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Features and Futures of Smart Antennas for Wireless Communications: A Technical Review

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Abstract

Smart antenna is one of the most proficient and dominant technological innovations for maximizing capacity, improve quality, and coverage in wireless communications system. This work presents relevant comprehensive technical review of research work, unanswered questions, and untried methods on smart antennas technology for wireless communication systems. This also examines most of the significant improvements in the field of smart antennas technologies and the related fields in wireless communication systems. An evaluation of the analytical techniques for the theoretical analysis of adaptive beamforming algorithm, level of the system performance optimization approaches has been highlighted. Performance realistic evaluation and implementation cogent parameters areas for the deployment of smart antennas on the performance system in wireless communication systems have been also examined.

Keywords: Antenna arrays, Beamforming algorithm techniques, Direction of arrival, Signal processors, Smart antennas techniques, Wireless communication systems

1. Introduction

For proper efficient performance of wireless communications, smart antennas play a vital role that cannot be overemphasized [1]. Therefore, wireless communications and smart antennas are combined especially in signal and data transmission [2-6]. Smart antenna technology is becoming interesting as the communication technologies are receiving dynamic change worldwide. One of the benefits of smart antenna technology is capacity rise [7-10]. However, Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) increment are reported in [1, 11, 12]. It increases the capacity of TDMA in three stretches while it increases CDMA five stretches.

Smart antennas can be defined as a system that combines series of antenna arrays with various units for the Adaptive Signal Processing (ASP) to be carried out in space and time. It can also be referred as innovative signal processing techniques which are implemented proficiently to use the directional information of wireless communication network users [1, 5, 6, 13, 14]. Owing to increase in total number of users along with new high bit rate data, researchers had predicted a massive upsurge in communication traffic that will be witnessed in mobile and personal communications systems [1]. The development is seen in second generation which will definitely be witnessed in the fifth generation (5G) systems. Smart antenna technology differs substantively in the midst of wireless communication uses in proposing the auspicious contemporary and forthcoming of empowering a sophisticated capacity in wireless networks [1, 10, 15].

As higher the signal impairments in wireless communication occur, the smarter antenna solutions are needed [1, 16, 17]. Spectral/user density enhancement can be achieved through the technology of smart antenna [5, 8]. Smart antenna techniques have ample research consideration, due to the utmost prospects for improved user density [1, 4, 17-19]. Smart antenna techniques offer a narrow beam configurations designed for transmitter/receiver (transceiver). In the Industrial Scientific and Medical (ISM) band frequencies of *2.4 GHz*, applied tapered beam antennas are be able to deliver *9 dB* of gain, and decrease interference to additional communication bustle off the sidelobes of the antenna beam patterns [1, 3, 8]. With the purpose of improving the performance of smart antenna process, effective design of beam formation pattern is vital depending on the subjected antenna considerations [16, 20-27]. They offer an extensive range of methods to increase wireless system performance [28].

Smart antennas array modifies its pattern with dynamism to regulate to noise, prying and multipath. It could be useful in received signal enhancement and as well as beam formation transmission. It puts nulls in the track of interferers by means of adaptive bring up to date of weights associated with each antenna element [1, 5, 6, 16]. Smart antennas can transform its radiation array through an in-house response controller despite the fact that the antenna system is functioning.

Smart antennas offer better capacity and performance advantages over ordinary antennas for the reason that they can be used for the perfect antenna analysis patterns for the fluctuating traffic or Radio Frequency (RF) environments in wireless network [1, 5, 6, 16, 24, 29]. Smart antennas can be distinctly demarcated as a method to Instantaneous Air Interface (IAI) using a Software Defined Radio (SDR). This technology uses various antennas, digital processors, and composite algorithms to adapt the transmit and receive (transceiver) signals at base station [30, 31].

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Smart antenna techniques is well suitable for the base stations on account of high system tricky situation and extraordinary power depletion. Therefore, smart antenna techniques have been applied to mobile stations and handsets [1, 6, 30, 31]. It nullifies nearly all the co-channel interference consequential in improved quality of reception and lesser dropped calls [8].

The signal processing in the smart antenna estimates the Direction of Arrival (DOA) [32-34] and formation of Adaptive Beam Forming (ABF) algorithm [8, 11, 35-38]. *Basha et. al.* [16] have proposed a beamforming using hybridization of soft computing techniques and later in terms of DOA. The DOA of smart antenna estimates the direction of interferer signals against the desired user [1, 33-37].

The objective of this article is to present a comprehensive technical review of the latest trends and to discuss the future aspects in the area of smart antennas. In the Section II, smart antennas history has been briefly viewed. The Section III highlighted some of the benefits of smart antennas in wireless communication systems. The various types of smart antennas and their principles with basic configurations have been discussed in the Section IV. In the Section V, novelty of diverse for antenna array configurations and performance improvements for smart antennas has been discussed. Modeling of RF security using smart antennas by *Oluwole* and *Srivastava* has been explained in the Section VI with the combining schemes. In Section VII, the effects of mutual coupling in smart antenna arrays has been explained, which is a major challenge in smart antenna arrays. Smart antenna systems for mobile ad hoc networks (MANETs) has been examined in the Section VIII. The Section IX, the open problems in smart antenna arrays has been highlighted for the researchers to examine. Smart antenna reconfigurability has been discussed briefly in Section X, while the proposed study by *Oluwole* and *Srivastava* has been clearly identified that surpasses the existing research output. Finally, Section XI concludes this technical review and mentioned the future prospects of smart antennas in wireless communications.

2. Brief History of Smart Antennas

The term Smart Antennas (SAs) came in to existence in early 1990s at the time of well built adaptive antenna arrays were used in the military applications to overwhelm interfering signals from the opponent, were carried out by a number of scientists into mobile communications [17]. As a result of the features of smart antennas, its technology was used in military communication systems such as radar, where narrow beams were used with the purpose of interference avoidance rising from noise and other jamming signals [8, 38]. In the last 15 years, this topic has acknowledged extensive attention essentially as a result of the propagation of mobile communication procedures [32]. Generally, smart antennas are used in fixed wireless communication systems as Wireless Local Loop (WLL) and in mobile wireless communication systems to improve coverage, capacity and spectral efficiency [5, 7, 8, 18, 29, 39]. Specially, in cellular systems, the use of smart antennas permits lesser cost placements with cells of reasonable enormous size. Encompassing the smart antenna outset, researchers operated on the technology to use it for individual communication engineering to allow more users in the wireless network by means of quashing interference [6, 40]. The introduction of very fast and low cost digital signal processors has made smart antennas practical for cellular land and satellite mobile communications systems [9, 41].

3. Background on Smart Antenna

This research offers a wide-ranging features, overview and futures of smart antennas for wireless communications, and their role in antenna communication systems. The background covers areas that comprises the foundation of the research work.

Shivapanchakshari and Aravinda (2017) review the significance of smart antennas in relation to wireless communication systems. The authors clarified various existed smart antenna techniques and methods. Smart antennas have the ability to present nulls in the direction of interferers through updating of the weights by adaptation. This is done so as to mitigate any interferences of signals. This section gives the conceptual description of the Smart Antenna (SA), types and techniques are discussed briefly, while the detailed explanation are given in the subsequent section.

At present the smart antennas are utilized in numerous communication capacities. Since the unadventurous theory, smart antenna is fundamentally categorized as Switched Beam and Adaptive Array system. The classification of switched beam system is: single beam directional and multi-beam directional antenna. Correspondingly, adaptive array system is taxonomy is: single user beam forming and multi-user beam forming.

One of the most important aspect of smart antenna is adaptive beamforming technique. This technique conglomerates the several antenna inputs from the antenna array with the intention of forming a constricted beams for individual users present in a cell. *Vijayan and Menon (2016)* discussed on the smart antenna with adaptive beamforming, and multiple access technique that can ensure the coverage without losing connectivity at long distance. The objectives of the authors was to find the Direction of Arrival of the signal received from the trawling container touching at a continuous velocity for adaptive direction-finding of the antenna beam. The direction of arrival parameter gives the phase and amplitude of the signal transmitted from the fishing vessel. *Oluwole and Srivastava (2018)* discussed adaptive beamforming as one of the radio resource controlling systems and define it as a process by which an adaptive spatial signal processing are performed on array of antennas. By the addition of the signals weights constructively in the preferred direction of signal, adaptive beamforming technique creates radiation pattern on antenna array thereby nulling pattern in the unwanted direction that is interference. These arrays are antennas in the smart antenna context. Adaptive beamforming are normally used to achieve spatial selectivity at transmitting and receiving ends. The authors used adaptive beamforming algorithms techniques (Least Mean Square and Recursive Least Square) for the smart antennas arrays. Uniform array of isotropic elements *M (10, 15, and 20)* were considered having their coordinate system in the direction of y. The spacing of the antenna elements are varied at d *(0.5λ, 0.6λ and 2λ)*. The angles at which the grating lobe appears, steering angle, and the antenna element's effect spacing on beamforming was examined.

