

Review of Research Techniques to Improve System Performance of Smart Antenna

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Abstract

Today, the significance of the wireless communication is known all over the world. In order to achieve the better communication, many techniques and methods have been introduced. Among these techniques, smart/adaptive antennas are trending topic in the research domain. The smart antennas consist of various antennas arrays and have the ability to optimize the radiation and reception of the desired signals dynamically. Also, in order to avoid or mitigate the interferences, smart antennas can introduce nulls in the interferers direction by adaptive updating of the weights linked at every antenna element. The smart antennas can also enhance the quality of reception and reduce the dropped calls. This paper discusses the various survey topics related to smart antennas, Adaptive Beam Forming (ABF) algorithm etc. Also the various existing researches are discussed to know the research gap for future research scope.

Keywords

Smart Antenna, Switched Antenna, Adaptive Antenna, Beam-Forming Mechanism, Single/Multi Direction

1. Introduction

The wireless communication in today's generation plays an important role for communication. The growth in the use of wireless communication has led the demand of communication channels which can give improved spectrum utilization [1]. Thus, the smart antenna technology is widely used to improve the system capacity and performance. The signal processing in the smart antenna is meant to estimate the direction of arrival *i.e.* DOA and formation Adaptive Beam Forming (ABF) algorithm [2] [3]. The DOA of smart antenna estimates

the direction of the interferer signals against the desired user. This estimation helps to adjust the weights of ABF by which radiated power get maximized towards the respective users and also the radiation nulls can be introduced in the interference signals directions [4]. The ABF can enhance the significant signals and also suppresses the interferences by performing the spatial filtering over the array element. Later, the every array elements weight factor can be changed according to the change in the signal environment. At normal condition, the ABF technique will effectively suppresses the interferences without change in the desired signal [1] [2]. In case of mobile communication, users always demand the high speed data sharing and voice services. Also, the operator also supports higher number of users in each base station in order to downgrade the network cost and make the affordable services for the users/subscribers [1] [2] [3]. Thus it needs to have higher capabilities/data rate in the wireless system. The drawback with the existing broadcast spectrum is limited; the traffic is increasing exponential in the limited/fixed bandwidth that will degrade the system performance and signal quality. In case, uni-directional antennas are utilized at base stations, then the reception and transmission of every user's signals will generate interference for other users present in the same system and by which the entire system becomes interference limited [1] [2] [3] [4] [5].

The existing wireless modems implements DSP in the time dimension via modulation, equalization and advanced coding techniques. The advantage of the SAs is to integrate and also exploit the multiple antennas generated extra dimensions at the transceivers to increase the overall performance of the network. The smart antenna based systems use the modem that will combine the multi-element antennas signals both in time and space [4]. The smart antenna can be used for both receiving and transmission at base stations and the user ends. The implementation of smart antenna at base station is more significant as the practical requirements/constraints limits the use of multiple antennas at user end. The smart antenna is the combination of several radiation antenna elements area and the DSP in order to receive and transmit in adaptive manner [2] [5] and [6]. The term adaptively is used because it automatically adjusts the dynamic directionalities of the radiation pattern in response to the signal environments. The smart antennas are also commonly known as the adaptive antennas, by which the smart antenna can enhance the channel capacity, extends the coverage range [2]. A smart antenna is an array of radiating antenna (ARA) elements combined with DSP to transmit and receive in the adaptive manner [3]. Means, it adjusts the directionality of its radiation pattern automatically in response to the signal environment. *i.e.* adaptive array antennas. Thus smart antenna can enhance channel capacity, coverage range extension etc. [4] [5] [6] [7].

In this paper a subjectively and extended survey of existing researches are discussed. The paper discusses about the existing techniques to improve system performance of smart antenna. The sectional portioning of the paper is given as. Section 2 discussed the concepts relating to the smart antennas, Section 3 gives the essentials of coverage and connectivity in smart antenna, section 4 describes

the existing research survey, Section 5 describes research gap/research issues, Section 6 gives the future line of research, and Section 7 concludes the paper.

