© 2014 IJIRT | Volume 1 Issue 6 | ISSN : 2349-6002

Smart Antenna System and Signal Propagation

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ABSTRACT: **To radiate or receive electromagnetic waves we need antenna. An antenna or aerial is a system of elevated conductors which couples or matches the transmitter or receiver to free space. Smart antenna (also known as adaptive array antennas, multiple antennas, MIMO) are antenna arrays with smart signal processing algorithms used to identify spatial signal signature such as direction of arrival of the signal and to track and locate the antenna beam on the mobile/target. In this paper we will discuss about smart antenna system and signal propagation.**

I. INTRODUCTION

Over the last decade, wireless technology has grown at a formidable rate, thereby creating new and improved services at lower costs. This has resulted in an increase problem is to use spatial processing. As Andrew Viterbi, founder of Qualcomm Incclearly stated: “Spatial processing remains as the most promising, if not the last frontier, in the evolution of multiple access systems” .Spatial processing is the central idea of adaptive antennas or smart-antenna systems. It is only of today’s advancement in powerful low-cost digital signal processors, general purpose processors (and ASICs—Application-Specific Integrated Circuits), as well as innovative software-based signal-processing techniques (algorithms), that smart antenna systems have received enormous interest worldwide. As the number of users and the demand for wireless services increases at an exponential rate, the need for wider coverage area and higher transmission quality rises. Smart-antenna systems provide a solution to this problem. This chapter presents an introduction and general overview of smart-antenna systems. First, it gives the reader an insight on smart-antenna systems using the human auditory system as an analogy. Then, it presents the purpose for smart antennas by introducing the cellular radio system and its evolution.

II.SMART ANTENNA ANALOGY

The functionality of many engineering systems is readily understood when it is related to our human body system. Therefore, to give an insight into how a smart-antenna system works, let us imagine two persons carrying on a conversation inside a dark room. The listener among the two persons is capable of determining the location of the speaker as he moves about the room because the voice of the speaker arrives at each acoustic sensor, the ear, at a different time. The human signal processor the brain computes the direction of the speaker from the time differences or delays of the voice received by the two ears. Afterward, the brain adds the strength of the signals from each ear so as to focus on the sound of the computed direction. Furthermore, if additional speakers join in the conversation, the brain can tune out unwanted interferers and concentrate on one conversation at a time. Conversely, the listener can respond back to the same direction of the desired speaker by orienting the transmitter(mouth) toward the speaker.

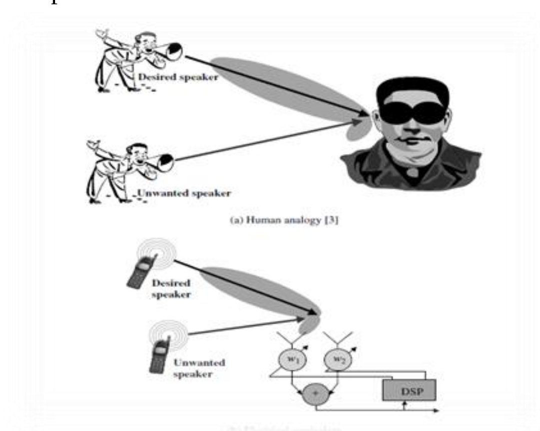

Fig 1:Smart-antenna analogy (a) Human analogy (b) Electrical equivalent

Electrical smart-antenna systems work the same way using two antennas instead of the two ears and a digital signal processor instead of a brain [refer to Figure1(b)].Therefore, after the digital signal processor measures the time delays from each antenna element, it computes the direction of arrival (DOA) of the signal-of-interest (SOI),and then it adjusts the excitations (gains and phases of the signals) to produce a radiation pattern that focuses on the SOI while, ideally, tuning out any signal-not-of interest(SNOI).

III. OMNIDIRECTIONAL SYSTEMS

Since the early days, system designers knew that capacity was going to be a problemespecially when the number of channels or frequencies allotted by the FederalCommunications Commission (FCC) was limited.Each shaded hexagonal area in Figure 2 represents a small geographical areanamed *cell* with maximum radius *R* [24]. At the middle of each cell resides a basestation equipped with an omnidirectional antenna with a given band of frequencies.Base stations in adjacent cells are assigned frequency bands that contain differentfrequencies compared to the near cells. By limiting the coverage area to withinboundaries of a cell, the same band of frequencies may be used to cover differentcells that are separated from one another by distances large enough to keep interferencelevels below the threshold of the others. The design process of selecting and allocating

