Lecture-1

Basic concepts of smart antennas

7.1 Introduction:

In antenna arrays, the main beam is steered via phase shifters to the directions of interest. These arrays are called phased arrays or scanning arrays. This general approach of phase shifting has been referred to as electronic beam steering and in this process the phase of the current at each antenna element is changed directly. This static synthesis approach to achieve the spatial diversity can not meet the recent requirements of wireless communication as the properties of these arrays remain static with time.

In recent years, it has been observed that the substantial increase in the development of broadband wireless access technologies and improved cellular systems, experiences an enormous rise in traffic for mobile and personal communications systems. The rise in traffic puts a demand on both manufacturers and operators to provide sufficient capacity in the networks. This becomes a major challenging problem for the service providers to solve. A major limitation in capacity and performance is co-channel interference caused by the increasing number of users and the multipath fading and delay spread. Research efforts investigating effective technologies to mitigate such effects have been going on and among these methods *smart antenna* employment is the most promising technology.

Smart antennas have alternatively been called digital beamformed (DBF) arrays or adaptive arrays (when adaptive algorithms are employed). The term *smart* implies the use of signal processing in order to shape the beam pattern according to certain conditions. Adaptive beamforming is a dynamic process which updates the antenna array's performance with time by collecting feedback (see Fig. 7.1) from the surrounding environment like the signals being propagated, interfering objects (i.e., buildings, trees, cars), outside electromagnetic interference (i.e., competing mobile users, radar jammers), etc. to keep the array in an optimum state. For an array to be smart implies sophistication beyond merely steering the beam to a direction of interest. Smart essentially means computer control of the antenna performance. Smart antennas hold the promise for improved radar systems, improved system capacities with mobile wireless, and improved wireless communications through the implementation of space division multiple access(SDMA).

Smart antenna patterns are controlled via algorithms based upon certain criteria. These criteria could be maximizing the signal-to-interference ratio(SIR), minimizing the variance, minimizing the mean square error(MSE), steering toward a signal of interest, nulling the interfering signals, or tracking a moving emitter to name a few. The implementation of these algorithms can be performed electronically through digital signal processing. This requires that the array outputs are digitized through the use of an A/D converter.

In short Smart antenna systems combine:

1. Antenna array technology with 2. Digital signal processing algorithms to make the antenna system "smart.".

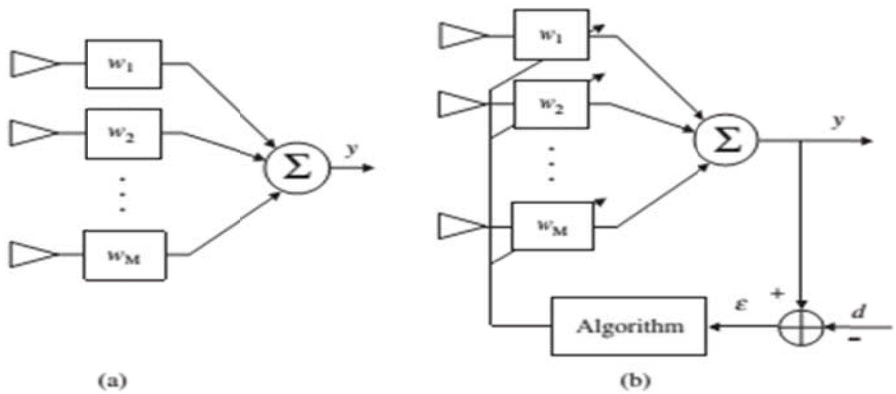


Fig. 7.1 (a) Traditional antenna array (b) Smart antenna system

7.2 Need for Smart Antenna Systems:

Wireless communication systems, as opposed to their wireline counterparts, pose some unique challenges. In recent years due to increase in the number of users and demand for high bit rate data service there is a substantial increase in traffic for mobile and personal communications systems. These challenges can be handled by the smart antenna, which can provide:

- High network capacity
- Improved quality and coverage of service.