2. Background

This section gives the conceptual description of the Smart Antenna (SA), types, and techniques. The detailed explanation is described below.

2.1. Smart Antenna

Basically, a system with smart antennas exhibit number of antennas and also includes Digital Control (DC) system. The combination of the above gives the beam forming intelligence, thus the term smart antenna is originated. The addition of more number of elements in a smart antenna based system can bring changes in its physical system. Thus, because of composite system, antenna can perform shifting of signals before it gets transmitted to every successive element. The block diagram of smart antenna is shown in **Figure 1**, which consists of number of radiating elements, control unit, dividing/combining network. Based on the number of inputs the processor will control the feeder components of antenna and that optimizes the communication links. Thus, smart antennas are not just an antennas but acts as complete transceiver.

The smart antenna consists of set antenna components, which dynamically make changes in the antenna pattern to filter the interference, noise in the channel and solve the effect of the multipath fading over the interested signal. The smart antenna can receive and transfer the signals in both the spatially sensitive, adaptive manner. The smart antenna is effective due to combination of digital signal processing (DSP) software and antenna components. This combination enhances the performance/capacity in the wireless system. The smart an-

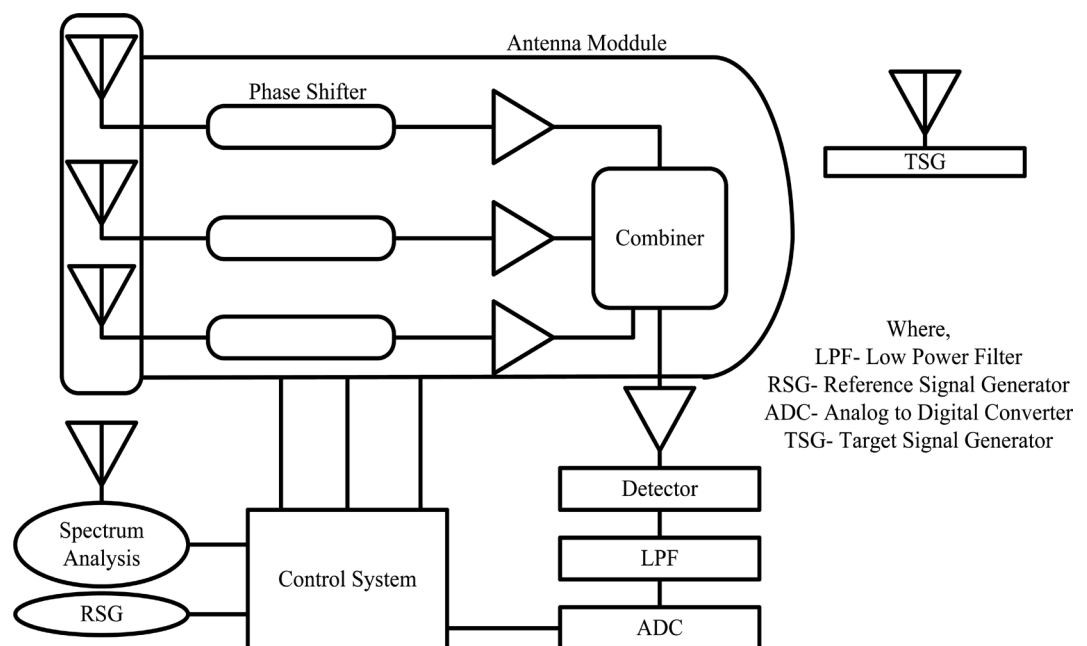


Figure 1. Architecture of Smart Antenna.

tenna mainly located at the base stations due to need of sophisticated DSP.

