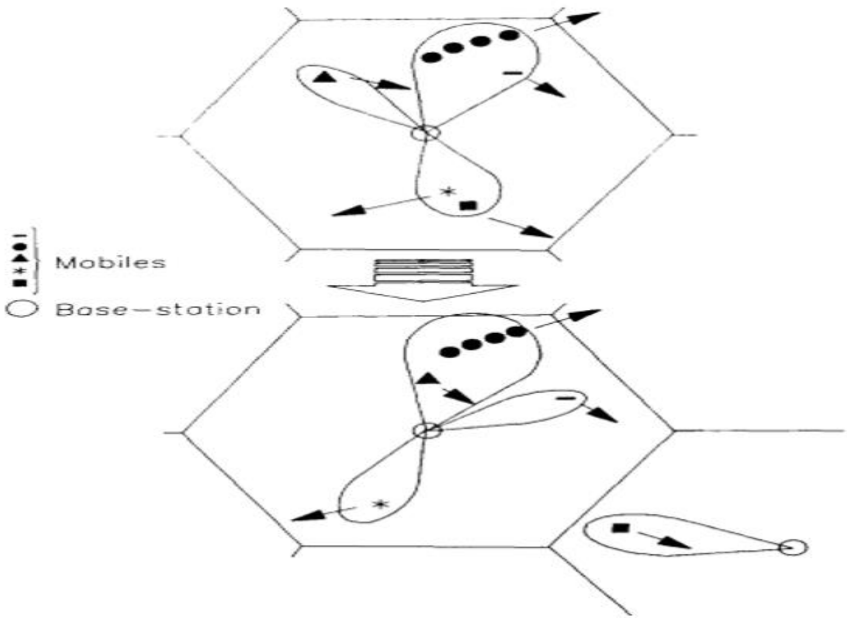

Fig 2. Optimal Beamforming

B. **Adaptive Array Antenna Systems**

Adaptive systems can achieve more excellent system performance than switched–beam systems. Array signal processing allows the antenna system to exploit path diversity by combining coherent multipath components. The adaptive pattern created can be optimized to enhance the desired user's signal while simultaneously suppressing interfering signals. However, the theoretical performance benefits achieved by an adaptive system may be offset by the cost and complexities encountered in implementation [13]. In addition, several technical issues complicate adaptive systems. Specifically, downlink beamforming is difficult due to multipath and frequency duplexing. Since the goal is to select the best single direction to transmit to the user, the base station processor must detect changes in power along the subscriber's path. However, as the subscriber moves quickly, this becomes more difficult because the received signal may change rapidly. Signal degradation can occur if the downlink beamformer cannot track these changes. Further, the beams formed on the downlink are determined by uplink signal measurements. Because all cellular systems are frequency duplexed, errors in the downlink beamformer are introduced because of the different uplink and downlink signal characteristics [14].

III. THIRD-GENERATION STANDARDS

In the 3rd generation and beyond of wireless communication systems, intelligent antenna designers face the challenge of minimizing the effect of channel environment variations [15-17] due to multipath propagation or high mobility of users. Moreover, an enormous increasing demand for wireless traffic volumes such as multimedia applications, image/video, data, and voice is also challenging to accommodate. The designed smart antenna must also be suitable for future requirements of broadband wireless systems [11] and [18-19]. To gain wide acceptance, the intelligent antenna should be capable of data transfer at 2 Mbits/sec rates in the 3G wireless system or exceed 50 Mbits/sec in the 4G environment [10], [20-22]. The intelligent antenna must support additional features such as robustness, reliability [10], reconfigurability, transparency [11-12], and low cost. Over the years, much research has investigated options for integrating smart antennas into intelligent communication networks. Smart antennas differ in their "intelligence" level depending on their application [23-24].

Innovative antenna technology for mobile communication has gathered enormous interest and attention during the last few years. This is due to the advances in flexible algorithms at the receiver and transmitter in communication systems.

