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Array (Smart) Antennas Improve GSM Performance

Cornelius A. D. Pahalson*, Nuhu Habila, Hyat Markus Gaga

Department of Science, School of Science and Technology, Plateau State Polytechnic, Barkin Ladi, Nigeria
Email: *pahalson12@gmail.com

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Abstract

As wireless data applications over cellular networks become more widespread, the pressure to increase capacity will become even more intense. Capacity in the 800 and 900 MHz bands, where bandwidth is restricted, is already becoming a limiting factor. This paper attempts to address how the application of smart antenna systems has brought about improvements in call quality and increased capacity through reduced Interference in Mobile Communication. The smart antenna may be in a variety of ways to improve the performance of a communications system. Perhaps most importantly is its capability to cancel co-channel interference. It helps in improving the system performance by increasing the channel capacity, spectrum efficiency, extending range coverage, speech quality, enabling tighter reuse of frequencies within a cellular network and economically, feasible increased signal gain, greater, reduced multipath reflection. It has been argued that Smart antennas and the Algorithms to control them are vital to a high-capacity communication system development.

Keywords

GSM, Signal Quality, Smart Antenna, Carrier-to-Interference Ratio, Co-Channel Interference

1. Introduction

One of the technologies that can contribute to the improvement of wireless systems is the smart antenna (SA). A "smart antenna" system uses spatially separated antennas called array antenna and processes received signals with a digital signal processor after analog to digital conversion and the name is derived from an adaptive filter or "adaptive filter signal processing". This type of antenna that is combined with a digital signal processor is called by the name of smart antenna or software antenna or "Digital Beamforming Antenna" (DBF Antenna) [1]. The Utilization of an array (smart antenna) is considered to be one of the most important measures to increase capacity in cellular mobile radio systems and is presently studied worldwide. Smart antenna technologies are capable of reducing the required transmission power and combating interference. Therefore, the application of smart antennas to Global System for Mobile Communication (GSM) performance seems to be unavoidable and very promising concerning system efficiency [2]. Various smart antennas concepts exist and their applicability is manifold. Smart antennas are most often realized with either switch-beam or fully smart array antenna [3].

The technology of the smart antennas for mobile communications has received enormous interest worldwide in recent years. The reason for introducing smart antennas is the possibility for large increase in capacity: an increase of three times for time division multiple access (TDMA) systems and five times for code division multiple access (CDMA) systems has been reported [4].

Though smart antenna techniques are new in the area of mobile communications, the technology itself was introduced in 1960's. Smart 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 [5].

The application of smart antenna systems has achieved significant improvements in call quality, performance metrics and network capacity in AMPS and (CDMA) networks worldwide [6]. This experience is now being directed towards the development of a new antenna system that will provide these advantages to GSM networks. The first trial of the new system (called Spotlight GSM) takes place in Shanghai in 1999 as part of a cooperative agreement between Meta Wave (Switched-Beam SA) Corporation and the Shanghai Post & Telecommunications Administration.

Another major benefit of the smart antenna system is the ability to control the power of each of the 30-degree beams to "sculpt" the optimal cell site pattern.

Noise due to spill-over from nearby sites can be controlled, and tough coverage problems can be addressed, through the shaping of cell footprints. Network capacity can also be increased by transferring traffic between cell sites, or by changing handover boundaries.

The other potential advantages of using smart antennas to resolve problems in modern wireless communication include increasing range, offering new services to customers, improving security, and reducing multipath fading and interference [7] [8] [9]. In other words, smart antennas employ powerful numeric processors and control systems, which increases the cost of the smart antennas system including transceiver complexity, resource management and physical size.

1.1. Switched Beam Antenna Technology

Smart antennas integrate several interference-controlling technologies that help carriers make better use of their scarce radio frequency (RF) spectrum as well as their current cell sites and network infrastructure. Smart antennas replace existing base station antennas with an array of high-gain narrow-beam antennas [10]. These multi-beam antenna arrays (which include twelve 30-degree beams for full 360-degree coverage) improve reception of the signal from the mobile handset, at the same time picking up significantly less interference than 120-degree or omnidirectional antennas that are commonly used [11].

Sophisticated beam-switching algorithms and RF signal-processing software are incorporated in smart antenna design. For each call, software algorithms determine the beams that maintain the highest quality signal and the system continuously updates beam selection, ensuring that customers get optimal quality for the duration of their call [12].