2.2. Types of Smart Antenna

Due to the system complexity and higher power consumption, the smart antenna mechanisms are mainly considered at base station. Currently the smart antennas are used in various communication areas. From the conventional theory, smart antenna is basically classified as Switched Beam and Adaptive Array system (Figure 2). The switched beam system is further classified into single beam directional antenna and multi-beam directional antenna. Similarly, adaptive array system is further classified into single user beam forming and multi-user beam forming. Basically, switched beam system uses only fundamental forms of switching between a priori array beams and discrete directional antenna. On the other hand, adaptive beam forming is used for assessing amount of signals being received by the user.

i) Adaptive Antennas (AAs)

These are the antenna arrays which dynamically changes the antenna pattern to control the interference, multipath and noise. The main functionality of these antennas is that it sets enhances the received signals and also generate the beams to transmit the signals. These antennas release the broadcast energy to the narrow beam which cannot found in conventional antennas. Based on the signal distribution in air, this antenna optimizes the real time based distribution to the desired user and avoids the other users to occupy the same channel in same/adjacent/distant cell [1]-[8].

The significance of AAs is that the generated antenna beams can adaptively tracks the signal direction, *i.e.* no other signals are included in the interferer direction. In AAs, there is no inter-cell issue is found due to continuous tracking of user. The AAs can enhance the capacity in greater extent than switched beam. The AAs can have extensive signal processing through DSP. The main drawback of these antennas is that the cost of installation is very high [8].

ii) Switched Beam (SB) systems

These kind of systems are formed by a switch function among the distinct pre-defined beams/directive antennas of an array. The point at which the top level performance can be achieved as receiver power is considered in SB systems. These antennas exhibit high directivity, which helps to achieve some gain [8] [9].

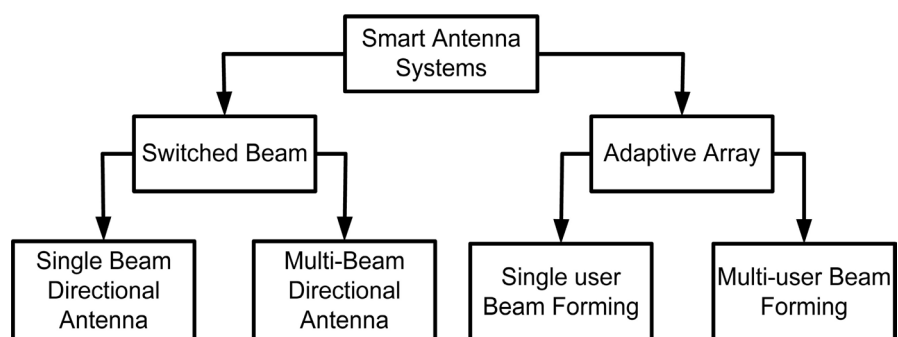


Figure 2. Types of Smart Antenna.

These systems can be implemented easily and the cost is low. Also, the system uses the algorithms to select the beam. This system needs only interaction among the base station receiver. The main drawback of this system is that the inter-cell interferences among the beams are needed to be handled and also it cannot mitigate the interference components of multipath near to the desired signal [10].

iii) Adaptive BeamForming (ABF)

The adaptive beam forming [11] [12] [13] (ABF) combines the multiple antenna inputs from the antenna array in order to form the narrow beams for individual users present in a cell. The beam former (BF) is also known as adaptive antenna. The beam former indicates the antenna capability (direct the flow of signals in a particular direction). In the **Figure 3**, P is the weight vector and it can be formulated by input $I(t)$ received through various antennas. The adaptive processor will then minimize the errors $Er(t)$ among the array output $y(t)$ and desired signal $ds(t)$.

The ABF needs a proper signal processing, which is more expensive as per the commercial applications point of view. The digital beam forming (DBF) in the wireless communication gives the complex digital data obtained through received signals. The advantage of the beam former is that it adjust the complex weights present at the output end of every array sensor and by which a pattern is produced which optimizes target signals reception at a particular direction with statistical sense. Also, the beam forming estimates the signal coming from the particular direction even at presence of noise and interference of co-channels.