Different levels of intelligence have been introduced to the intelligent antennas, ranging from simple switching between predefined beams to optimum beamforming. A tremendous increase in traffic for mobile communication systems is anticipated shortly. This is because the number of users is increasing, and new high-bit-rate data services are also being introduced to the existing mobile networks. This trend is observed for second-generation (2G) systems and will continue for 3 G systems. The increase in traffic will demand that telecommunications equipment suppliers and operators find more network capacity. Intelligent antennas are one of the most promising techniques for increasing mobile networks' capacity. The most important feature of an innovative antenna system is its ability to cancel cochannel interference. The radiation from cells that use the same set of channel frequencies is likely to cause co-channel interference. Therefore, co-channel interference in the transmitting mode can be reduced substantially by focusing a directive beam in the direction of the desired user and nulls in the direction of the other receivers. Similarly, co-channel interference can be reduced in the receiving mode by knowing the directional location of the signal's source and utilizing interference cancellation. An innovative antenna system needs to differentiate the desired signal from the co-channel interference for an innovative antenna system to function correctly. Usually, this requires either "prior" knowledge of a reference signal or the direction of the preferred signal source to achieve its desired objectives. Various methods in the literature estimate the direction of sources with conflicting demands of accuracy and processing power. Also, there exists a variety of algorithms with multiple speeds of convergence and required processing time to update array weights. In some applications, the properties of signals can be exploited, eliminating the need for training signals [25-26]. The primary migration paths from the present 2G to 3G systems are GSM/TDMA and DMA. Moving to 3G services stresses the already strained and finite frequency resources. Smart antennas are regarded as one of the components in third-generation systems that solve wireless network capacity constraints [27]. The GSM/TDMA 3G migration path is from GPRS to EDGE to WCDMA. Packet-and-circuit-switched services can be mixed with bandwidth on demand and delivered simultaneously to the user. WCDMA uses a network protocol structure similar to GSM, thereby enabling the use of existing GSM networks as the core network infrastructure. The CDMA migration path is from IS-95 CDMA to cdma2000. The Main Characteristics of the 3G Cellular Standard are summarized in Table 1.

Table 1 Characteristics of the 3G Cellular Standard

3G standard	Cdma 2000				W-CDMA		
Subclass	1x	1xEV-Do	1xEv-Dv	3x	UMT	FCMA	T-phone
Channel Band Width MHz	1.25	1.25		3.75	5		
Chip rate (Mchips/s)	1.2288			3.6864	3.84		
Peak Data Rate (Mbps)	144	2.4	4.8	5-8	2.4 (8 – 10 with HSDPA)		
Modulation	QPSK (DL), BPSK (UL)						
Coding	Convolutional (low rate) Turbo (byte rate)						
Power control	800Hz				1500Hz		

IV. 3G NETWORK SUPPORT FOR ARRAY ANTENNAS

Smart antennas have experienced widespread success in improving network performance in 2G networks. Given the provisions in the 3G standards for intelligent antennas, operators will experience even greater capacity and performance benefits. These provisions include auxiliary pilots supporting spot beams, adaptive beamforming, and switched beams [12]. Spot beams increase coverage or capacity in a specific geographic area. The beam is not associated with a particular subscriber and does not track subscribers as they move through the coverage area. Spot beams, which increase the link margin, allow the subscriber stations to transmit at reduced power, thereby increasing range and capacity. If a specific subscriber user requires a high data rate or has entered an area with high propagation loss, a spot beam can be directed to that particular subscriber. In this case, the beam is steered as the subscriber moves throughout the coverage of the cell. When the subscriber enters an area of adequate coverage that does not require a spot beam, the subscriber is returned to the control of the common pilot channel.

Using adaptive beamforming on the downlink increases the performance of a CDMA system by improving the link budget for a single subscriber or a cluster of subscriber units. Adaptive beamforming extends the range toward subscribers in difficult propagation conditions, such as the edge of a cell coverage area or building basements [14]. The directed coverage of an adaptive antenna can increase the data rate due to the improved link margin. Switched-beam systems in 3G networks operate by switching the user between one of several narrow beams. This has the effect of creating limited sectors without handoff penalties. Since the capacity in a CDMA system increases with the number of sectors, replacing a 120? Being switched between beams, each user does not require its auxiliary pilot channel.

V. CONCLUSION

The hooks for intelligent antennas in the 3G standard provide more flexibility in the supported intelligent antenna systems. To operators, this means more options for implementing smart antenna systems in their 3G networks. The increase of voice and data services in 3G networks perpetuates the need for additional capacity. Switch-beam smart antennas have demonstrated significant capacity gains and performance improvements in 2G networks. As operators plan for and migrate to 3G, switched-beam technology will provide a natural first step toward a cost-effective 3G smart antenna implementation. The 2X capacity improvements demonstrated in 2G networks will apply to 3G networks, easing the burden of accommodating capacity needs associated with the growing demand for wireless communications.

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