Oluwole and Srivastava (2017), designed smart antenna to improve radiation in one direction and null out interference in other direction. This was realized by increasing the directivity of the antenna element which leads to gain in a specific direction. At high frequency, transmission of signals is characterized with impairments. The authors proposed and examined smart/ adaptive antennas array at terahertz (THz) frequency range, which was applied for far distance communications and far-field region of antenna. The adaptive/smart antenna array was appropriately operational in the range of *300 GHz to 3 THz* for wireless local area network (WLAN) applications that uses high-frequency (HF) radio waves.

4. Benefits of Smart Antennas in Wireless Communication Systems

More specifically, the benefits derived from a smart antenna system can be described as following three ways:

4.1. Schemes for Coverage and Capacity Enhancement (SCCE):

Smart antennas upsurges the coverage range and capacity of a wireless communication system [1, 5, 7, 42]. The coverage range is merely the range of likely communication between mobile and base station [31]. Its capacity is quantify by the number of users that a system can support in a particular area [1, 39, 43].

4.2 Range Extension

In thinly occupied zones, lengthening coverage is frequently imperative than increasing capacity. In such zones, the gain obtained by smart antennas can lengthen this range of a cell to cover a larger area.

The coverage area is the area where communications are needed mostly nearby the base station e.g. for standardized propagation area the coverage area is:

$$A_C = \pi R^2 \tag{1}$$

while the concentrated transmit/receive range is equal as a whole in azimuthal directions. Here A_c and R are the coverage area of the cell and maximum transmit/receive range, respectively. The rough estimate between coverage areas to antenna gain is derived from exponential path loss model:

$$P_r = P_t G_t G_r PL\left(d_0\right)\left(\frac{R}{d_0}\right)^{-\gamma} \tag{2}$$

where P_r is the power at the receiver. Rearranging Eq. (2) will give:

$$R = d_0 \left[\frac{P_t G_t G_r PL\left(d_0\right)}{P_r}\right]^{\frac{1}{\gamma}} \tag{3}$$

and from Eq. (1), the coverage area varies with antenna gain as:

$$A_c \propto G^{\frac{2}{\gamma}} \tag{4}$$

i. Capacity

It has a close relationship with spectral efficiency, in addition to the sum of traffic obtainable by respective user [18]. Spectral efficiency (channel/km^2/MHz) can be written as:

$$E = \frac{\frac{B_t}{B_{ch}}}{B_t N_c A_c} \tag{5}$$

where B_t is the total bandwidth of the system voice channels either in the transmit/receive mode.

ii. Intereference Reduction and Rejection

In places where is a large population, the capacity increase is paramount. Therefore, to increase the capacity, one must take interference reduction on the downlink and interference rejection on the uplink into consideration. Directional beams of smart antenna systems are normally used for steering in order to reduce the interference to the barest minimum. In wireless communication systems, one can experience interference to co-channel, provided that it is in the purview of narrow beamwidth of the smart antennas [31, 44, 45]. There is reduction of interference using smart antenna systems by nulls formation and by placing it in the interfering co-channel user's direction. Interference reduction and rejection can allow N_C to be reduced, increasing the capacity of the system. Also, the number of cells per cluster can be decreased, increasing spectral efficiency, and capacity [7, 18, 46, 47].

iii. Spatial Filtering (SF) and Intereference Rejection (IR)

In wireless communication systems, the application of smart antennas leads to spatial filtering achievement, thereby increasing the Signal Strength (SS) [1, 25-27]. Network capacity is increased by controlling the interference level received from other users and base stations [48-50].

iv. Great Sensitivity Reception

Initially, smart antenna systems were useful in the provision of range extension because antenna array has a directional gain. Assuming we have M antenna element array, each provides extra gain that are directional which is referred to as $D = 10\ log_{10}M$. Rural cells find the application useful provided they are needed in large areas coverage than in urban settlements.

v. Spatial Division Multiple Access (SDMA)

The process of separating signals by the application of smart antennas in wireless communication is referred as SDMA. This process lets various subscribers to operate at the same frequency and their signals are spatially separated at the base station [31, 51]. The process permits various users on the same frequency and slot in a CDMA systems and identical code in the same unit cell [11, 12, 52]. Hence, this process (Smart antennas processing for SDMA) produces equal spatial channels over a particular channel such as time, code and frequency in a conventional way.

The SDMA technology is compatible with most of the air interfaces. Therefore, modern wireless communications systems organize antenna arrays in SDMA configuration [39]. In this situation, at the base station will be an established communication between various users that are active in the cell, when the beams are directed to them and thereby null out any user that want to cause interferences in any form [30, 31, 53]. The system has two advantages: (a) the targeted users will have enough power in comparison with antennas that are omnidirectional and (b) the adjacent cells interference are decreased in that directions selected are the main target in the cells [54-57].

A. Multipath Mitigation (MM):

Wireless channels consist of various propagation path connecting the transmitter and receiver [58]. The signals received by the transmitter have several components that travel in various directions and path. Each multipath component arrives with a delay (depends on path length). This causes Inter Symbol Interference (ISI), and imposes an upper limit for data rate. For a multipath channel, the general problem to affect it is fading. To combat this fading, one can use smart antennas coding techniques. These two techniques are highly essential in combating fading, but smart antennas have advantages over coding [6, 59-61]. Due to several multipath components, one can experience different phases, hence a multipath fading. In space, at certain instances the various components in the channels always cancel one another. Therefore, at the received signal level, there are deep fades. Smart antennas are always using to mitigate ISI, fading, and Bit Error Rate (BER) reduction when there is occurrence of multipath fading. Least Squares Constant Modulus Algorithm (LSCMA) has the capacity to reduce BER [62-64].

B. Direction Finding (DF)

An interesting application of adaptive antennas is direction finding e.g. emergency 911 services. The geolocation techniques use direction of arrival and time differences in the received signal at multiple base stations to locate the mobiles [65]. The advantages of direction finding are highlighted as:

- Simplicity of inconsistency that might arise between the scarcity of resources in spectrum and radio communication.
- In contrast, due to smart antennas reconfigurability, they are mostly used in Multiple-Input Multiple-Output (MIMO) wireless system [18, 19, 66].
- Smart antennas are prominent tools for being used in the effective management of the physical layer when being referred to Signal to Interference plus Noise Ratio (SINR) at the receiver. The DOA algorithms are effective for tracking of user within a cell and smart antennas can track user within a cell via direction of arrival algorithms [6, 32, 67].

5. Types of Smart Antennas with Their Principles and Configurations

A smart antenna system performs the following three steps:

- The DOA of all the incoming signals including the interfering signals and the multipath signals are estimated using the DOA algorithms.
- The desired user signal is identified and separated from the undesired incoming signals.
- After that beam is steered in the direction of the desired signal and the user is tracked as that moves while placing nulls at interfering signal directions by constantly updating the complex weights [1].

However, the direction of radiation of main beam in an array depends upon the phase difference between the antenna elements of the array. Hence, it is possible to continuously steer the main beam in any direction by adjusting the progressive phase difference (β) between the elements. The same concept forms the basis in adaptive array systems for which the phase is adjusted to achieve maximum radiation in the desired direction (fig. 7).

In a beamforming network, the signals incident at the individual elements are combined to form a single desired beam formed output. Before the incoming signals are weighted they are brought down to baseband or Intermediate Frequencies (IF). The digital signal processor accepts the IF signal in digital format and then processed it. The processor interprets the incoming data information, determines the complex weights (amplification and phase) and multiplies the weights to individual element output to optimize the array pattern. This is based on a particular criterion, which minimizes the contribution from various noises and interferences while producing maximum beam gain at the specific direction.

As earlier defined in section I, smart antennas are array of antenna elements that has signal processing and combined in space and time. Processing of the signal spatially has an advantage during the design of the system. It makes provision for degree of freedom which helps to improve the system performance. Improvement in system performance helps to increase the channel capacity and spectrum efficiency. Therefore, the coverage range is extended via steering of multiple beams in tracking of mobile cells [14]. Smart antenna systems are frequently classified as switched beamer and adaptive array systems [6-8, 29, 40, 41, 68-70].

There are two well-known categorization techniques to implement smart antennas that dynamically change their antenna pattern to mitigate interference and multipath effects while increasing coverage and range. They are (a) switched-beam systems and (b) adaptive array system. Smart antenna array processing [6, 41, 42, 71-75] is based on the configuration of the spatial correlation matrix at the antenna array. In the design of smart antenna [43, 44, 76] techniques, system architecture, implementation and complexity limitations need to be considered.

A. Switched Beam/Lobe Systems

The switched beam system comprises a RF switch between discrete directional antennas pattern of an array which can be formed by beamforming network, while aiding high gain and controlled beamwidth [45-48, 77-80]. This approach can be considered as an extension of cellular sectrorization scheme [49, 50]. It has a number of fixed antenna beams covering various specific sectors. The system will turn on a beam towards a desired signal at a time in order to increase the received signal strength. If the received signal is changing direction or multiple desired signals exist, the system will turn on the appropriate beam, so that all the desired signals can be covered [51, 52, 81].