The beam switching takes place automatically as a mobile user moves. The green cells reuse the frequencies currently assigned to the mobile, so they are potential sources of interference. The use of a narrow (30-degree) beam reduces the number of interfering sources "seen" at the base station [3].

As the mobile moves, the Spotlight smart antenna system continuously monitors the signal quality to determine when a particular beam should be selected. Within a sector of four beams, this function is accomplished automatically by the spotlight system, with no handover required by the cell network equipment [13].

Smart antennas help cellular carriers use their limited allocation of the radio frequency spectrum as efficiently as possible. The performance gains achievable with smart antenna systems are due primarily to the dramatic increases in the carrier-to-interference (C/I) ratio they provide [4].

Interference is a significant factor in the performance and capacity limitations of a cellular system [14]. It causes cross-talk, missed or dropped calls, and upsets customers. Most importantly, interference limits how closely operators can reuse frequencies and therefore, how much traffic-carrying capacity can be extracted from the finite RF spectrum [15].

Interference can come from another mobile handset, other cell sites operating on the same frequency, or out-of-band RF energy leaking into the allocated spectrum. The most usual types of cellular interference are co-channel interference and adjacent channel interference as show in **Figure 1**. Co-channel interference is caused by transmissions from non-adjacent cells using the same set of frequencies. This type of interference is usually most noticeable near the boundaries of a cell. Where there is the minimal physical separation from neighboring cells using the same frequencies. Adjacent channel interference is caused by RF leakage on the subscriber's channel from a neighboring cell using an adjacent frequency. This can occur when an adjacent channel user is operating near the subscriber's receiver, or when the user's signal is much weaker than that of the adjacent channel user.

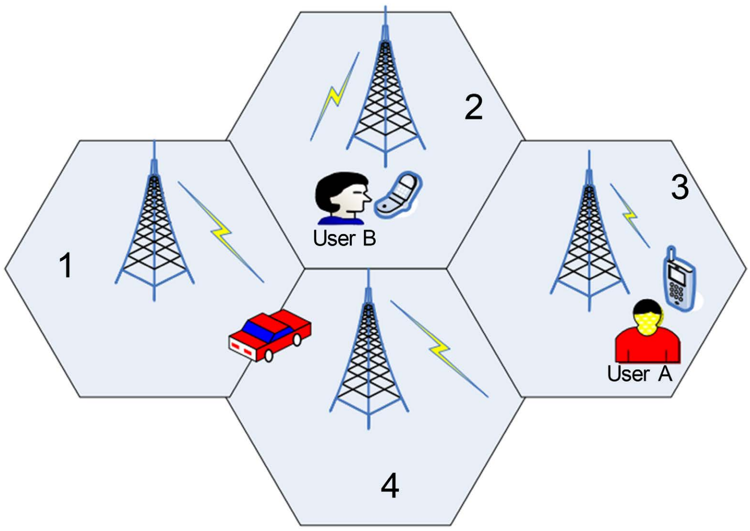

Figure 1. In-band interferences of RF signals in a typical cellular communication network.

Carrier-to-interference is an important indicator of call quality; it is a measure of the ratio between the mobile phone signal (the carrier signal) and an interfering signal. For users, a higher C/I ratio means less static, fewer dropped calls, and improved audio quality; for operators, a higher C/I ratio allows the signal range to be extended and a tighter frequency reuse pattern to be adopted, thereby increasing overall system capacity [16].

1.2. Smart Antenna Systems

Meta Wave's field experience has demonstrated that narrow-beam antennas deliver dramatic improvements in audio quality and C/I when compared with omnidirectional or three-sector analog antenna systems [17] as show in **Figure 2** and **Figure 3**.

