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Adaptive Antenna using Metamaterial

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Abstract: ***This paper presents an innovative concept of designing Smart antenna using metamaterial. The term "smart (adaptive) antenna" generally refers to any antenna array, terminated in a sophisticated signal processor, which can adjust or adapt its own beam pattern in order to emphasize signals of interest and to minimize interfering signals. Metamaterials are artificial materials engineered to have properties that may not be found in nature. They are assemblies of multiple individual elements fashioned from conventional microscopic materials such as metals or plastics, but the materials are usually arranged in repeating patterns. Metamaterials gain their properties not from their composition, but from their exactingly-designed structures. Antenna designs incorporating Metamaterial can step-up the radiated power. It behaves as if it were much larger than its actual size, because its novel structure stores and re-radiates energy. The combined system of Adaptive antenna using metamaterial is expected to play a key role in meeting the demands of the wireless communication system of the future.***

Index terms: Adaptive antenna, metamaterial, spatial processing, permittivity, permeability

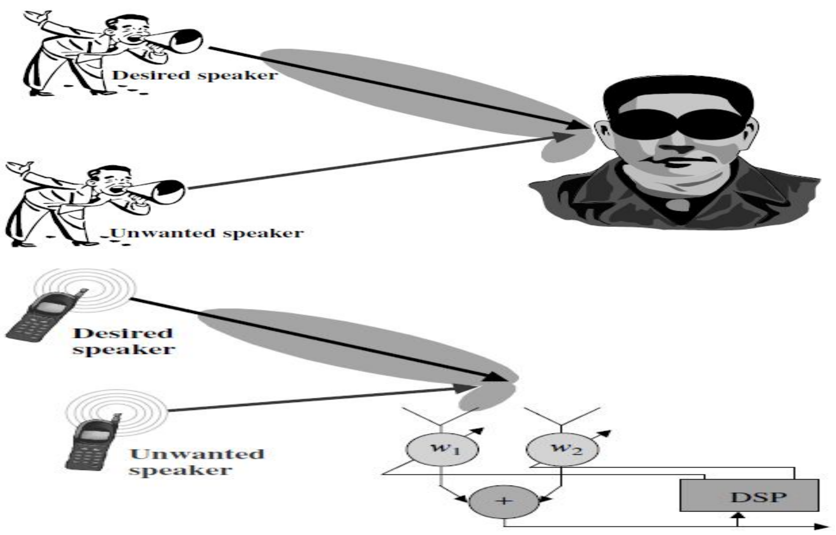

Fig 1 - Smart antenna analogy

I. Introduction

Smart antennas are used in mobile communication to improve gain at the base station. The term "smart (adaptive) antenna" generally refers to any antenna array, terminated in a sophisticated signal processor, which can adjust or adapt its own beam pattern in order to emphasize signals of interest and to minimize interfering signals. Spatial processing is the central idea of adaptive antennas or smart-antenna systems.

A smart antenna is a phased or adaptive array that adjusts to the environment. That is, for the adaptive array, the beam pattern changes as the desired user and the interference move, and for the phased array, the beam is steered or different beams are selected as the desired user moves. Adaptive antenna array is an array of multiple antenna elements with the received signals weighted and combined to maximize the desired signal to interference and noise (SINR) ratio. This means that the main beam is put in the direction of the desired signal while nulls are in the direction of the interference.

Recently, there has been great interest in the study of Metamaterial both theoretically and experimentally. Metamaterial are artificial materials synthesized by embedding specific inclusions, for example, periodic structures, in the host media. Some of these materials exhibit either negative permittivity or negative permeability.

If both permittivity and permeability of such materials are negative at the same frequency, then the composite possesses an effective negative index of refraction for isotropic medium and is referred to as a left-handed Metamaterial.

Antenna designs incorporating Metamaterial can step-up the radiated power. The newest metamaterial antennas radiate as much as 95 percent of an input radio signal. Metamaterial antennas are as small as one-fiftieth of a wavelength.

Metamaterial permit smaller antenna elements that cover a wider frequency range. A Metamaterial antenna behaves as if it were much larger than its actual size, because its novel structure stores and re-radiates energy.