These systems consist of basic switching task between distinct directive antennas/array of antennas. It has a higher network capacity due to its development of antenna arrays and signal processing techniques to centre its energy in a specific beamwidth when compared to omnidirectional antenna. Due to its high directive beams, it chooses the beam which gives the best Signal to Noise ratio (SNR). In some recent researches, it has been verified that in Wireless Local Area Network (WLAN) access points can use switched beam for the extension of their network capacity [53, 54, 82-

85]. This approach is usually realized using passive feeding networks, such as Butler matrices. Various techniques have been proposed through research to reduce the sidelobe level in switched beam antennas are:

- *Chou* and *Yu* [55] have examined a switch beam in which the transmitting antenna switches beams to search for the receiving antennas from a spot to another as those conceptually introduced in the conventional far-field smart antennas. The author used one dimensional beam switching device in the antenna design with the other dimensions to ensure that focused fields are radiated in the designated near zone.
- The technique of increasing the number of radiating elements and using power dividers to obtain amplitude taper across the antenna array. This requires an increase of antenna aperture and consequently narrower beams are accomplished and there is a reduction in beam crossover.
- The technique in which two separate feeding networks are used for generating all beams, which results in the need of switching between feeding networks or doubling the aperture size [56, 86].

Switched beam antenna systems employ array of antenna which radiates some coinciding fixed beams that cover a selected angular space. Fig. 1 shows a beamforming network comprising of a phase shifting network, which forms various beams looking in a specific direction. The RF switch function as an actuator that activates the exact beam in the desired direction, while the control logic as a selector that picks the right beam. The control logic is controlled by algorithm that scans all the beams and chooses the one that receives the strongest signal centred on a measurement through the detector.

This switched beam approach is easy in operation nevertheless is not appropriate for high interference zones, but best suitable for zero interference environment. With the aid of multibeam feed networks (Butler matrix), one can have a beam switching antennas, but such a Butler matrix are large in size and lossy. Therefore we have more than portable smart antennas. Some of the approaches that utilize fixed phase shifting networks (Butler matrix arrays and Blass matrix arrays) are discusses as follows:

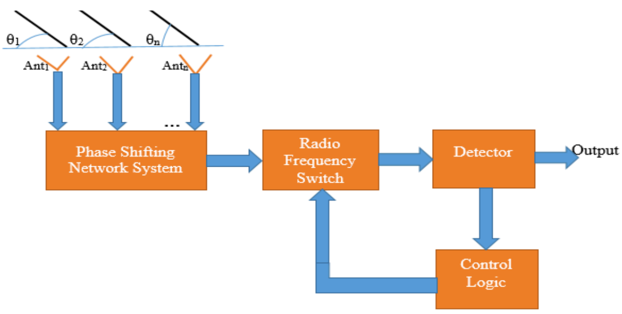


Fig. 1. Block diagram of a switched-beam antenna structures.

i. Butler Matrix Arrays

A Butler matrix consists of *N* multiple inputs and *N* multiple outputs [58]. Each of the input port will produce linear phase distribution at each output. In comparison to other networks, Butler matrix has advantages such as easier implementation with its hybrids and phase shifters than others switched beam networks. Therefore, the beam generated by Butler matrix is narrow and has high directivity also beam scanning continuity is realizable. Its amplitude/phase is accurate and high in operational, the matrix generated by Butler matrix can decouple orthogonal modes in a natural form, it has low insertion loss. Butler matrix techniques is used to provide the essential phase shift for a linear antenna array and to control the beamforming and beam steering process. The advantages of using the Butler matrix include frequency reuse and improved signal to noise ratio [49]. It is a beamforming network that uses the combination of 90^0 hybrids and phase shifters [10, 30, 42, 87].

The N x N Butler matrix is a passive microwave network consisting of *N* inputs, *N* outputs, *N* hybrids, *N* crossover to isolate the cross-lines in the planar layout and some phase shifters [52, 88]. To form multibeam radiation, the phase difference between antenna elements for *d*-spaced *N*-element array for the p^{th} beam radiation direction of θ is given by [2, 70]:

$$\mu_n = kd \sin\theta = \pm \frac{2p-1}{2N} \times \pi$$

A typical complete *8 x 8* Butler matrix array is shown in fig. 2. Exciting one of the input ports by RF signal, the output ports feeding the array elements are excited correspondingly although in a progressive phase between them. This gives the beam radiation at a particular angle. However, there is a need for multiple beams, two or more input ports needed to be excited instantaneously.

Earlier, various researchers proposed a beam-steering antenna array using a Butler matrix, which has an irreducible complexity [89, 121], while others have used Electromagnetic Band Gap (EBG) structures to produce reconfigurable agile antennas. However, reconfigurable EBG structures contain lots of active elements, which lead to higher complexity, supply, and cost.

Obviously, the major challenge of reconfigurable antennas resides in the number of active elements used in the design. The multiport network of Butler matrix is relatively bulky and intricate. It presents a multilayer *N x N* Butler matrix based on corrugated slot-coupled structures, which operates at UWB band (*3.1 GHz* to *10.6 GHz*) with excellent phase and amplitude performance, and makes use of highly optimized building elements (i.e. phase shifters and quadrature hybrids) with better broadband performance.

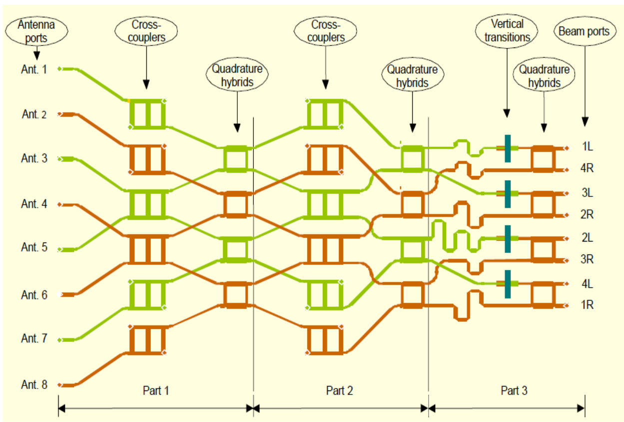


Fig. 2. Butler Matrix array [70]

ii. Blass Matrix Arrays

A Bass matrix consist of a microwave feeding network for antenna arrays comprising of a number of rows that are equivalent to the number of beams to be instantaneously created and a number columns joined to the radiating elements as shown in fig. 3 [30]. It is a very flexible beam-former, suitable for broadband operation. It has the capacity to generate random beams at random positions and in spite of random shapes. It is cheaper and has a low profile and has two sets of transmission lines.

The transmission lines are normally referred to as (rows and columns) matrix. The rows and columns matrix are traversed as each row and column crossover through a directional cross coupler. The corresponding feed lines must be ended on a matched load in order to avoid signals reflection due to the application of signals at each input port. The signals are propagated through the feed lines. The radiating elements are excited because at each crossover a slight percentage of the signal is coupled into each column. *Chen et. al*. [71] have demonstrated the principle of Blass matrix arrays using a double layer planar Substrate Integrated Waveguide (SIW). With SIW, slot array antennas were installed at the output ports of the upper radiating SIWs.

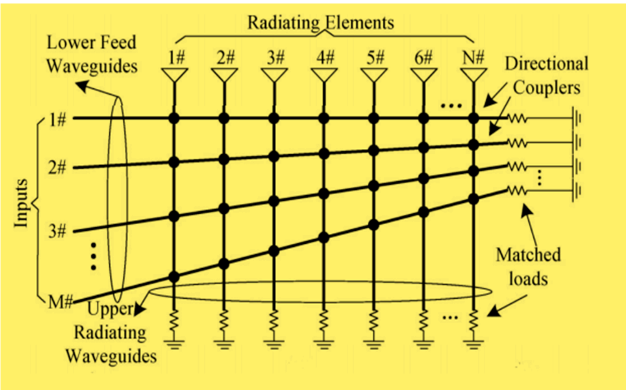


Fig. 3. Schematic of a Blass matrix [71].

B. Dynamically Phased Array (Direction Finding) Systems

In a phased array, the phases of the exciting currents in control of the beam steering in each of the antenna element of the array are adjusted to change the pattern of the array, typically to scan a pattern maximum or null to a desired direction. Phased array antennas make use of the Angle o Arrival (AOA) information from the desired user to steer the main beams towards the desired user [85, 92]. In this case, directions of arrival from the users are first estimated, and then the weights of the beamformer are calculated in accordance with the specified directions. For the signal received from the mobile subscriber (with DOA algorithm) this will enable continuous tracking of the user and it is obvious as generation of switched beam concept. The receiver power is maximized and it does not null the interference. Phased array using active array configurations can adapt the antenna pattern according to the change of mobile communication environment [62].

In an article by *Stine* [90] it has been concluded that an array of antenna elements can be pointed in a direction by changing the phase of the signals emitted from each element. Therefore, it arrives on the wavefront in the preferred direction at the same time. Thus constructively interfering in the pointing direction and destructively interfering in other directions. For the same elemental pattern, the power pattern of an array antenna is the product of the power pattern of the individual elements.

Electronically steered phased arrays have ability to generate a directive beam according to given control signal and possible multipath mitigation solution [70, 91]. The phased arrays have been developed for mobile stations in satellite communication system [40].