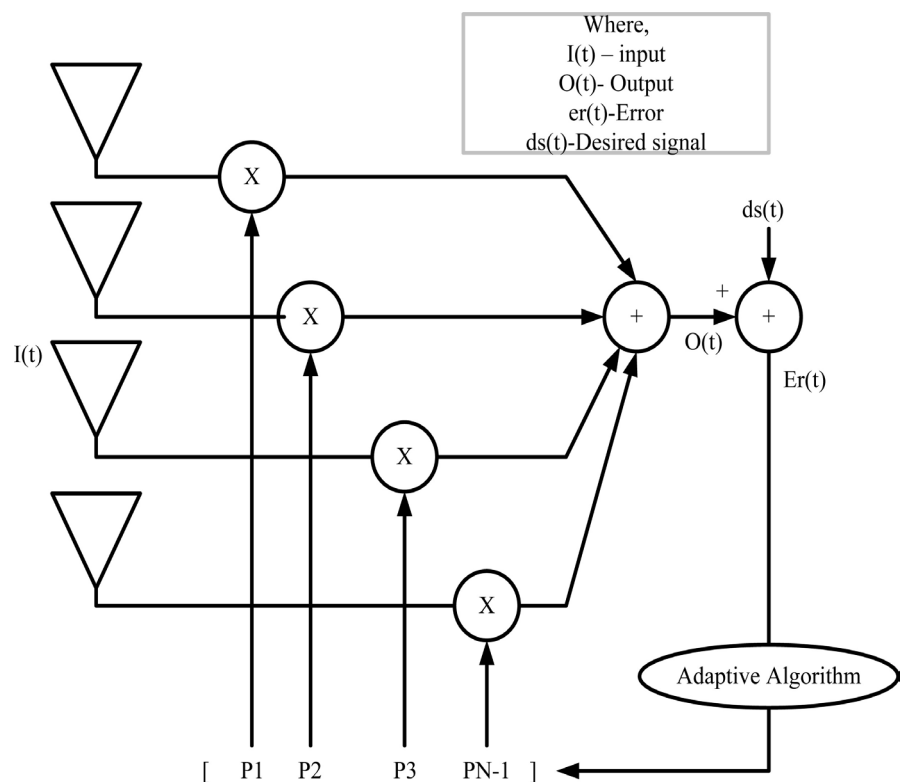


Figure 3. Adaptive Beam forming.

The ABF can be achieved with the advanced DSP and software's. The energy of an desired beam can generate the significant gain and facilitates the signal extension.

The main disadvantages of the narrow beam are that it faces interferences, allows more users in a same cell at same time and at same frequency. By implementing ABF, cell spectral efficiency can be multiplied up to ten-times. The traditional beam former steers the gain of an antenna in a particular direction of desired signal. There are two variety of algorithm which helps to achieve ABF. *i.e.* Recursive Least squares (RLS) and Least Mean Squares (LMS) algorithm.

- **Recursive Least Squares (RLS):** This adaptive algorithm, which provides the rapid convergence speed. This algorithm identifies the coefficients which minimizes the weighted linear least squares of the input signals. The input signals in this algorithm are considered deterministic and exhibits its significance in cost of computational complexity [13] [14].
- **Least Mean Squares (LMS):** This algorithm is presented in 1959 by Window and Hoff as adaptive algorithm. This algorithm uses the gradient based method to calculate the gradient vector of the available data. This algorithm consist an iterative process that brings the successive corrections in negative direction of the gradients with least errors. This algorithm is quite simple and doesn't need a correction functions or matrix inversion [13] [14].

The smart antenna based systems gives the following significances [11]:

- Enhanced coverage, Enhanced capacity
- Enhanced link quality, Enhanced data rate
- Low power consumption
- High sensitive reception, Reduced costs
- Suppression of Interference
- Lower absorption rate
- Enhanced spectral efficiency
- Reduced multipath fading

3. Existing Access Techniques

In modern communication system, there exist various access techniques and are explained as below and are given in **Figure 4** [1] [12] [14] [15].