II. PROPOSED METAMATERIAL BASED SMART ANTENNA

The design focuses on the implementation of a DSP based three-element adaptive antenna array. Adaptive antenna array systems represent the most advanced smart antenna approach to date. Using a variety of new signal-processing algorithms, the adaptive system takes advantage of its ability to effectively locate and track various types of signals to dynamically minimize interference and maximize intended signal reception. The difference between a smart (adaptive) antenna and fixed antenna is the property of having an adaptive and fixed lobe-pattern, respectively. The secret to the smart antennas ability to transmit and receive signals in an adaptive, spatially sensitive manner is the digital signal processing capability present. An antenna element is not smart by itself; it is a combination of antenna elements to form an array and the signal processing software used that makes smart antennas effective. This shows that smart antennas are more than just the “antenna”, but rather a complete transceiver concept.
An Adaptive Antenna Array is a set of antenna elements that can adapt their antenna pattern to changes in their environment. Each antenna of the array is associated with a weight that is adaptively updated so that its gain in a particular look-direction is maximized, while that in a direction corresponding to interfering signals is minimized. In other words, they change their antenna radiation or reception pattern dynamically to adjust to variations in channel noise and interference, in order to improve the SNR (signal to noise ratio) of a desired signal. This procedure is also known as adaptive beam forming or digital beam forming.

A. SMART ANTENNA RECEIVER

It shows schematically the elements of the reception part of a smart antenna. The antenna array contains *M* elements. The *M* signals are being combined into one signal, which is the input to the rest of the receiver. As the figure shows, the smart antenna reception part consists of four units. In addition to the antenna itself it contains a radio unit, a beam forming unit and a signal processing unit.

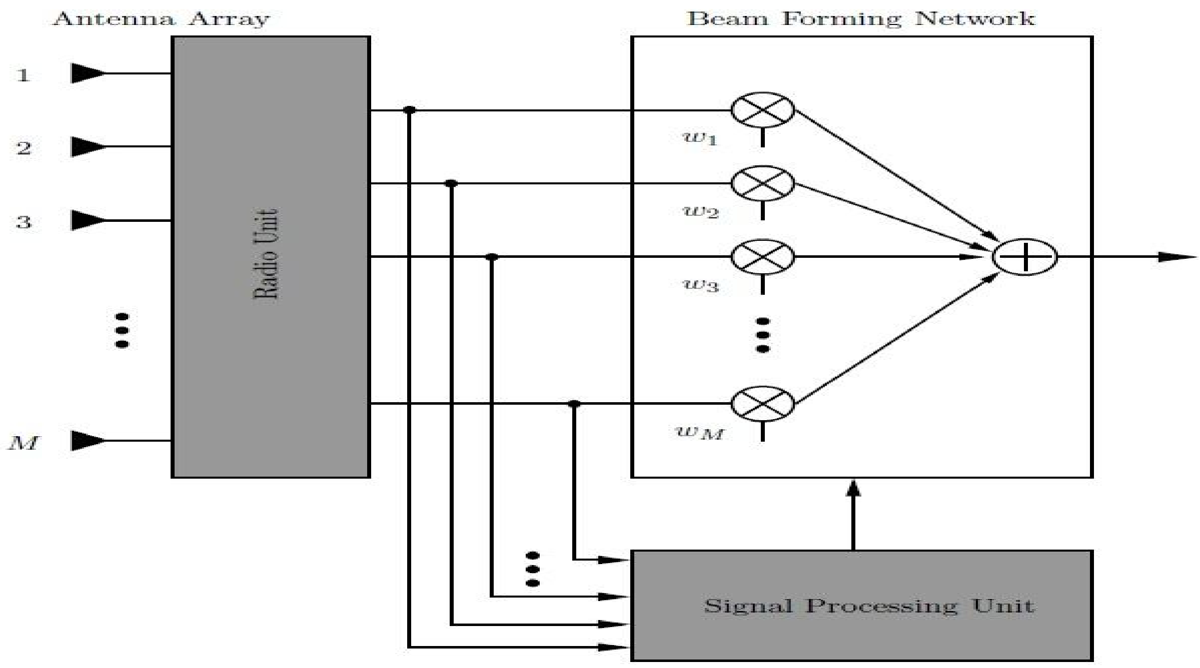

Fig 2- Smart antenna Receiver

The radio unit consists of down-conversion chains and (complex) analog-to-digital converters (A/D).There must be *M* down-conversion chains, one for each of the array elements. The signal processing unit will, based on the received signal, calculate the complex weights $w1, \ldots, wM$ with which the received signal from each of the array elements is multiplied.

