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COMMUNICATIONS

ANTENNA ARRAYS — APPLICATION POSSIBILITY FOR MOBILE COMMUNICATION

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Scientists, communication specialists and engineers are developing sophisticated antenna arrays to be used in various mobile communication systems, including landmobile, indoor-radio, satellite-based systems. The antenna arrays are generally mounted on vehicles, aircraft, ships, satellites and base stations. An application of antenna arrays has been suggested in recent years for mobile communication 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 show that when an array is appropriately used in a mobile communication system, it helps in improving the system performance by increasing the channel capacity and spectrum efficiency, extending the range coverage, steering multiple beams to track many mobiles, and compensating aperture distortion electronically. It also reduces multipath fading, system complexity and cost. It has been argued that adaptive antennas and algorithms to control them are vital to high-capacity communication system development.

K e y w o r d s: antenna, antenna array, phased array, adaptive antenna, beamformer

1 INTRODUCTION

An antenna array may be used in a variety of ways to improve the performance of a communication system. Perhaps most important is its capability to suppres co-channel interferences. An array works on the premise that the desired signal and unwanted co-channel interferences arrive from different directions. The beam pattern of the array is adjusted to suit the requirements by combining signals from different antennas with appropriate weighting. The scheme needs to differentiate the desired signal from the co-channel interferences and normally requires either the knowledge of a reference signal, a training signal or the direction of the desired signal source to achieve its desired objectives. There exist a range of schemes to estimate the direction of sources with conflicting demands of accuracy and processing power. Similarly, there are many methods and algorithms to update the array weights, each with its speed of convergence and required processing time. There has been a wide range of research covering the development of antennas suitable for mobile communication systems.

2 NOTES ABOUT AN ANTENNA ARRAY

Antennas in general may be classified as omnidirectional, directional, phased array, adaptive and optimal. An omnidirectional antenna has an equal gain in all directions and is also known as an isotropic antenna. Directional antennas, on the other hand, have higher gain in certain directions than in others. The direction in which the gain of the antenna is maximum is referred to as the bore-sight direction of the antenna.

A *phased array antenna* uses an array of simple antennas, such as omnidirectional antennas, and combines the signal induced on these antennas to form the array output. Each antenna forming the array is known as an element of the array. The direction where the maximum gain would appear is controlled by adjusting the phase between different antennas. The phases of signals induced on various elements are adjusted so that the signals due to the source in the direction where the maximum gain is required are added in phase. This result in the gain of the array being equal to the sum of the gains of all individual antennas.

The term *adaptive antennas* is used for the phased array when the gain and the phase of the signals induced on various elements are changed before combining to adjust the gain of the array in a dynamic fashion, as required by the system. In a way, the array adapts to the situation, and the adaptation process is normally under control of the system [1]. With adaptive arrays, the signals received by each antenna are weighted and combined to maximize the output SINR [2].

An *optimal antenna* is one in which the gain and phase of each antenna element are adjusted to achieve the optimal performance of the array in some sense. For example, to obtain the maximum output SNR by cancelling unwanted interferences and receiving the desired signal without distortion may be one way of adjusting gains and phases of each element. For a given array, the beam may be pointed in different directions mechanically moving the antenna array. This is known as mechanical steering.

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Beam steering can also be accomplished by appropriately delaying the signals before combining them. This process is known as electronic steering, and there are no mechanical movements. For narrow-band signals, the phase shifters are used to change the phase of signals before combining them. The required delay may also be accomplished by inserting varying lengths of coaxial cables between the antenna elements and the combiner. Changing the combinations of different lengths of these cable leads to different combinations of beam steering networks to point to beam in different directions, which is sometimes referred to as beam switching [1].

Electronic beam steering can be used in mobile applications to enhance spectrum efficiency as well as to reduce the problems associated with multipath propagation. The use switched parasitic antenna elements to achieve beam steering has been examined [4]. As mobile systems now operate over two or more frequency bands, antenna arrays that operate in more than one frequency band are required. Preferably these antennas can operate at the two frequencies simultaneously with similar coverages (similar radiation patterns). In [5] the design and simulation results of a dual-band smart antenna using RL and L loaded wire elements are presented. Previously, lumped impedance loads in wire elements were used to increase the bandwidth. The array comprises six loaded monopole elements on an infinite ground plane. The elements are arranged with a centre-fed element surrounded by a circle of five symmetric parasitic elements. The parasitic elements become reflectors when shorted to the ground using pin diodes. When not shorted, the parasitic elements have little effect on the antenna characteristic. The antenna has five beam directions at 72° spacing through 360°. One smart antenna implementation strategy uses an adaptive antennas array, consisting of an array of antenna elements arranged in a straight line, circular or planar geometry, whose outputs are adaptively combined through a set of complex weights to form a single output. Unfortunately, adaptive antennas have strong implementation costs and complexity constraints because they cannot be integrated into an arbitrary cellular system in a straightforward manner [9]. Another implementation strategy uses a switched-beam antenna, consisting of a multiple narrow-beam directional antennas along with a beam- selection algorithm. Switched-beam smart antennas offer a potentially more desirable solution than the adaptive antenna array since they are based on a well-known technology, require no complicated beam-forming (combining) network, and require no significant changes to the existing cellular infrastructure.