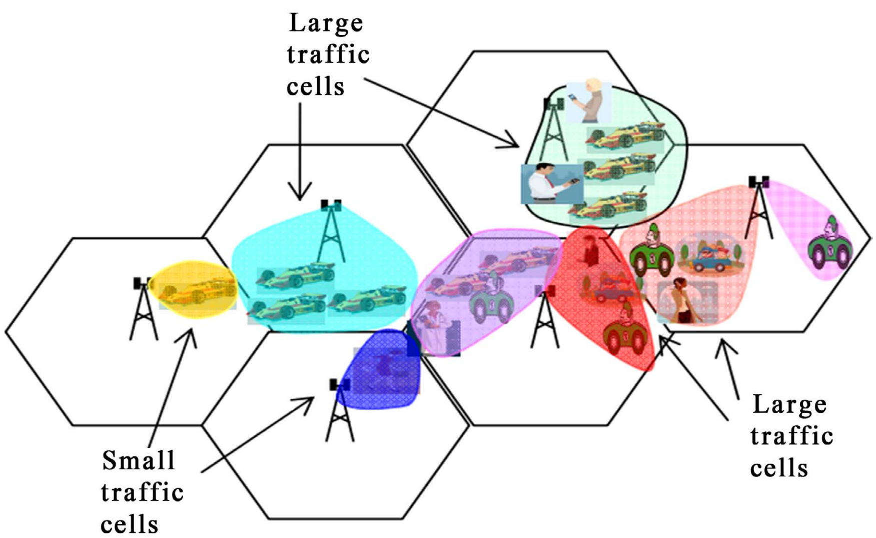

Figure 2. Application of smart antennas for dynamic re-sectoring on a cellular communication system [19].

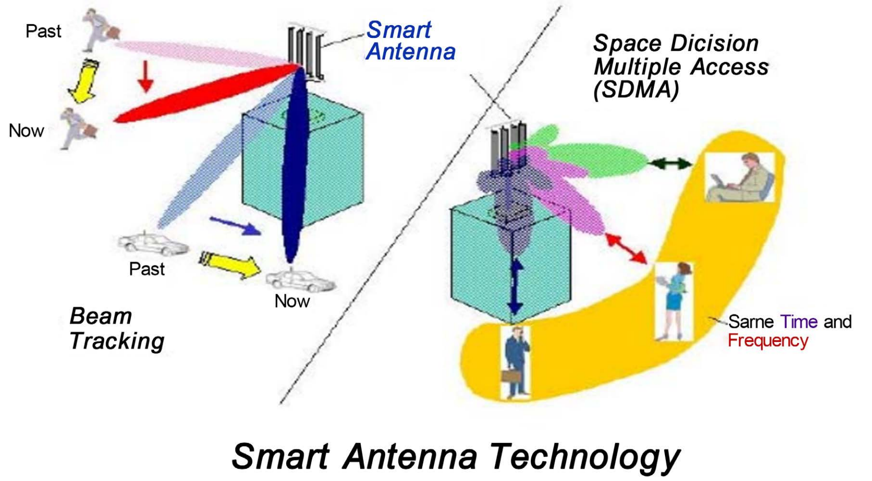

Figure 3. Smart antenna technology [20].

For example, testing was performed at a cell site with an existing omnidirectional antenna in a suburban area with an abundance of tall evergreen trees. The cell antennas were mounted near the top of a metro tower. A driving test was conducted with a mobile station transmitting a carrier signal while three interfering mobile stations transmitted on the same frequency. To create an accurate model of behavior in a mobile environment, the interfering signals and the carrier were moving while transmitting. The interfering mobiles were driven in defined routes in small areas to remove the possibility of fading on one of the antenna systems. Audio and C/I measurements were taken simultaneously for a channel on the existing omnidirectional antenna and a channel on the narrow beam antenna. On average, the narrow beam antenna system improved C/I by 10 dB for AMPS channels [18].

In another field test, a three-sector trial was conducted at two urban sites selected for their call volume and complex interference environment. One of the cell sites was a tower with the antennas mounted approximately 33 metres above ground level. Testing was performed with the same configuration as the omnidirectional system testing, but with two interfering transmitters radiating within the coverage of each 120-degree sector at all times. When compared to the conventional three-sector antenna, the narrow beam antenna showed an average C/I improvement of 7.6 dB.

In addition to analyzing the field trial data, numerous simulations of narrow beam C/I levels have been carried out. With an N = 7 reuse pattern, these simulations showed that narrow beam antenna technology offered a 12.2 dB C/I improvement over omnidirectional antenna systems and a 6.5 dB C/I improvement over three-sector antenna systems. The simulated results were confirmed by the field trial results for analog systems.