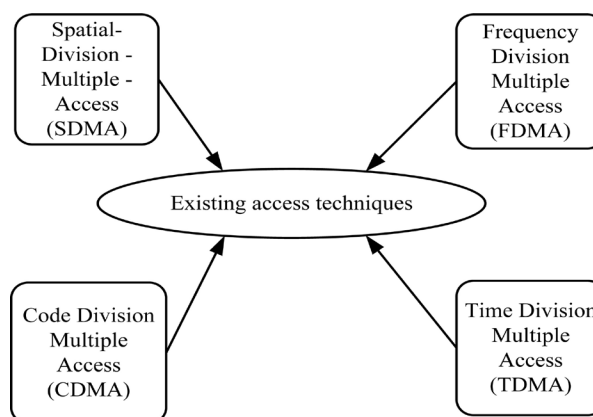


Figure 4. Existing Access Techniques.

3.1. Spatial-Division-Multiple-Access (SDMA)

In this access technique, the access is performed based on the direction of the entering signal. This method helps to enhance the capacity, reduce the interference and improve the entire link quality of wireless communication. This method ranges from the switched beam mechanism to adaptive antenna. The access method enhances the capacity and QoS in the communication network. By using this method several mobiles can be communicated in one base station at same frequency.

3.2. Frequency Division Multiple Access (FDMA)

In this access method, “the total bandwidth can be divided with number of simultaneous users, where each user can be allocated with a channel and bandwidth”.

$$i.e. \text{ User allocation} = \frac{\text{Total Bandwidth}}{\text{Users}}$$

3.3. Code Division Multiple Access (CDMA)

The development of these techniques was found in World War II, where the different countries military units started to search the effective technique to block the enemies’ radio signals by jamming. The technique spreads the energy of signal information.

3.4. Time Division Multiple Access (TDMA)

In this technique, the capacity of channel is can be used as much as possible and later the bit stream can be divided into frames and these frames can be divided as time slots allotted for each users. The system based with this technique uses only two time slots/frame for each user.

4. Coverage and Connectivity in SAS

The adaptive antennas can enhance the capacity and or connectivity area of wireless communication system. The coverage area in communication system is just the area where the communication among the mobile unit and the base station takes place [2] [7]. Correspondingly, there exist there exist three essentials respected to SAs such as, Interference mitigation, capacity and range extension and are explained as below.

4.1. Interference Mitigation/Rejection

In the populated areas, the enhancement of the capacity is major point. There are two main strategies to enhance the capacity *i.e.* Interference mitigation (at downlink)/rejection (at uplink). Thus, to mitigate the existing interference, the directional beam can be steered towards the mobiles while to reject the interference by forming nulls/directional beams at base station receives the antenna patterns at interfering direction of co-channel users.

4.2. Capacity

The capacity of an system is the spectral efficiency and also traffic offered by various users. The number of users which supported based on the traffic generated by various users and channels in each cell.

4.3. Range Extension

The extension of the coverage in the sparsely populated area is major issue than enhancing the capacity. In these areas, the generated gain of adaptive antennas can extend the cell range to cover the more users and large area than other antennas.

5. Literature Survey

This section incorporates with the existing researches in the field of smart antenna. There are various studies have been carried out and have given significant outcomes. In this various recently introduced researches related to Quality of Service (QoS), Routing, Energy Efficiency and security is discussed.

5.1. Research in QoS of Smart Antenna

A research of Jain and Agarwal [16] described the coverage and connectivity improvement concept in wireless communication using smart antenna system. It is mentioned that the researches in this field is more as the smart antennas offer better network performance. Author has mentioned that to attain the better network performance the network provider must need to calculate the gain for performance computation using propagation results of smart antenna. Authors have analyzed the performance of the proposed system and found that better coverage in cell area.