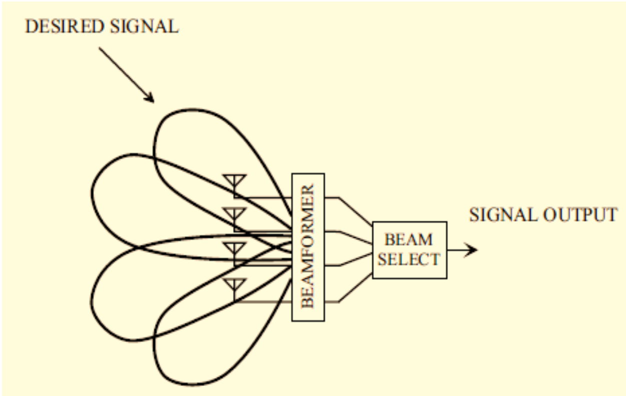


Fig. 4. Phased array [1].

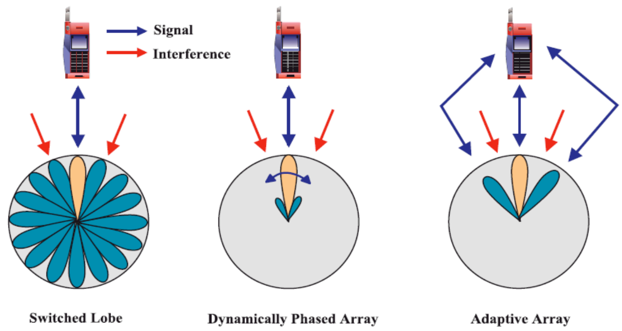


Fig. 5. Different smart antenna concepts [91].

C. Adaptive Array (Optimum Combining) Systems

The adaptive antenna is a core system component in future generation mobile networks due to its operational benefits by use of the spatial domain via adaptive beamformer [2, 93], and can also be referred to as digitally adaptive beamformers or adaptive antenna. In adaptive array systems to increase the capacity and the coverage to improve the link quality and spatial reuse, the signal processing methods are used. The beamforming and the DOA algorithms represent some examples in this area. Here, the beam pattern is adapted to the received signal using a reference signal e.g. to determine the direction of interferers. The beam pattern can be adjusted to null the interferers. The adaptive antenna is capable of increasing the reception of intended signals and suppressing the interference signals. This capability is achieved through algorithms that are able to locate the direction of both desired and interference signals. This information is then used to steer the main beam towards the desired signals and place nulls on the interference signals by an adjustable weighting set [48, 94].

Adaptive antennas have the capacity to separate the desired signals from interferer signals and external noise (filter antennas). This can be realized by radiation power in a precise direction and rejecting undesired signals from other incidence angles [92]. It has been presented by *Dietrich et. al.* [30] that the adaptive arrays provide a better range increase and the received signal quality than switched beam (multi-beam) antennas. Since switched beam antennas require less complexity, particularly w.r.t. weight/beam tracking, they appear to be preferable for CDMA [11, 91, 95]. In contrast, adaptive arrays are more suitable for TDMA applications, especially with the large angular spread. The adaptive array system is the smartest of the three techniques and characterizes the utmost advanced smart antennas method up to the present time. Using a diversity of state of art signal processing algorithms, the system tracks down the mobile user signals dynamically by steering the main beam radiated towards the user and simultaneously forming spatial nulls in the directions of the radiation pattern of the unwanted interference signal. This Technology is used to detect and monitor signals in heavy interference environments as in fig. 4.

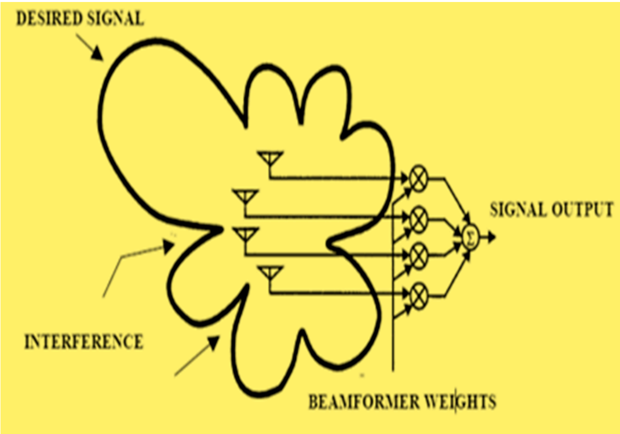


Fig. 6. Adaptive array [1].

Arrays are incorporated in the system like switched beam systems. Normally, the received signals from the individual spatially scattered antenna elements are multiplied by weights. These weights are complex in nature and have the capacity to change the amplitude and phase. A weight is normally assigned to each antenna array element amplitudes and phases, these are constantly updated/adjusted electronically to reflect/generate desired radiation pattern in response to the changing signal environment. This is done in order to increase the antenna gain in the desired direction while attenuating in the direction of the unwanted signals.

Both systems attempt to increase gain in accordance with the user's location. However, only adaptive system provides optimal gain with simultaneously identifying, tracking, and minimizing interfering signals. Switched beam and adaptive array systems have several hardware characteristics in common and are well known by their adaptive/smart signal processing algorithms capabilities (intelligence) [7, 40, 41].

The algorithm constantly differentiates between desired signals, multipath, and interfering signals in addition to the directions of arrival calculations. Adaptive arrays consist of adjusting beam pattern in multipath environments to use the SNR on the antenna array gain and nulling out interference in the direction of the signal [92, 96]. Due to the ability of adaptive array system to adjust the radiation pattern to the RF signal environment in real time, hence it provides more degree of freedom [1, 6, 11, 30, 97].

Fig. 5 shows the basic layout of an adaptive antenna array that has numbers of antenna array. The array of antenna elements are connected together through the controller to form a Beamforming network output. For a signal S of wavelength λ (plane wave) incident on an N element array with spacing d from direction (θ, φ), the phase shift due to propagation delay from the origin to element (x_i, y_i, z_i) can be expressed as:

$$\delta j = \frac{2\pi}{\lambda}\left(x_i \cos j \sin\theta + y_i \sin j \sin\theta + z_i \cos\theta\right) \qquad (6)$$

For the case of a linear array with elements equally spaced along the x-axis *(δ_x = d)*, the received signal at antenna element n can be expressed as:

$$x_n(t) = s(t) e^{-j\frac{2\pi}{\lambda} nd \cos\varphi \sin\theta} \qquad (7)$$

and the signal at the antenna array output is

$$y(t) = \sum_{n=0}^{N-1} w_n x_n(t) = s(t) \sum_{n=0}^{N-1} w_n e^{-j\frac{2\pi}{\lambda} nd \cos\varphi \sin\theta} = s(t) f(\theta,\varphi) \qquad (8)$$

where the term $f(\theta,\varphi)$ is the array factor. For a signal incident from direction (θ,φ), the phase of the signal available at each antenna element represents the *steering vector*. The set of steering vectors for all values of (θ,φ) is called the *array manifold*.

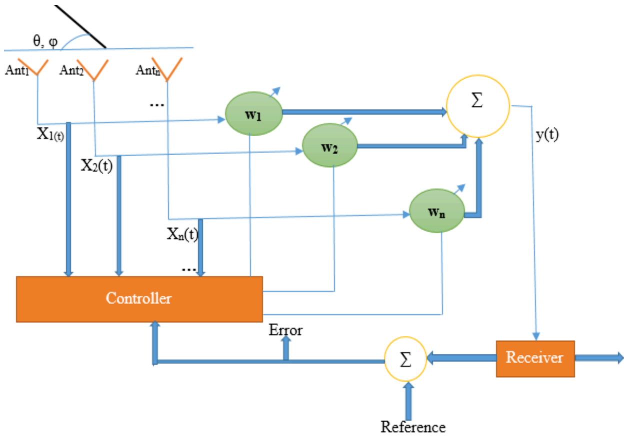


Fig. 7. Basic layout for adaptive antenna array.

By adaptive arrays system, the signals can be distributed through space (real time basis) by focusing the signal to the desired user and steering it away from other users occupying the same channel in the same cell and adjacent/distant cell. It has best performance out of the three types of antennas mentioned in previous sections. By directing the broadcast energy into a narrow beam one can achieved the increased gain, better range of signal path, reduced multipath reflection, improved spectral efficiency and network capacity. However, the disadvantage is the complexity of receiver, resource management and the physical size [7, 18, 41, 98]. In adaptive systems, pattern optimization is done by real time active weighting of the received signal and can adapt to changes in the radio environment.

A phase frontier is generated by a linearly changing the phase difference in the elements in the array which are combined to yield the array output. However, these weights are computed by adaptive algorithm (preprogrammed) into the DSP unit, which manages the radiated signal from the base station [30, 31, 99].

Adaptive antenna technology can dynamically alter the signal patterns near infinity to optimize the performance of the wireless system. These arrays use signal processing algorithms to continuously differentiate between desired signals, multipath, and interfering signals and calculate the DOA.

Moreover, switched beam systems offer limited performance enhancement as compared to the traditional antenna systems. Generally, greater performance improvements can be achieved by implementing advanced signal processing techniques to process the information obtained by the antenna arrays. Unlike switched beam systems, the adaptive array systems are really smart because they are able to dynamically react to the changing RF environment. They have a multitude of radiation patterns compared to fixed finite patterns in switched beam systems to adapt to the ever changing RF environment.