The improvement in C/I translates directly into capacity improvement. In an analog system, 18 dB C/I is required to maintain an acceptable call. This C/I level can only be obtained with an N = 7 three-sector system, but with a smart antenna system, an 18 dB C/I level can be obtained in an N = 4 three-sector system. This is a 100% increase in capacity. One realization of this concept involves reducing the required C/I (as measured with an omnidirectional antenna) using adaptive antennas. This allows the system to have fewer cells in a cluster and increase spectral efficiency as show in Table 1 and the simulation result using Matlab in Figure 4.

Table 1. Simulation values for relations Re-Use factor (Q), Carrier to Interference Ratio (C/I), Cluster size (*N*), and Spectrum Efficiency for Omni and Sectors Cell.

System	Cluster Size (N)	Carrier to interference ratio (C/I) dB	Re-Use Factor (Q)	Channel Bandwidth (KHz)	Spectrum Efficiency Channels/ MHz/Km^2
Omni	1	1.8	1.73	200	63.900
	3	11.3	3	200	25.504
	4	13.8	3.46	200	23.078
	7	18.7	4.56	200	19.825
	12	23.3	6	200	17.761
120˚ sectors	4	18.6	3.46	200	19.893
	7	23.4	4.56	200	17.723
	12	28.1	6	200	16.173
60˚ sectors	3	19.1	3	200	19.617
	4	21.6	3.46	200	18.447
	7	26.4	4.50	200	16.686
	12	31.1	6	200	15.373

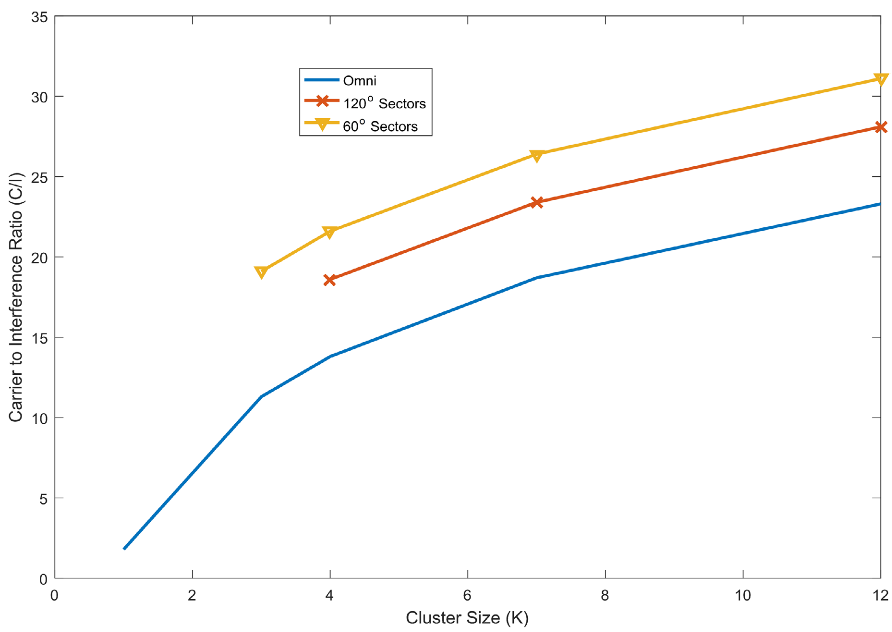

Figure 4. Variation of cluster size (N) with carrier to interference ratio (C/I) for omni, 120˚ sectors and 60˚ sectors.

Among the alternatives that aim to increase the network capacity, higher order sectorization, and in particular a six sectorized configuration, is nowadays attracting a lot of attention for cellular cell-deployments since a higher number of sectors per site results in improved site capacity and coverage. A six sectorized configuration is attractive for both roll-out phase and growth phase of the network. In the roll-out phase, the radio access network is planned with 6-sector sites instead of 3-sector sites with the advantages that less sites are needed for the same capacity and coverage requirements and to combat the problem of network congestion and instability. In the growth phase, the six sectorized configuration can be used to upgrade existing 3-sector sites where the traffic grows beyond the current sites' capabilities. Hence, a six sectorized configuration is able to enhance the performance of congested hotspots at the cost of a slight performance degradation in the surrounding sites. Therefore, we recommend that with the parameters and the assumptions that were considered in the study, the adoption of 6-sector sites along with 3-sector sites in cellular cell -deployments allows service operator to reduce capital expenditures compared to the only adoption of 3-sector sites.