Smart Antennas (SAs) can enhance the communication system performance, that includ:

- **Improved system capacities:** Smart antennas enable reduction in co-channel interference, which leads to increase in the frequency reuse factor. That is smart antennas allow more users to use the same frequency spectrum at the same time bringing about a tremendous increase in capacity.
- **Range improvement:** Smart antennas provide narrow beamwidth and increased gain compared to conventional antennas using the same power. The increase in the gain leads to increase in the range and the coverage of the system. Therefore fewer base stations are required to cover a given area.
- Smart antennas can **reduce both co-channel interference and multipath fading**.
- This provides **a higher signal-to-interference ratio** and lower power levels.

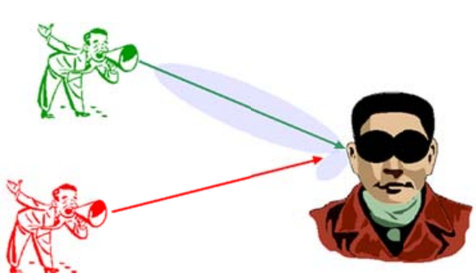
- These antennas can be used to **find the angles-of-arrival (AOA)** which is especially beneficial in radar systems.
- **MIMO** (Multiple Input Multiple Output) **compatibility** in both communications and radar.
- **Reduction of transmitting power:** Ordinary antennas radiate energy in all directions leading to a waste of power. Comparatively smart antennas radiate energy only in the desired direction. Therefore, less power is required for radiation at the base station. Reduction in transmitting power also implies a reduction in interference towards other users.

7.3 Overview of Smart Antenna Systems:

The basic idea on which smart antenna systems were developed can be correlated with the operation of the human auditory system. A person is able to determine the Direction of Arrival (DoA) of a sound by utilizing a three-stage process:

- One's ears act as acoustic sensors and receive the signal.
- Because of the separation between the ears, each ear receives the signal with a different time delay.
- The human brain, a specialized signal processor, does a large number of calculations to correlate information and compute the location of the received sound.

Let us imagine two persons carrying on a conversation inside an isolated room as illustrated in Fig.7.2. 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 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. Utilizing a similar process, the human brain is capable of distinguishing between multiple signals that have different directions of arrival. Thus, if additional speakers join the conversation, the brain is able to enhance the received signal from the speaker of interest and tune out unwanted interference. Therefore, the listener has the ability to distinguish one person's voice, from among many people talking simultaneously, and concentrate on one conversation at a time. In this way, any unwanted interference is attenuated. Conversely, the listener can respond back to the same direction of the desired speaker by orienting his/her transmitter, his/her mouth, toward the speaker.



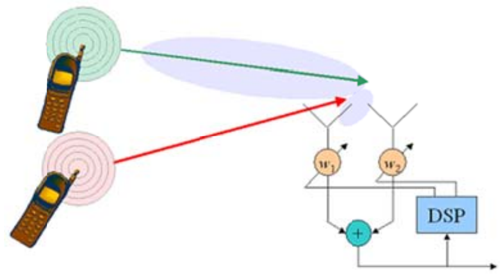


Fig 7.2 Human auditory function

Fig 7.3 Two element electrical smart Antenna

Electrical smart antenna systems work on the same principle using two antennas. Here the antennas are related to two ears of the human auditory system. In the smart antenna a digital signal processor is used which can be related to the brain of the human as seen in Fig.7.3. Thus, based on the time delays due to the impinging signals onto the antenna elements, the digital signal processor 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.

Transferring the same idea to mobile communication systems, the base station plays the role of the listener, and the active cellular telephones simulate the role of the several sounds heard by human ears. A digital signal processor located at the base station works in conjunction with the antenna array and is responsible for adjusting various system parameters to form the beam of the antenna array in the desired signal direction and nulls in the direction of signals-not-of-interest (SNOI). Thus, the system forms the radiation pattern in an adaptive manner, responding dynamically to the signal environment.

So the operations of the smart antenna discussed above can be summarized as:

- Beam steering: (Placing antenna beam maxima toward Signals Of Interest (SOI)).
- Null steering: (Placing antenna beam minima, ideally nulls, toward interfering signals/Signal Not Of Interest (SNOI))
- Spatial diversity: (Allowing different users to share the same spatial system resources (SDMA))