These weights will decide the antenna pattern in the uplink direction. The method for calculating the weights will differ depending on the type of optimization criterion. Weight is complex adjustment of amplitude and phase. A maximum gain beam towards the strongest signal component is directed. 'Direction of Arrival (DoA)' is first estimated and then the weights are calculated.

B. SMART ANTENNA TRANSMITTER

The transmission part of the smart antenna is schematically very similar to the reception part. The signal is split into *M* branches, which are weighted by the complex weights *w*1, . . . ,*wM* in the beam forming unit. The weights, which decide the radiation pattern in the downlink direction, are calculated as before by the signal processing unit. The radio unit consists of D/A converters and the up converter chains. In practice, some components, such as the antennas themselves and the DSP will of course be the same as on reception. The same approach of estimating the DoA is used in transmitter.

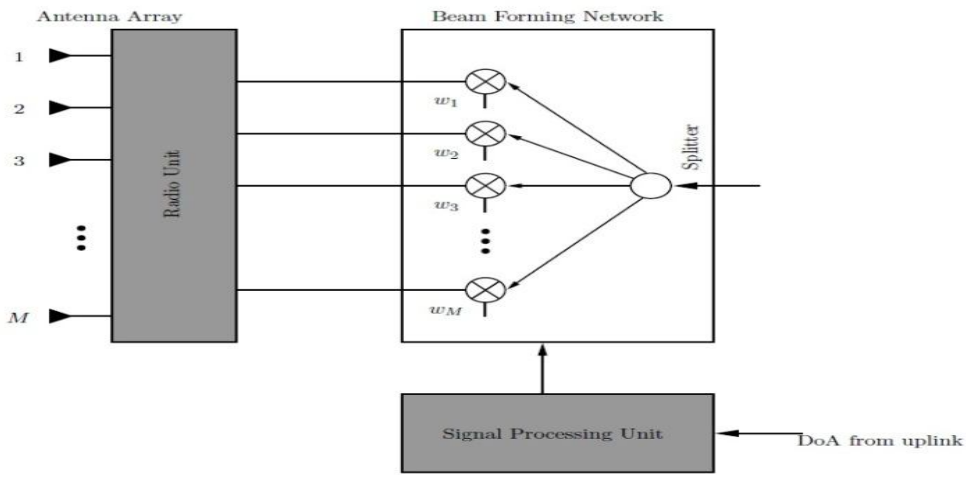

Fig 3- Smart antenna transmitter

The assumption is directional reciprocity, i.e., the direction from which the signal arrived on the uplink is the direction in which the signal should be transmitted to reach the user on downlink. The strategy used by the base station is to estimate the DoA of the direction (or directions) from which the main part of the user signal is received. This direction is used on downlink by choosing the weights *w*1, . . . ,*wM* so that the radiation pattern is a lobe or lobes directed towards the desired user. In addition, it is possible to position zeros in the direction towards other users so that the interference suffered by these users is minimized. It is assumed that the interferers observed by the base stations are mobile stations and that the interferers observed by the mobile stations are base stations. This means that when the base station on transmission positions zeros in the direction towards other mobile stations than the desired one, it will reduce the interference suffered by these mobiles. If, however, the interferers observed by mobiles are other mobiles, as maybe the case, there will be a much more fundamental limitation in the possibility for interference reduction at the mobile.

Certain beamforming algorithms are used in smart antenna system to estimate direction of arrival. Some of these are multiple signal classification (MUSIC), Estimation of Signal Parameters via Rotational Invariance Technique (ESPRIT), constant modulus algorithm (CMA) etc. The selection of any of the algorithm is based on the requirement of the user, efficiency and complexity of the system.

III. BENEFITS OF SMART ANTENNA SYSTEM

Capacity Increase - The principle reason for the growing interest in smart antennas is the capacity increase. In densely populated areas mobile systems are normally interference-limited, meaning that interference from other users is the main source of noise in the system. This means that the signal to interference ratio, SIR, is much larger than the signal to thermal noise ratio, SNR. Smart antennas will on average, by simultaneously increasing the useful received signal level and lowering the interference level, increase the SIR.

Range Increase - In rural and sparsely populated areas radio coverage rather than capacity will give the premises for base station deployment. Because smart antennas will be more directive than traditional sector or omnidirectional antennas, a range increase potential is available. This means that base stations can be placed further apart, potentially leading to a more cost-efficient deployment. The antenna gain compared to a single element antenna can be increased by an amount equal to the number of array elements.