The collaborative work of Li and Wang [17] explains the QoS optimization in OFDM network for moving users by using semi smart antennas. It is observed that the most of the patterns may change on user movement. In order make better changes in qualified user's movement in pattern a periodic optimization (PO) method is introduced and achieved the same without excess triggering.

The work of Li *et al.* [18] have given a semi smart antennas implementation to optimize the radio resources in OFDMA network and offer a better quality of service. The semi SAs helps to solve the co-channel interferences in cell edge side and optimize the energy consumption. Author have used the system level simulation and analyzed the proposed system performance by which concluded that the desired throughput has achieved.

The work of Imtiaj *et al.* [19] described the performance analysis of the various ABF algorithms in smart antenna. The ABF algorithm in smart antennas gives null steering, maximum coverage, better system capacity giving enhanced QoS than other antennas.

The performance analysis study on WSN with smart antennas is presented in Skiani *et al.* [20]. The study mainly concentrated on the WSN issues like routing, QoS, interference, power consumption etc. The study analysis which described

in the test cases gives that with smart antennas 20% of QoS, 50% of efficiency and the power consumption is improved.

In order improve the QoS in vehicular communication by smart antennas optimization method is proposed in Constantinescu and Borcoci [21]. Author is focused on the issues related to the mobility management, scheduling tasks, neighbor discovery and interference range and also the base station issues like availability of bandwidth and coverage, velocity V_s throughput, availability/continuity of service. This study gives the desired research in vehicular communication.

The above research survey is summarized in **Table 1**.

5.2. Research in Routing of Smart Antenna

In this, the recent researches in routing of smart antenna are discussed. These researches are selected from the IEEE Xplore. A Diamond Shaped Mesh Network (DSMN) routing is illustrated in Bao *et al.* [22] with the cross layer design to attain the benefits of Multi beam SAs. This routing mechanism has two unique features like

- a) Cross layer design integrated with routing mechanism with multi beam smart antenna s.
- b) The routing is of diamond shape and impalements multipath routes.

The simulation is used for performance analysis and found that high throughput is attained. Author Cikovskis [23] have presented the cancellation of the interpath interference in wireless network by smart antennas. In order to avoid the data degradation by interferences, a smart way of routing and transmission mechanisms are needed to used along with the smart antenna. In this work author have used analytical method to analyze the performance of the smart antenna and found that the cancellation of interferences depends on the degree of antennas freedom used.

A multicast delay based routing algorithm is introduced in the work of Hung *et al.* [24] by using the smart antenna. In this smart antenna are used because of its reusability and low power consumption. The performance analysis gives that

Table 1. Summary of research in smart antenna for QoS.

Authors	Problem Addressed	Outcome
Jain and Agarwal [16]	QoS	Better coverage and connectivity with smart antenna
Cuthbert and Wang [17]	QoS	QoS without much triggering using semi smart antenna
Li <i>et al.</i> [18]	QoS and radio resources	Optimized resource usage and better QoS
Intiaj <i>et al.</i> [19]	Performance and QoS	Better QoS with smart antenna
Skiani <i>et al.</i> [20]	Performance analysis	Improved QoS, efficiency and power consumption
Constantinescu and Borcoci [21]	Issues and QoS	Vehicular communication, QoS enhancement factors

Table 2. Summary of research in routing of smart antenna.

Authors	Problem Addressed	Outcome
Bao <i>et al.</i> [22]	Smart antenna routing	High throughput and performance
Cikovskis [23]	Smart antenna routing	Better cancellation of the interferences
Hung <i>et al.</i> [24]	Smart antenna routing	Better throughput and optimization of power consumption
Loh <i>et al.</i> [25]	Smart antenna routing	High throughput and performance
Babu <i>et al.</i> [26]	Smart antenna routing	Enhanced performance compared to uni-directional antenna

that the algorithm with smart antenna gives better power consumption and throughput.