Switched-beam antennas are based on the retro-targeting concept. The selection of the activated receive beam is based on the received signal-strength indicator. Forward-channel transmission is over the best received beam, *ie*, the same beam is used for both reception and transmission. Beam forming is accomplished by using physically directive antenna elements to create the aperture and, thus, the gain. If the received CIR (carrier-to-interference ratio) falls below some pre-set level during a call, the (BS) base station then switches to the best available beam for transmission and reception. The directive nature of the narrow antenna beams ensures that, in a given system, the level of co-channel interference experienced from and by neighbouring co-channel cells is much lower on average than that experienced when using conventional wide-coverage BS antennas.

3 PHASED ARRAY

With phased arrays, the signals received by each antenna are weighted and combined to create a beam in the direction of the mobile. The same performance can also be achieved by sectorized antennas, whereby a different antenna is used to form each beam. As the number of antennas increases, the received signal gain (range) increases proportionally to the number antennas, but only until the beamwidth of the array is equal to that of the angle of multipath scattering around the mobile [2].

4 CONVENTIONAL BEAM FORMING

Adjusting only the phase of signals from different elements to point a beam in a desired direction is the conventional method of beam pointing or beam forming. The gain of each signal is kept the same. This determines the total gain of the array in the beam pointing direction, also known as the look direction. The shape of the antenna pattern in this case is fixed, that is, the positions of the side lobes with respect to the main beam and their level are unchanged or, when the main beam is pointed in different directions by adjusting various phases, the relative position of the side lobes with respect to the main lobe does not change. This, however, may be changed by adjusting the gain and phase of each signal to shape the pattern as required. The amount of change depends upon the number of elements in the array.

With an M-element array, one is able to specify $M-1$ positions. These may be one maximum in the direction of the desired signal and $M-2$ minima (nulls) in the directions of unwanted interferences. This flexibility of an M-element array to be able to fix the pattern at $M-1$ places is known as the degree of freedom of the array. For an equally spaced linear array, this is similar to an $M-1$ degree polynomial of $M-1$ adjustable coefficients, with the first coefficient having the value of unity.

5 ARRAYS IN MOBILE COMMUNICATIONS SYSTEMS

Arrays may be used in various configurations for mobile communications. The systems considered include base-mobile, indoor-mobile, satellite-to-satellite communications systems.

The base-mobile system consists of a base station situated in a cell and serves a set of mobiles within the cell.

The baase statio system transmits signals to each mobile and receives signals from them. It provides the link between the mobiles within the cell and the rest of the network.

Multiple antennas at the base station may be used to form multiple beams to cover the whole cell site. For example, three beams with a beam-width of 120° each or six beams with a beam-width of 60° each may be formed for the purpose. The base station with adaptive beams is used to find the location of each mobile, and then beams are formed to cover different mobiles or group of mobiles. This set-up is different from the one discussed previously, where a number of beams of fixed shape cover the whole cell. Here, the beams are shaped to cover the traffic. As the mobiles move, the different beams cover different clusters of mobiles, offering the benefit of transmitting the energy toward the mobiles.

In contrast to steering beams toward mobiles, one may adjust the pattern so that it has nulls toward other mobiles. A null in an antenna pattern denotes a zero response. In practice, however, this is seldom achievable, and one creates a pattern with a reduced response toward undesirable interferences. Formation of nulls in the antenna pattern toward co-channel mobiles helps to reduce the co-channel interference in two ways. In the transmission mode, less energy is transmitted from the base toward these mobiles, reducing the interference from the base to them. In the receiving mode, this helps to reduce the contribution from these mobiles at the base. The use of antenna arrays for indoor mobile radio systems is discussed in [3], [7].

In satellite-mobile systems, the mobiles (mostly vehicles) directly communicate with the satellite, in contrast to a system where a base station acts as a repeater station by communicating with the satellite on one hand and the mobiles on the other. An array mounted on board of the satellite provides the beam-generation facility. Depending upon the type of array system utilized, many scenarios are possible.