New Services -When using smart antennas the network will have access to spatial information about users. This information can be used to estimate the positions of the users much more accurately than in existing networks. Positioning can be used in services such as emergency calls and location-specific billing.
Security - It is more difficult to tap a connection when smart antennas are used. To successfully tap a connection the intruder must be positioned in the same direction as the user as seen from the base station.
Reduced Inter-Symbol-Interference (ISI) - Multipath propagation in mobile radio environments leads to ISI. Using transmit and receive beams that are directed towards the mobile user of interest reduces the amount of multipaths and therefore the inter-symbol-interference.

IV. IMPLEMENTING METAMATERIAL FOR THE ANTENNA ARRAY.

The above system which uses the conventional antenna array in the smart antenna system can be replaced by metamaterial. Metamaterial are artificial materials synthesized by embedding specific inclusions, for example, periodic structures, in the host media. Some of these materials exhibit either negative permittivity or negative permeability. If both permittivity and permeability of such materials are negative at the same frequency, then the composite possesses an effective negative index of refraction for isotropic medium and is referred to as a left-handed Metamaterial. The name is used because the electric field, the magnetic field and the wave vector form a left-handed system. This Metamaterial is typically realized artificially as composite structures that are composed of periodic metallic patterns printed on dielectric substrates.

V. ADVANTAGE OF METAMATERIAL

- Antenna can be designed with **one fiftieth** wavelength.
- Phase compensation due to negative refraction.
- Transmission line dispersion compensation.
- Negative refractive index metamaterial supporting 2-D waves.
- Left-handed behavior in LC loaded transmission lines.
- Growing evanescent waves in negative-refractive-index transmission-line media.
- Backward wave antenna using an NRI loaded transmission line.
- Planar NIMs with periodic loaded transmission lines.

VI. HARDWARE DESIGN

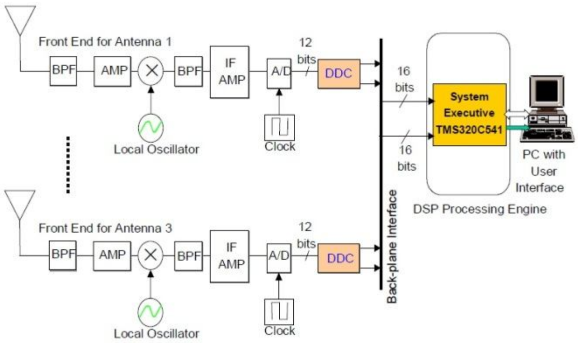

Fig 4 – Block diagram of Adaptive Array System

A block diagram of the adaptive array system is shown in Figure 4. The antenna segment of the multi-sensor test bed consists of a custom made linear array of three quarter wavelength monopoles spaced half a wavelength apart. The elements drive a set of identical analog front ends. Rather than using direct sampling at RF, the analog tuning segment performs down- conversion to IF for band pass digitization. The analog tuner down converts signals at an RF of 2050 MHz. It has a noise figure of 5 dB, and provides 75 dB of spurious free dynamic range in a 2 MHz IF bandwidth with a minimum detectable signal of -111.4 dB.

The RF band pass filter provides rejection of out of band interference. The RF low noise amplifier (LNA) increases the level of the signal before it reaches the mixer and basically determines the noise figure of the receiver.

Following RF amplification, the signal is mixed down to IF. A common clean LO-signal is used to drive the mixers of all the branches of the analog tuners. Post-mixer band pass filtering provides rejection of undesired out-of-band signals, mixer spurious products, and RF and LO mixer-leakage.

After amplification of the analog IF signal, IF digitization using harmonic sampling takes place. Once the IF signal has been digitized, the HSP50016 digital down-converter is used to demodulate the desired signal to its complex baseband in-phase and quadrature components. By relieving the DSP from the processing burden associated with the down conversion functions, more computational power becomes available for the tasks required for array processing. Digital down conversion not only eliminates the need for another IF stage but it also overcomes many of the problems related to analog down conversion and low pass digitization.

Thus, after proper signal conditioning, the IF signal is down converted, down sampled, and filtered for baseband processing with the adaptive array algorithm in the TMS320C541 EVM evaluation board.

VII. CONCLUSION

In this way Adaptive antenna array can be designed using Metamaterial. An innovative concept of designing Smart antenna using Metamaterial is proposed. Metamaterial gain their properties not from their composition, but from their designed structures. Antenna designs incorporating Metamaterial can step-up the radiated power.It behaves as if it were much larger than its actual size, because its novel structure stores and re-radiates energy.

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