In Loh *et al.* [25] have given the concept of performance assessment of the adaptive routing in WSN by using smart antenna. The smart antenna in this performs the significant role in performance enhancement and power optimization.

Babu *et al.* [26] given the concept of enhancing wireless network performance by using cognitive radio with smart antenna. Authors have studied the performance of wireless network by using the smart antenna. The architectural design of proposed method with spatial selectivity allows the load sharing in various bands which increases throughput. From the analysis of the simulations, authors work found that the interferences occurred for the licensed users during the implementation of uni-directional antenna. These above literatures are summarized in **Table 2**.

5.3. Research in Energy Efficiency of Smart Antenna

This section describes the research performed to bring the energy efficiency in the smart antennas.

Hanaoui and Mounir [27] exhibited the idea talking about the directional correspondence with smart antenna to improve the power efficiency in wireless communications. Author makes a perspective of ground with hubs by utilizing Matlab. The author concluded with the significance of energy efficiency with smart antennas.

The work of Kristem *et al.* [28] gives the significant discussion regarding the selection of antenna to achieve energy efficiency in wireless communication. Author presents discussion regarding proper energy allocation, Symbol error probability at pilots and data, and optimal selection rule in time-varying channels for the two schemes.

The significant work of Zhu *et al.* [29], gives the energy saving mechanism called Transmission Mode (TM) selection in semi SAs. The proposed method is combined with the semi-SAs to attain energy saving. In this, based on the zooming scheme the identified transmission nodes were switched off/ sleeping mode without lowering the cell coverage. The optimization of TM mechanism to attain energy efficiency was defined and used generic algorithm to achieve the optimal solution. From simulation results found that the proposed TM selection

mechanism in network combined with semi-SAs can offer significant energy efficiency in network.

Later, the research towards the energy efficiency for wireless network with smart antennas in multipath environment is presented in Tang and Ramanathan [30]. Later, Adaptive Antenna (AA) array combined with Multiple-Input-Multiple-Output (MIMO) channel model used for wireless multipath environments. The study gives that energy efficient one hop multicast in such environment.

In Ayodele *et al.* [31] described the smart antennas analysis to improve the signal quality and also spatial processing. This research work focused on the smart antennas can optimizes the Signal-To-Noise-Ratio (SNR) of multiple antenna arrays in. In order to improve communication channel performance adaptively, a measure such as SNR and dynamic range need to be used. The proposed antenna arrays are adapted and aligned in magnitude and phase. These above literatures are summarized in **Table 3**.

5.4. Researches in Security Concerns of Smart Antenna

This section discusses the selected significant researches towards the security concerns, ABF in smart antenna. The research expressed in Yuanjian and Xiaohui [32] discusses the ABF method in SA system. This work illustrates a new ABF by analyzing and improving an algorithm based on projection of gradient vector. The proposed algorithm was implemented to a Uniform Linear Array (ULA) and its improved structure to compare its performance with that of the conventional LMS algorithm. The results obtained give the significances of the proposed method in performance and throughput wise. The discussion regarding security system modelling based on smart antenna is found in Oluwole and Srivastava [33]. This work uses three antenna elements array. (i) First element was used to transmit/receive the radio frequency signal. This transceiver used to receive also acts remotely to transmit information signal virtually to base station. (ii) The other two elements in base station were used as descrambler against any illegitimate activities. This work considers the imperative securities challenges such as authentication, attacks, privacy and secrecy. In the choice of frequency bandwidth for the transmission of signal, IEEE standard 802.11 designed for

Table 3. Research in Energy efficiency of smart antenna.

Authors	Problem addressed	Outcome
Hanaoui and Mounir [27]	Energy Efficiency	Significant energy efficiency with smart antenna
Kristem <i>et al.</i> [28]	Energy Efficiency	Good analysis for selection of antennas in wireless communication
Zhu <i>et al.</i> [29]	Energy Efficiency	Better network energy efficiency with semi-smart antenna implementation
Tang and Ramanathan [30]	Energy Efficiency	Better energy efficiency in MIMO network
Ayodele <i>et al.</i> [31]	Energy Efficiency	Proficient signal quality and interference rejection

Table 4. Research in security of Smart Antenna.