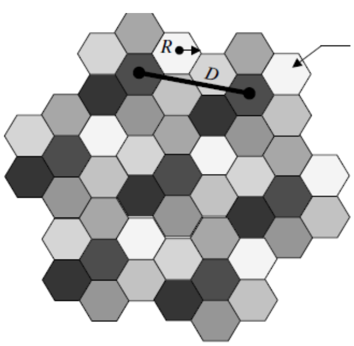

Fig 2: Typical cellular structure with 7 cells reuse pattern

the same bands of frequencies to different cells of cellular base stations within a systemis referred to as *frequency reuse*. This is showninFigure 2 by the repeatingshaded patternor *clusters* cells having the same shaded pattern use the samefrequency spectrum. In the first cellular radio systems deployed, each base stationwas equipped with an omnidirectional antenna with a typical amplitude pattern as thatshown in Figure 3, Because only a small percentage of the total energy reached thedesired user, the remaining energy was radiated in undesired directions. As the numberof users increased, so did the interference, thereby reducing capacity. An immediatesolution to this problem was to subdivide a cell into smaller cells; this technique isreferred to as *cell splitting.*

IV. CELL SPLITTING

Cell splitting as shown in Figure 4, subdivides a congested cell into smallercells called *microcells*, each with its own base station and a corresponding reduction inantenna height and transmitter power. Cell splitting improves capacity by decreasingthe cell radius *R* and keeping the *D/R* ratio unchanged; *D* is the distance between the

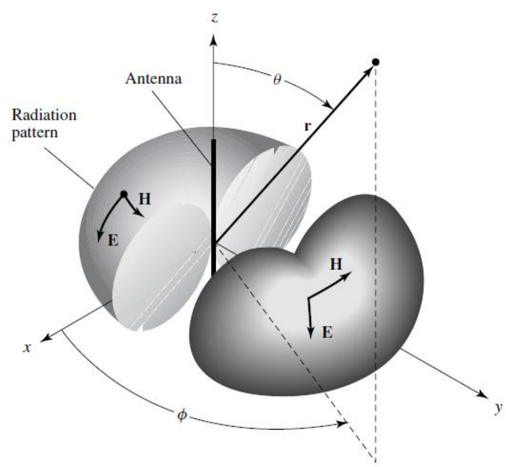

Fig 3: Omnidirectional antenna pattern

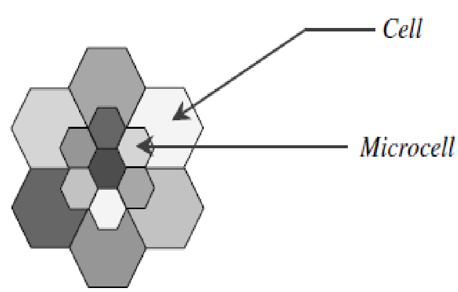

Fig 4: Cell splitting

middleof the clusters. The disadvantages of cell splitting are costs incurred from theinstallation of new base stations, the increase in the number of *handoffs* (the processof transferring communication from one base station to another when the mobile unittravels from one cell to another), and a higher processing load per subscriber

V. SECTORIZED SYSTEMS

As the demand for wireless service grew even higher, the number of frequenciesassigned to a cell eventually became insufficient to support the required number ofsubscribers. Thus, a cellular design technique was needed to provide more frequenciesper coverage area. This technique is referred to as *cell sectoring* where asingle omnidirectional antenna is replaced at the base station with several directionalantennas.

VI. SMART-ANTENNA SYSTEMS

Despite its benefits, cell sectoring did not provide the solution needed for the capacityproblem. Therefore, the system designers began to look into a system that coulddynamically sectorize a cell. Hence, they began to examine *smart antennas*.

Fig 5:Sectorizedbase-station antenna

Many refer to smart-antenna systems as smart antennas, but in reality antennas are not smart; it is the digital signal processing, along with the antennas, which makes the system smart. Although it might seem that smart-antenna systems is a new technology, the fundamental theory of smart (adaptive) antennas is not new .In fact, it has been applied in defense-related systems since World War II

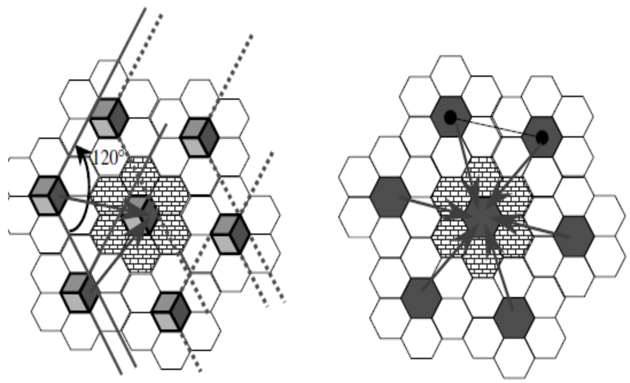

Fig 6: Co-channel interference comparison between (a) sectoring, and (b) omnidirectional