Fixed-shape beams: in a simplistic situation, beams of fixed shape and size may be generated to cover the area of interest. Proposed fixed-beam antennas use multibeam phased arrays for mobile communications.

Traditionally, phased arrays have been used in a feed network to control the beam coverage area. A typical system consists of a high-gain large reflector antenna along with an array of feed elements placed in the focal plane of the reflector in a particular geometry able to generate a limited number of fixed-shape spot beams. A particular beam is selected by choosing a combination of feed elements. The steering of beams is achieved by controlling the phases of signals prior to the feed elements. Dual circuitry is employed for transmit and receive modes for the signal to flow in both directions.

Dynamic beams: A system using fixed-shape beams does not require knowledge of the traffic conditions, as does a system generating spot beams of varying shapes and sizes dictated by positions of the mobiles. This also helps to reduce the transmitted power due to its directed nature of transmission, relaxing the need to generate large amounts of power onboard of a satellite. The system is generating an arbitrarily shaped beam to be pointed at a desired location.

Recent developments in monolithic MMCI (monolithic microwave integrated circuit) technology, which allows fabrications of power amplifiers, phase shifters and low noise amplifiers directly coupled to radiating elements, provides multibeam functionality using a very small space onboard of the satellite. The technology enables one to fabricate a large number of active elements that may be independently controlled by digital hardware. This, along with digital signal processing, gives one the ability to generate a large number of independent beams of arbitrary shapes, which may be steered at any desired location. Such active elements have been used GLOBSTAR and IRIDIUM systems. Panels containing a large number of elements are used to generate many fixed-shape beams.

Array on Mobiles: When mobile satellite systems use a number of antennas mounted on a vehicle, then the beam electronically steered in the direction of a satellite uses phase shifters. Electronic steering is not utilized for German TV-SAT2 system using multiple antennas. It employs four sets of pre-oriented antenna elements mounted on four faces of truncated pyramids. Fixed beams from each set are formed separately and are switched depending on the orientation on the mobile relative to the geostationary satellite used. The system is useful for larger vehicles, such as buses and trains.

Separate elements that are alternately placed side by side in a planar configuration for transmit and receive modes use digital beam-forming techniques for tracking two satellites in multisatellite systems. The systems uses low-orbit satellites.

A spherical array mount, useful for ships and aircraft employs digital beam forming to control the beam direction.

6 PERFORMANCE IMPROVEMENT USING AN ARRAY

An antenna array is able to improve the performance of a mobile communication system in a number of ways. It provides the ability to reduce co-channel interferences and multipath fading resulting in a better quality of services, such as reduced BER (bit error rate) and outage probability. Its capability to form multiple beams could be exploited to serve many users in parallel, resulting in an increased spectral efficiency. Its ability to adapt beam shapes to suit traffic conditions is useful in reducing the interference. We use an antenna array to reduce delay spread and multipath fading. Delay spread is caused by multipath propagation where a desired signal arriving from different directions gets delayed due to the different travel distances involved. An array with ability to form beams in certain directions and nulls in others is able to suppress some of these delayed arrivals. In the transmit mode, it focuses energy in the required direction, which helps to reduce multipath reflections causing a reduction in the delay spread.

An antenna array has the property of a spatial filter which may be exploited in transmitting as well as receiving modes to reduce co-channel interferences. In transmitting mode, it can be used to focus radiated energy forming a directive beam in a small area where the receiver is probably located. This in turn means that there is less interference in the directions where the beam is pointing.

In [8] the gain improvement of a low-complexity multibeam antenna system is investigated. The multi-beam antenna uses 12 or 24 narrow beams, each with fixed pointing directions. Selection combining is used to switch the strongest two directional beams. The first multibeam antenna had 12 beams, each with approximately 30 beamwidth. The antenna physically consisted of tree panels with four beams per panel. The second multibeam antenna was a 24-beam array with approximately 15° beamwidth per beam. Again, the antenna physically consisted of three panels, each panel had eight individual beams. Switching between fixed beams dramatically reduces the complexity of the associated signal processing hardware and also allows the antenna system to be readily integrated with existing cell site receivers.

Array design suitable for mobile communications is an area of active research and many prototypes have been built, analyzed and tested. These designs include:

- an eight-element array of spiral antennas with a mechanical steering capability and gain of 15 dB,
- a 12-element array mounted on a truncated pyramid with electronic steering,
- a spherical array with beam-forming capabilities.

7 CONCLUSION

This paper shows a dynamic and fast-growing industry. Mobile communications is a field that in the future will play an increasingly important role in both our professional and personal lives.

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