Authors	Problem addressed	Outcome
Yuanjian and Xiaohui [32]	Adaptive Beam-Forming method	Significant energy efficiency with smart antenna
Oluwole and Srivastava [33]	Security issues in smart antenna	Discussed the challenges and solutions

wireless system had been maintained. The work concludes an significant scopes of the security issues and solution to overcome. These above literatures are summarized in **Table 4**.

6. Existing Research Issues/Research Gap

From the prior section, it can be seen that there has been various forms and types of contribution from smart antenna in communication system. Majority of the existing research work towards smart antenna has addressed the problems that are closely related to problems associated with highly constraint channel capacity over mobile networks. Hence, we can represent the significant contribution of smart antenna is to assist in enhancing the performance of the system over maximized capacity of channel as well as to improve the spectral efficiency along with explicit enhancement towards coverage. We have also seen that two categories of smart antenna *i.e.* switched and adaptive antenna has also special contribution towards energy efficiency, QoS, system performance etc. Apart from this, significant issues, there are various significant open research issues pertaining to smart antenna.

6.1. Open Problems in Adaptive Array Antenna

Although, we speak highly about adaptive array antenna, however, it is potentially shrouded with pitfalls. The first problem in using adaptive array antenna is its implementation issue which is associated with higher complexity with respect to design. Moreover, such forms of research work have heavy dependencies over precise estimation of channel as well as speed of convergence related to its Beamforming mechanism. Hence, adoption of adaptive array antenna has definitive problems towards implementation in MAC layer. Therefore, applicability of different forms of smart antenna towards cross layer is a significant problem that is still unsolved.

6.2. Lesser Techniques towards Multicarrier Techniques

There is comparatively lesser number of studies towards multiplexing techniques over wireless network. For an example, Orthogonal Frequency Division Multiplexing (OFDM) is one of the dominant techniques used in 3G and 4G network and a variant of it is also a part of investigation in 5G networks. In reality, there are very number of research journals (only 8 journals published in IEEE Xplore since 2010) towards such forms of multicarrier technologies with respect to smart antenna. It is in a very nascent stage of research.

6.3. Ineffective Test-Bench

It has been observed that majority of the research work carried out in smart antenna has used simulation based study and less number of investigations towards real-time implementation. Although, there is nothing wrong in performing implementation using simulation based study, but existing research work has failed to prove its applicability towards real-time usage. There is not a single benchmarked studied using simulation-based approach posing threat to internal validity.

Apart from this, the existing researches focused on the smart antenna are failed to give the efficient smart antenna system and faces some of the following issues. For the diversity, there is need of multiple antennas at the terminal end. Many of the researchers are thought that adaptively combining the signals of antennas rather than using not blocked antennas. The use of multiple antennas significantly increases throughput in existing system; however it also increases the power and also decreases the quality of communication performance.

7. Conclusions

The technology smart antenna is playing a vital role in wireless communication. The smart antenna exhibits various benefits in coverage enhancement, data rate enhancement, spectrum efficiency enhancement, interference reduction, which are all the vital factors in better wireless communication. In this paper, we have discussed the significant factors related to the smart antenna, adaptive Beam Forming algorithm, issues, techniques etc. Also, a section with existing research work is described with different areas of interest in smart antenna. A research gap is included which gives a significant factor to future research interest.

The bandwidth, system performance, signals quality and efficiency are the major concerns in the futuristic wireless communications (OFDM). Thus, the technology like smart antenna and allocation of resources adaptively are used to bring effectiveness in the OFDM systems. But the implementation of ABF can introduce the complexity and by which resource allocation may altered/get affected. Thus, there is a need of proper resource allocation system with smart antenna, which can bring effectiveness in the QoS and reduce the complexity in the allocation.

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