An adaptive array uses antenna arrays controlled by signal processing. This processing steers the radiation beam towards a desired mobile user and follows the user, and at the same time minimizes interference arising from other users by introducing nulls in their directions. These systems referred to as smart antennas. The processing is governed by complex computationally intensive algorithms [7, 9, 41, 100].

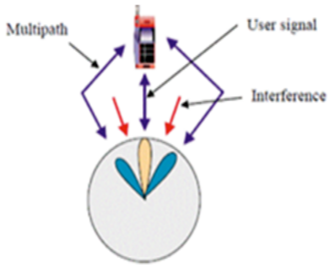


Fig. 8. Adaptive/smart antenna array [91].

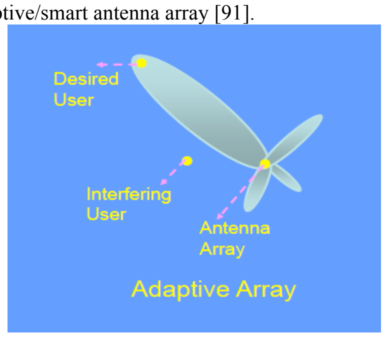


Fig. 9. Smart antenna array [91].

6. Novelty of Diversity for Antenna Arrays Configurations and Performance Improvements

Structural design of smart antenna system insight the research in signal processing and antenna technologies. This has led to a breakthrough for researchers in this area. This is popularly known as a *smart antenna divide* for the reason that is an arrangement of antenna arrays and signal processing algorithms. For smart antenna designers, a suitable smart antenna can be designed by first considering the arrays of antenna. The smart antenna arrays have the capacity to deliver signals from each antenna element to the digital systems for processing individually. The Digital Signal Processing (DSP) has no correlation to do with the individual antenna design, but has a special function in that the antenna modeling are sampling at each point in the spatial domain. This technique of smart antennas design is referred to as analytical method of smart antennas. Researchers had supported these techniques with remarkable results in the field of smart antennas and have been effective until now. The explanations of the systems are DOA rough calculation and astonishing accuracy beamforming systems, which make use of the developments in digital signal processing algorithms. Investigation into smart antennas has made antenna arrays processing [15] and DSP designate a special research interest. Most of the signal processing algorithms in smart antennas is used in the area of estimation of DOA and beamforming processing algorithms.

Table 1. Features of three main techniques of smart antennas.

Switched Beam Technique	Dynamically Phased Arrays Technique	Adaptive Arrays Technique
Fixed multiple directional beams and narrow beamwidths are used.	It can be used to steer arrays so as to increase its sensitivity in a specified direction.	It steers beam towards SoI and places null in the interference directions.
It needed a phase shifts in comparison to Butler matrix which are supplied by means of simple fixed phase shifting.	It is normally used so as to deliver diversity reception.	It requires implementation of DSP technology
Simple algorithms are selected for beam selection.	Its capacity to allow beam jumping within the juxtapose target happens in few microseconds.	Beam and null steering require complex adaptive algorithms.
In comparison with adaptive array, reasonable interaction is required the base station and mobile unit.	It has enough capacity to make available agile beam even under computer control.	It has a better advantage of increased capacity and coverage over switch beam systems because of improved interference rejection.
It is cheap and has low complexity in structure due to its low technology	Indiscriminately methods of surveillance and tracking.	It is difficult and expensive to integrate into existing cellular systems.
Simple and cheap to Integration into existing cellular system.	Its dwell time are free and eligible.	As the mobile moves, continuous steering of the beam is vital, as the mobile unit and base station needs constant contact.
Significant increase in coverage and capacity is provided in comparison with conventional antenna based systems.	It has multiple mode of function during its operation through the simultaneous emission of various beams.	Continuously adapting the pattern towards the optimal characteristic
Due to multiple narrow beams usage, frequent intra-cell hand-offs between beams have to be handled as mobile changes position from one beam to another.	Dynamically Phased Arrays systems have a constant operation despite even if there is fault in one of the components which reduces its beam sharpness.	Frequent intra-cell hand-offs are less due to continuous following of the mobile user.
It can neither distinguish between direct signals nor interfering/multipath signals, hence the interfering signal increases more than the desired signal.	It has a limited coverage area of 120^0 in azimuth and elevation angle, which is a disadvantage.	Multipath components can either be added or rejected through the delays correction so as to improve signal quality.

To advance in the effectiveness of smart antennas, there is prerequisite to implement it with the modern advanced efficient algorithms. The performances of smart antennas depend on the proper implementation of algorithms for DOA estimation and bam forming [11]. There are quite a lot of algorithms centered on diverse principles for bring up to date and calculating the optimal weights. The algorithms such as MUSIC [7, 10, 18, 30], Root MUSIC [16], and ESPRIT [10, 30], blind source separation, and SDMA [10, 30] have enhanced the capacity of cellular systems. To improve the performance of smart antennas, it is necessary to bridge the gap between the antenna design domain and the DSP domain. Hence, the journey of smart antenna techniques began and a large amount of scientific contributions have been published on numerous conferences and in peer reviewed scientific journals and books. Many researchers have investigated various techniques for improving the performance of the smart antenna arrays in mobile communication systems [15, 29, 40, 45, 57, 60, 61, 101]. There are various signal processing algorithms such as Least Mean Square (LMS), Recursive Least Square (RLS), Normalized Least Mean Square (NLMS), Fractional least Mean Square (FLMS) and Constant Modulus Algorithm (CMA), etc. The selection of step size is critical in LMS technique because this algorithm is prone to instability, if step size is not selected appropriately [76]. Some of improvement in these LMS algorithms is variable step size LMS algorithms [18, 24], variable length LMS algorithm [24], and transform domain algorithms [76].

The main functions of Smart antennas are: (a) DOA estimation and (b) beamforming [16]. The DOA is used to measure angle of arrival of the incoming signals. The purpose of the measurement of AOA in smart antennas helps in the delivery of necessary functionality and optimization of transmission/reception. The information received by the antenna array is passed to the signal processor within the antenna and this provides the required analysis. This is achieved through the direction of arrival algorithms. After the analysis of DOA and interfering signals, the control circuitry within the antenna is able to optimize the directional beam pattern of the adaptive antenna array to provide the required performance.

By the phased arrays, the direction of radiation of the main beam in an array is subjected to the phase difference between the antenna elements of the array. Hence, it is possible to continuously steer the main beam in any direction by adjusting the progressive phase difference between the elements. The power of smart antenna comes from the fact that it can steer and reshape its radiation pattern to maximize SNR or interference alleviation [16]. This is done electronically using beamforming algorithms without the involvement of the mechanical parts to steer the array [4].

Intrinsically, this section doesn't challenge to recapitulate the myriad output results in the areas of smart antennas that diverges from the statistical information theory to model operation, nevertheless, just to summarize some precise accomplishments the authors have confidence in predominantly noteworthy. For the reason that beamforming is realized through software, it is promising to examine a comprehensive range of beamforming algorithms devoid of the prerequisite to adapt the system hardware for each algorithm [25, 46, 47].

The recital developments on smart antennas rest on optimization of numerous groups of algorithms. To increase the competence of smart antennas, there is prerequisite to contrivance in approximately additional algorithms. The recital of smart antennas are governed by using the appropriate application of algorithms for DOA estimation and Beam-forming [6, 9, 29, 32-36].

A. Algorithms List of Improvements on Algorithms

Recently, there has been much interest on fast algorithms for the computation of the above transforms. The ESPRIT algorithm is one of the best algorithms for the investigation of direction of arrival [24, 62]. *Godara* [24] has designated practical circumstances for obtaining the information of DOA, the array reaction vector, or the position signal essential for the imaginable putting into practice of beamforming performances by means of an array. Nowadays various evolutionary optimisation methods are in used for electromagnetic such as: Genetic Algorithm (GA) [8], Particle Swarm Optimisers (PSO), Central Force Optimisation (CFO), Differential Evolution (DE), Ant Colony Optimisation (ACO), Taguchi Method [62], Biogeography Based Optimisation (BBO) and Firefly Algorithm (FA).

The optimal choice of the algorithm, which makes it promising, to stretch the optimal explanation is a decisive phase because that proceeds at the conjunction speed and the substantial incorporation complication. Therefore, contemporary study effort in this area is focusing on the following serious issues:

- The design and improvement of innovative smart antenna processing algorithms that permits adaptation to fluctuating proliferation and network state of affairs and robustness contrary to network deficiencies [6].
- The design and improvement of state of art smart antenna approaches for optimization of performance at the system level and apparent maneuver transversely diverse wireless systems and raised area.
- Accurate performance estimation of the recommended algorithms and strategies centered on the origination of precise channel and interference representations and the overview of appropriate performance standard and simulation procedures.