2. Spotlight GSM

As in the successful AMPS and CDMA products, spotlight GSM replaces a 120-degree sector antenna with four 30-degree antennas. The system switches beams for transmission and reception based upon proprietary best beam selection algorithms. RF energy is transmitted on the downlink during each timeslot within a specific 30-degree beam, rather than across a complete 120-degree sector: co-channel interference is, therefore, substantially reduced in neighboring cells. Similarly, the beam-width open to receive co-channel interference is effectively reduced from 120-degree to 30-degree.

As in the case with the AMPS and CDMA systems, improving C/I is the key to increasing GSM network capacity and quality. Digital cellular technologies like GSM provide significant network capacity improvements compared with analog networks as frequency reuse may be increased (or cell spacing may be decreased) to provide equivalent quality service with a lower C/I than with analog networks. Spotlight GSM provides additional capacity by actually increasing C/I within the network. The 30-degree antennas effectively reduce co-channel interference by a factor of four relative to the single 120-degree sector antenna, corresponding to a theoretical improvement in C/I of 6 dB. The minimum C/I goal in a GSM network is about 9.5 dB. Once spotlight GSM has been applied within a cluster, frequency reuse within each base station may be increased while still achieving the network C/I criterion. For example, a change in reuse pattern from N = 4 to N = 3 can provide a capacity increase of 25% with the same number of base stations.

In a GSM system, up to eight through the interweaving of the digital data corresponding to voice, data, and signaling information. Each is assigned a one-timeslot within a continuously repeating frame of 4.6ms duration. In a standard GSM network, the RF energy corresponding to each frequency is transmitted across the entire 120-degree sector. Spotlight GSM confines this RF energy by communicating only with the mobile handset that is active in each timeslot through one of them 30-degree antennas. Therefore, RF energy is contained in terms of time as well as space. This is the basis for a reduction in interference generated and received.

Spotlight GSM uses high-speed digital signal processors to continuously choose the best beam for communication with the mobile. The system can select one of the four narrow beam antennas for transmission, or the two best beams for reception within each GSM timeslot, an interval of only 577 ms. This ensures continuous communication with substantially reduced interference. Furthermore, beams for transmission and reception are selected and switched independently, always ensuring the selection of the beam that provides the highest quality to users. Spotlight GSM is designed to interface to the standard RX and TX ports on existing base stations. Installation involves the replacement of the existing 120-degree antennas with a panel containing the four individually controlled 30-degree antennas.

Spotlight GSM is then co-located with the base station, and connected between the antenna and the base station. Remote monitoring, alarms, and administration facilitate ease of use and the modular architecture supports field upgrades of installed systems to two or three sector operation.

Spotlight GSM performs the beam switching without the need for additional communication with the base station so that installation presents no additional base station traffic load. Base station processor loads are often reduced due to a reduction in ineffective call attempts and redials caused by interference or poor coverage.

3. Conclusion

This paper gives a brief introduction to smart antennas capable of increasing capacity through interference reduction in mobile communications, which has been presented. Smart antennas are expected to be a vital part of future mobile communication systems like universal mobile telecommunication system (UMTS). The main benefit from exporting smart antenna is improvement in signal to interference or carrier-to-interference ratio. The advantages of interference reduction can either be exploited into capacity increase, making the system able to handle more customers within a limited frequency band, improve link quality e.g. higher bit rate or increased mobile cell range. Therefore, Smart Antennas make up an attractive solution that can be implemented in a practical, cost-effective, step-by-step process and also Smart Antennas offer several advantages over omnidirectional or sector antenna as discussed.

4. Recommendations

The number of mobile network subscribers increases constantly. At the same time, more efficient technologies should be developed in other to provide faster and more efficient network services for subscribers. As a result, the following are recommended for improved mobile performance.

a) The traffic on the network increases, which causes congestion of allocated spectrum as well as problem of the insufficient area. Hence, for enhancement of efficient coverage cell splitting and cell sectoring, techniques should be used to maintain the quality signal link, reducing co-channel interference and improved channel capacity.

b) New network technology should be developed for eliminating the cause of poor mobile signal receptions such as interference between base stations, network issues, network congestion, and distance from the base stations.

c) Network operators should be able to manage the radio resources to meet current as well as future demand without expensive investments to infrastructure.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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