Smart-antenna systems are basically an extension of *cell sectoring* inwhich the sector coverage is composed of multiple beams. This is achieved by the use of antenna arrays, and the number of beams in the sector (e.g., 120◦) is a function of the array geometry. Because smart antennas can focus their radiation pattern toward the desired users while rejecting unwanted interferences, they can provide greater coverage area for each base station. Moreover, because smart antennas have a higherrejection interference, and therefore lower bit error rate (BER), they can provide a substantial capacity improvement. These systems can generally be classified as either*Switched-Beam* or *Adaptive Array.*

VII. SIGNAL PROPAGATION

Up until now, the problem of capacity has been associated solely with co-channel interference and with the depletion of channels due to the high number of users. However, multipath fading and delay spread also play a role in reducing system capacity [3], [30]. Fortunately, because of the ability of smart-antenna systems to adapt to the signal environment, they are able to considerably reduce delay spread and multipath fading, thereby increasing capacity.

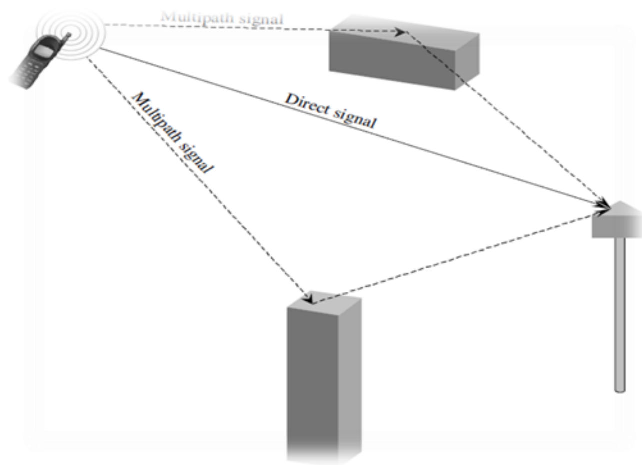

Fig 7: Multipath environment

The signal generated by the user mobile device is omnidirectional in nature; therefore, it causes the signal to be reflected by structures, such as buildings. Ultimately, this results inthe arrival of multiple delayed versions (multipath) of the main(direct) signals at the base station,
as depicted in Figure 7. This condition is referred to as *multipath* [3], [32]. In general, these multiple delayed signals do not match in phase because of the difference in path length at the base station, as shown by the example in Figure 8 [3]. Because smart-antenna systems can tailor themselves to the signal

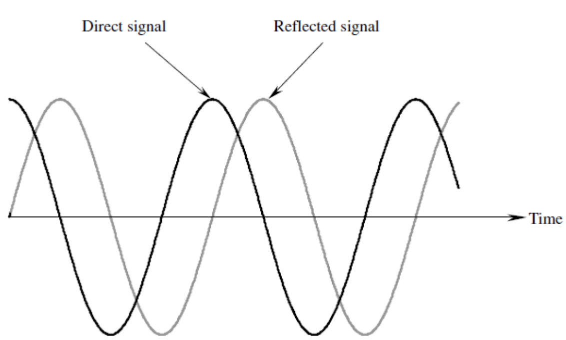

Fig 8: Two out-of-phase multipath signals [3]

Environment they can exploit or reject the reflected signals depending whether the signals are delayed copies of the SOI or the SNOIs. This is an advantage because smartantennas are not only capable of extracting information from the direct path of the SOI but they can also extract informationfrom the reflected versionof the SOI while rejecting all interferers or SNOIs. Therefore, because of this ability to manage multipath signals, smart-antenna systems improve link quality. As the signals are delayed, the phases of the multipath signal components can combine destructively over a narrowbandwidth, leading to *fading* of the received signal level. This results in a reduction of the signal strength.

VIII. SMART ANTENNA'S BENEFITS

The primary reason for the growing interest in smart-antenna systems is the *capacity*increase. In densely populated areas, mobile systems are usually interference-limited,meaning that the interference from other users is the main source of noise in thesystem. This means that the signal-to-interference ratio (SIR) is much smaller thanthe signal-to-noise ratio (SNR). In general, smart antennas will, by simultaneouslyincreasing the useful received signal level and lowering the interference level, increasethe SIR.

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