The investigation of the application, intricacy, and cost effectiveness concerns involved in recognition of the planned smart antenna performances. There are quite a lot of algorithms centered on diverse standards for bring up to date and calculating the optimal weights. The smart antennas algorithms can be categorized into following groups based on diverse methods.

i. Established on Adaptation

(a) *Continuous adaptation* – The algorithms centered on this method regulate the weights as the arriving data is check out and retain apprising it such that it joins to an optimum solution. This method is appropriate when the signal data are time fluctuating. These algorithms precise the weights as the received data are tested and constantly apprise them so that they unite at an optimal solution. This approach is suitable where the signal datas differ with time e.g. LMS algorithm, and RLS algorithm. Its principle for decisive the weight is centered on reducing the least square error (LSE) [45, 69-71].

(b) *Block adaptation* – The algorithms using this method calculate the weights built on the approximations acquired from a sequential block of data. This technique can be used in non-stationary environs on condition that the weights are calculated intermittently. These algorithms calculate the weights built on the evaluations acquired from a temporal block of data. This method can be used in fluctuating environs provided the weights are occasionally computed.

This algorithm necessitates the info of the preferred signal e.g. Sample Matrix Inversion (SMI) algorithm. In the SMI algorithm, the optimums weights are calculated by the correlation matrix and the cross-correlation vector by means of their balanced estimation [69].

ii. Established on Data Required:

(a) *Reference signal based algorithms* - These categories of algorithms are centered on minimization of the Mean Square Error (MSE) between the incoming signal and the reference signal. Consequently it is essential that a reference signal be accessible which has extraordinary correlation with the preferred signal e.g. LMS algorithm, RLS algorithm and the SMI algorithm. The LMS algorithm is comparatively simple, it neither necessitates correlation function calculation nor matrix inversions. The LMS algorithm errors are generally used adaptableness. The fastest adaptableness can be comprehended by means of sample matrix inversion methods.

The reference signal is not the definite preferred signal, in actual fact it is a signal that meticulously characterizes it or has robust correlation with it. In TDMA every single frame be made up of a sequence, which are normally used as a reference signal. In digital communication the synchronization signals can be used for the same purpose. The RLS is the paramount algorithm appropriate for anti-jamming uses and it frequently joins with instruction of enormousness more rapidly than LMS algorithm alternatively the disadvantage is the added complexity [45, 69-71]. Quite a lot of modifications of RLS algorithm are correspondingly recommended, one of which is Gradient based Variable Forgetting Factor (GVFF) RLS.

(b) *Blind adaptive algorithms* - These algorithms does not need any reference signal data. They themselves produce the requisite reference signal starting from the incoming signal to get the preferred signal [69] e.g. Constant Modulus Algorithm (CMA), MUSIC, Cyclostationary algorithm, and the Decision-Directed Algorithm (DDA).

The MUSIC algorithm for identifying the directions of the source signals dropping on the sensor array comprising smart antenna system has been used as the basis for assessing the DOA [8, 24, 36, 68]. The recital of algorithms to be precise, Direct Matrix Inversion algorithm (DMI) and CMA has the foremost advantage of simplicity with insignificant loss of precision. The ESPRIT and MUSIC algorithms are normally used for the estimation of direction of arrival. The methods have sophisticated resolution and precision. The simulation results presents that the recital of both ESPRIT and MUSIC have been enhanced with additional elements in the array, with enormous Polaroid of signals, and superior angular parting sandwiched between the signals. These improvements were comprehended in form of the high pitched in the MUSIC and lesser errors in angle detection in the ESPRIT. Definitely, MUSIC has extra stability, specific and delivered high resolution and this comprises innovative likelihood of user parting through SDMA. The MUSIC algorithm has been approximately utilized in mobile communication to measure the DOA of the arriving signals. From the point of view, it is conspicuous that it was extensively applied to evaluate the DOA. However, developing the algorithm for smart antennas design, more exact approximation is indispensable. Though, the conservative MUSIC algorithm aches for the reason that it lacks suppression in side lobes [16, 29, 68, 72].

Normalized Least Mean Square (NLMS) algorithm principle depends on reducing the MSE sandwiched between the output and reference signal. The algorithm regulates the step size in accordance to input signals, consequently it has improved performance of convergence and a reduced amount of signal sensitivity than conventional LMS algorithm [69-71].

The Genetic Algorithm (GA) is applied to the optimization of weighting elements and structure of smart antenna arrays [8, 44]. In ref. [8], smart antenna beamforming was demonstrated using a genetic algorithm. They proposed a hybrid technique for beamforming in smart antenna using interference, length of beam, number of patterns, phase angle, and gain. The hybrid technique includes generation of a set of chromosomes (i.e. position and phase angle for different angle) and to locate the beam pattern with maximum signal gain and phase angle of the antennas in a particular position.

Table 2. Research on Genetic algorithm

References	Main beam width	Minimum side lobe level	Directivity	Noise sensitivity	Robustness
Panduro, et. al. (Linear)	Yes	Yes	No	No	-
8	Yes	No	5		-
3	Yes	No	<3		-
4	Yes	No	<0.15		-
5	Yes	No	4.2-8.45		-
6	No	Yes	7.3-9.3		-
7	Yes	Yes	2.5-3.5		36.3-45.7%
101	-	-	-	-	-
Proposed (*Oluwole* and *Srivastava*)	Yes	Yes	9.5-10	Yes	52-60%

The proposed GA tagged by *Oluwole* and *Srivastava* [89] takes the following parameters into consideration in their research study output Main beam width, Minimum side lobe level, Directivity of 9.5-10, Noise sensitivity, and robustness of 52-60%.

7. Modeling of RF Security Using Smart Antennas

Smart antennas are applied in various areas of communications. One of its applications is in RF security systems reported by *Oluwole* and *Srivastava* [89]. The work introduces an analysis about how RF can be secured using smart antenna arrays. To receive radio signals, an antenna is required for signal propagation. Nevertheless, as the antenna will take up thousands of radio signals simultaneously, a radio tuner is indispensable to tune into a precise frequency. In the research analysis, three antenna elements array was used. The first antenna element is used for the transmission/reception (transceiver) of RF signal. The transceiver was purposely used for transmitting virtual information signal far away from the mobile station. (ii) The remaining two antenna elements at the mobile station are being used as descrambler against any illegitimate activities.

Wireless networks transmit their data at any layer of the open systems interconnection protocols stack using RF or optical wavelengths. Signal transmission through free space offers opportunities for interlopers and hackers that come from any direction. A foremost problem to secure communication systems is the probability of unlicensed penetration. The unlicensed penetration of this kind is popularly known as hacking. Numerous techniques have been employed to overcome the problem of hacking. This refers to a person/software that breaks into or interrupts computer systems or networks to manoeuvre data or generate havoc by uploading malicious code. HackRF provides an assessment equipment module for RF associated research and measurements which apply to a frequency range from *1 MHz* to *6 GHz*, and spread over many registered and unregistered as well as ham radio bands. Hacker may possibly target the RF modulation plane with customary electronic warfare, the objective could be congested with adequate RF power or echo attacks could possibly be used. Hacks could be away from modulation in binary level. This conveys that any signal received by the radio is sufficient to hack the system.

7.1. Smart Antennas as a Transceiver

Antenna arrays can be adopted in any wireless communication transceiver at communication base station that transmits/receives RF signals by means of a single or multiple antennas. The advantage of antenna arrays in such a communication station is responsible for the performance enhancements above the use of only one antenna element. These antenna enhancements comprise directionality, SNR, interference elimination for received signals, security, and decreased power transmitted signals requirement for the transmit power. Hence, antenna arrays could be adopted for signal transmission/reception.

The function of a transmitting antenna is to radiate the RF energy that is produced in the transmitter and channeled towards the antenna by means of transmission line. In this capability, the antenna performs the function of an impedance matching of the device to match the impedance of transmission line to that of free space. In addition, the transmitting antenna should target the most energy in sought directions and suppress the radiation in redundant direction. The transceiver comprises an array of transmit antenna elements. The array transmits antenna elements and the two other antennas connected to the main transceiver are used for the mode of the operation. Here in this research work, smart antenna is used for security purpose against any hackers on the RF transmission signals. The wireless transceiver antenna arrays is used for remotely transmitting information signal virtual to mobile station, while the two antennas at the mobile station is being used as descrambler against any criminal activities. The proposed block diagram for smart antenna RF security is shown in fig. 10. Transceiver uses antenna array for communicating in a cellular communication system with a polarity of mobile stations. Therefore, the antenna array of the transceiver is used in this research work to design and communicate with antennas at the mobile stations. When there is an attack on the RF, there will be signal alarm in the transceiver for remotely transmitting alarm information relative to mobile station.

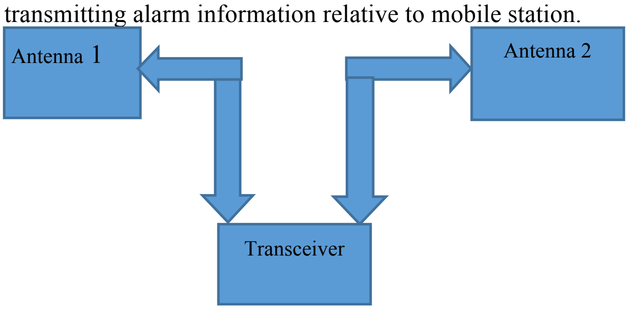


Fig. 10. Block diagram for RF smart antenna security system [89].

7.2 The RF Security Antenna Design

Most of the radio transceiver systems will have to a certain degree of related architectures and part common characteristics and difficulties. They all need some form of antennas, RF transmit and receive amplifiers, RF/baseband transmit and receive filters, transmitter and receiver modulation circuits and DSP, descrambler, frequency synthesizers and clock generators, and DC power supplies. All these are coupled together in figure 11.

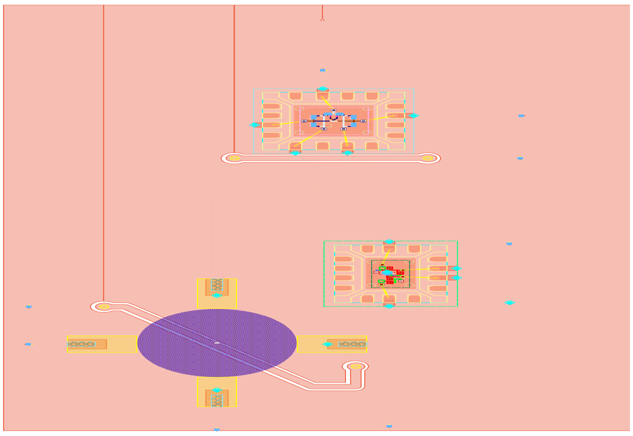


Fig. 11. RF board level smart antenna transceiver system layout [89].

The hacking prevention system works through a descrambler in the RF board level in Fig. 13. This is an electronic device that decodes a scrambled transmission, typically a radio signal, into a signal that is intelligible to the receiving device. This will make the radio or telephonic message impenetrable to hackers by analytically varying the transmission frequencies. A random number is generated in the descrambler. Using this random number, a key is calculated, which corresponds to the authorization packet corresponding to the generated random number. This generated key and the offset value, which corresponds to the generated random number, are used to calculate the descrambling key. The two antenna elements shown in fig. 12 perform the function of sensor networks between the transceiver and the outside world. Whenever there is an attack on the RF, an alarm switch included in the transceiver will indicate the presence of intruder/hacker on the system.

The transceiver comprises of an array of transmit antenna elements. The technique adopts the distant transceiver for signals reception when the central transceiver transmits downlink setting signals. When the focal transceiver likewise has a receive antenna array, the distant transceiver can transmit uplink setting signals to the central transceiver for decisive uplink identity/signature. The downlink and uplink identities/signatures are used to control a calibration task as a description for intruders/hackers in the successions that comprise the antenna arrays, and that facilitate downlink smart antenna processing identities to be driven from uplink smart antenna processing identities when the central transceiver includes channels for smart antenna processing according to identities.

Hence hackers can steal data/information on the transmitted signal. At frequencies outside the working range of frequencies, tracks and antenna elements do not behave as ideal elements. Fig. 13 shows the RF layout system for the work. The electronic antenna switch in the transceiver that links the antenna to the transmitter or receiver centered on the logic state of one or else two control levels. This switch was used to switch ON alarm system in the case of hackers/intruders. Immediately the alarm is ON, the transmitting signal will be blocked. This is similar to the case of loading a credit card on the telephone system. Whenever a wrong code is being sent twice, that line will be blocked. This will prevent theft/hacking on the system.

Fig. 12 shows the 3D EM preview of the designed fig. 11 before simulating using the EMDS simulator. This validated that the three dimensional design has been properly constructed.

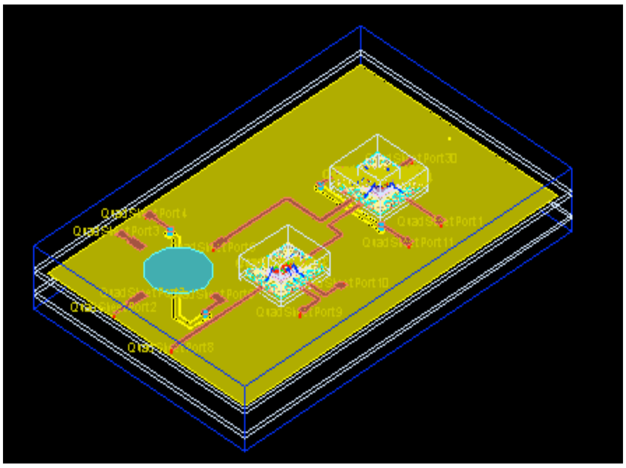


Fig. 12. Isometric 3D EM Preview of the designed Antenna [89].

Smart antennas combines the antenna arrays elements of the transceiver and that of the antennas at the mobile station for the optimization of radiation beam pattern, with smart signal processing algorithms used to recognize spatial signal identity/signature to track and identify whenever hacker wants to intrude on the transmitted signal. As the antennas at mobile stations communicate with each other using RFs between *1 GHz* and *7 GHz*, neighboring channels can only receive signal at frequency below *1 GHz* but not secured. If the neighboring channels receive signal at the specified/ designed frequency and hacking is ON, there will be no alarm in the system which are illustrated in fig. 13.

Research on smart antenna security is a new research in smart antennas, hence *Oluwole* and *Srivastava* [89] discovered on how smart antennas can be used for security against hackers as demonstrated in this and previous sections.

The diversity effect in smart antenna refers to the transmission and/or reception of manifold RF waves to increase the data speed as well as to diminish the error rate [6, 16]. Smart antennas employ two different combining schemes:

(i) Diversity combining (combines the signals from multiple antennas in a way that mitigates multipath fading, exploits the spatial diversity among multiple antenna signals, and achieves higher performance when multiple antenna signals are less correlated).

(ii) Adaptive combining (adjusts the antenna weights dynamically, suppressing interference signals, add multiple antenna signals, performs better for correlated antenna signals).

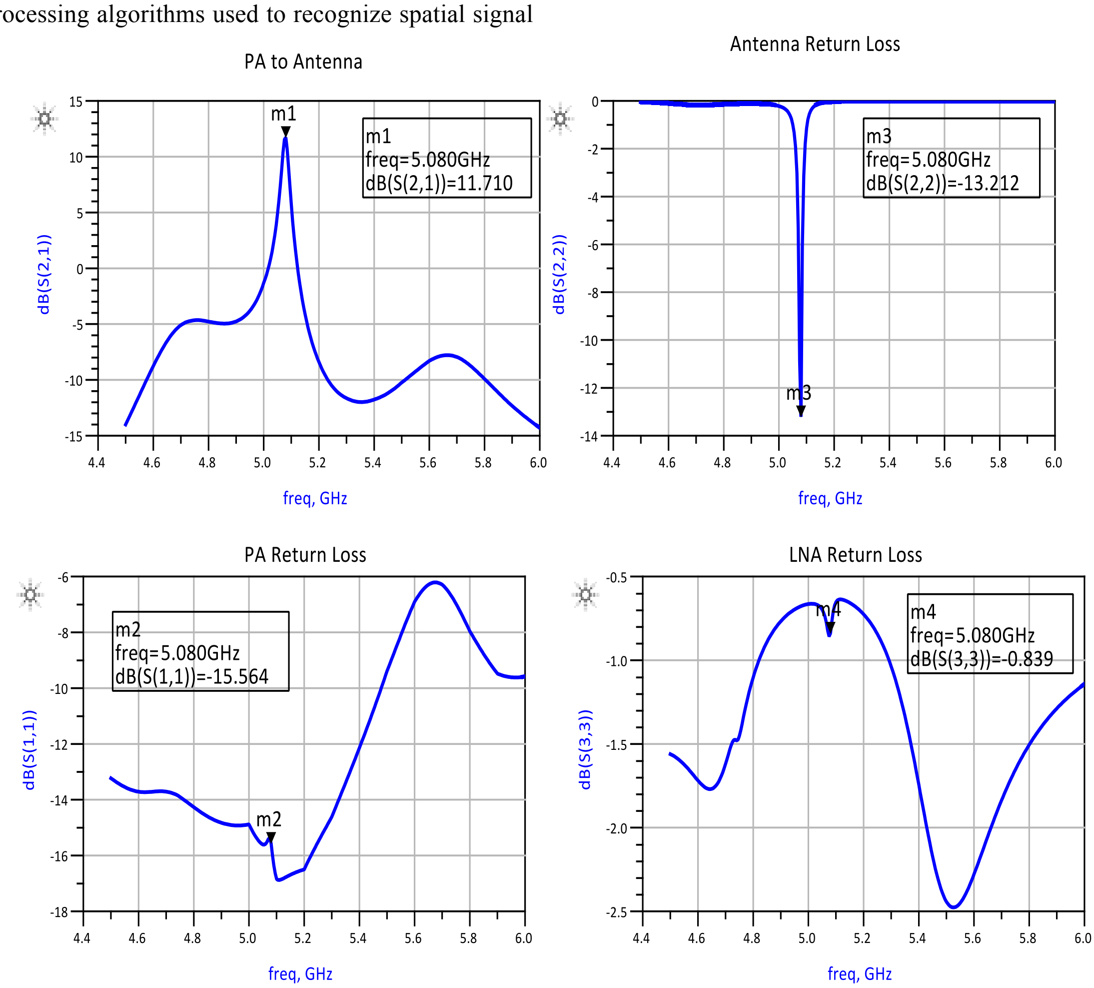


Fig. 13. Results of RF transceiver antenna [89].

Table 3. Research in security of Smart Antennas

Ref.	Problem Addressed	Outcome
89	Security issues in smart antenna	Discussed the challenges and solutions
38	Adaptive Beamforming algorithm method	Significant increased speed and improved reliability.
87	Application of smart antenna technologies in simultaneous wireless information and power transfer	Energy efficiency and spectral efficiency
46	Smart antenna system analysis, integration and performance for (MANETs)	Approaches to combat the effects of fading channels
14	DOA estimations using	Accurate DOA estimations using microstrip adaptive arrays in the presence of mutual coupling effect
45	Adaptive beamforming algorithms	Cancellation of multiple interference signals
69	Calibration errors and mutual coupling.	Statistical analysis of the beam pattern deviation for linear error

8. Effects of Mutual Coupling in Antenna Arrays

Theoretical array does't gives optimum array pattern synthesis performance. Practically, emphasis must be laid on the effects of system errors on antenna performance, for instance mutual coupling (which is an important electromagnetic characteristics between the antenna elements) [66, 93], cross correlation of the complex patterns, and signal's distortion on the circuitry of transceivers, affects the array gain, beamwidth, etc.

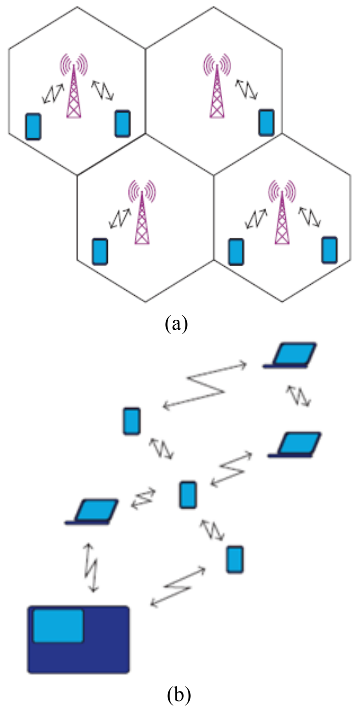
In a real antenna array, the antenna elements interact with one another electromagnetically and alter the currents and impedances from what would exist, if the elements were isolated. Mutual coupling effects between antenna elements in an array must be reduced because the existence of mutual coupling affects the performance of a smart antenna arrays when the inter-element spacing is greater than or lower than the half-wavelength, and also reduces the speed of its response [64, 94]. *Babur et. al.* [95] have analyzed mutual coupling effects and proposed adequate calibration on the beamforming transmit for the ideally orthogonal signals as well as for three typical space-time codes. *Abdala and Abdelraheem* [96] have analyzed the mutual coupling reduction between array elements by applying UC-EBG structure in between the antenna elements. The characterization of the EBG is prioritized, while the transmission coefficient from one element to another (with feeding the array elements individually) was examined separately. *Bernety and Yakovlev* [97] used a confocal elliptical metasurface cloak for the reduction of mutual coupling between neighboring strips of the dipole antennas located in close proximity to each other. The authors used a mantle cloaking method realized by conformal and confocal elliptical printed subwavelength structures in order to make resonating elements invisible. *Mikki* and *Antar* [98] analyzed a novel fundamental technique suitable for the analysis of near-field different from the previous perspective of far-field and circuit parameters were examined.

Mutual coupling are normally characterized by using the parameters such as mutual impedance, s-parameters, coupling matrix, or embedded element. Strong mutual coupling are experienced strongly whenever the arrays are able to scan its beam closely towards the end-fire direction [99]. With this, the steering vectors are bound to change. The change will cause inaccuracies in steering vectors of the antenna arrays. The performances of some adaptive nulling algorithms will be affected and also the estimation of the DOA [100]. It has a tremendous influence on the BER for the switched beam approach, hence reducing the system performance [46].

Various authors have analyzed the effect of short spacing between the transmitter and receiver and of mutual coupling and array manufacturing error on the estimation error [36, 37, 48, 59-66]. Their effects on DOA approximation were accurately addressed. It has been mentioned that the concentrated estimation error is contrariwise proportional to the distance between the transmitter and receiver and that the ranges and the standard deviation of the estimation errors can be reduced in the range of $0 < \theta_1 < 60^0$. Also, the mutual coupling and manufacturing error in the array antenna are the main causes of the estimation error in the DOA [24, 48, 59-62, 64, 65, 67] estimation experiment.

9. Smart Antenna Systems for Mobile *Ad Hoc* Networks (MANETS)

MANETs are the wireless networks where nodes can interconnect, whichever directly or indirectly deprived of any immovable substructure (fig. 14) [43]. Consequently, MANETs are predominantly imperative in locations, where the static substructure is not accessible, not confidential, too costly, or undependable. Characteristic presentations are vehicle to vehicle transport network, spare amenities in catastrophe situation (seismic activity, torrent, or fervor), strategic communications, and antenna networks [43].



(a)

(b)

Fig. 14.(a) Conventional cellular network with fixed infrastructure and (b) mobile ad hoc network [43].

The non-existence of a compacted mechanism tends to a self-organizing system functioning in a circulated method. Nodes that lie surrounded by each other's send collection can communicate unswervingly and are in control for dynamically determining each other. With the purpose of enabling communication between nodes that are indirectly are surrounded by each other's send range, intermediate nodes act as routers that relay packets generated by other nodes to their destination. Additionally, devices are permitted to link or leave the network and they may move randomly, possibly resulting in rapid and unpredictable topology changes causing link failure and the need of rerouting. In addition, mobile nodes typically work on batteries, hence have energy limitations, and exhibit great diversity in their range capabilities. To face these difficulties many research efforts have been done. In particular the use of smart antennas has emerged as an important area of research. [1, 9, 29, 43].

10. Open Problems in Smart Antenna Arrays

10.1 Research Gap in Adaptive Array Antenna

There are drawbacks in smart/adaptive antenna array. Implementation is one of the major issues in relation to higher complexity relating to design in smart antenna array. Research work in this area depends on specific estimation of channel besides speed of convergence in correlation to its beamforming technique. Therefore, implementation in MAC layer is difficult. The unsolved problem is its application towards cross layer.

Table 4. Effect of reconfigurability and number of antenna elements on smart antennas.

References	Polarization Reconfigurable	Beam Reconfigurable	Gain (dBi)	Antenna Element	Efficiency
10	No	Yes	6-7	-	≥70%
22	Yes	No	5	-	Not given
35	Yes	No	<3	-	Not given
49	Yes	No	<0.15	-	Not given
51	Yes	No	4.2-8.45	-	Not given
69	No	Yes	7.3-9.3	-	Not given
78	Yes	Yes	2.5-3.5	-	36.3-45.7%
Proposed: *Oluwole* & *Srivastava*	Yes	Yes	10.15-11.01	8	>77%

10.2 Insufficient Techniques in Multicarrier Systems

Multicarrier techniques are a promising area for researchers with respect to smart antenna. However, there are very few research and published works towards multiplexing techniques over wireless network.

11 Smart Antennas Reconfigurability

The reconfigurability characteristic of smart antennas differentiates it from the other antennas. Due to this, it can be applied in other areas such as MIMO. *Oluwole* and *Srivastava* have proposed a smart antenna with *8* element antenna arrays. The antenna elements are linear that consists of array of dipoles. The dipole antenna has a plane that is reflecting in nature. The performance characteristics of the smart antenna are achieved through the modification of sets of weights that are in array manner. The array weights have sets of electronic driven in form of vector modulators. The reconfigurable polarization and beam have been considered in this research work, while the gain and efficiency of the systems has advantages over the previous researched work.

12 Conclusions and Future Aspects of Smart Antenna

In this technical review article a synopsis for the advantages of utmost current progresses in smart antennas has been revised. The effective implementation of smart antennas depends on making an allowance for the specific features of the technology at an initial point in the design of prospect systems. In this analytical study, the utmost significant improvements in the study of smart antennas, for example reconfigurability to variable channels transmission and linkage situations, cross-layer optimization, and multiple-user diversity modus operandi. In addition, responsibilities such as the design of a suitable replication methodology and the exact validating of channel physiognomies, interference, and presentation losses have needed to be accessible in conjunction with flea market propensities, future projections, and the expectable profitable influences of smart antennas application. Furthermore, approximately imminent projections of different disciplines in smart antenna research are given and are highlighted in this manner.

- The knowledge of smart antenna is in performance a dynamic starring part in communication system. Smart antennas display numerous advantages in coverage development, statistics rate improvement, spectrum effectiveness improvement, interference decline, which determines the dynamic features in improved wireless communication.
- In areas of bandwidth, the ongoing research in this area by *Oluwole and Srivastava*, increases the performance of the antenna in terms of bandwidth, and looks into a way by which the quality and productivity which is vital to Orthogonal Frequency Division Modulation (OFDM). Consequently, this research will improve the efficient distribution of signal in OFDM systems.

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