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Review of Smart Antenna Approaches in Wireless Systems

C. Anand

Department of CSE, K.S.R. College of Engineering, Tiruchengode, India

E-mail: anandsione@gmail.com

Abstract

Wireless mobile communication is one of the rapidly growing fields of Information and Communication Technologies (ICT). The adoption of smart antennas will also minimize the cost. The success of smart antennas relies on two phases: In first phase, the features of smart antennas should be considered in design phase of next-generation wireless mobile communication systems. In second phase, the performance of smart antennas should be analyzed according to crucial parameters that satisfy the requirements of next-generation wireless mobile communication systems. The proposed research study summarizes the concept and types of smart antennas. Further, the most recent innovations in smart antenna domains such as varying network conditions, coverage & connectivity, Quality of Service (QoS), energy efficiency, routing are discussed.

Keywords: Smart antenna, wireless mobile communication, beamforming, direction of arrival (DoA), adaptive antenna, spectrum allocation

1. Smart Antennas

From past decades, antenna plays a crucial role in the civil and military applications by serving as a transducer to convert the guided waves of radio systems into free-space waves. The antenna systems employed in traditional wireless systems are omni-directional antennas. In recent years, smart antenna technologies are emerging as a viable solution to enhance the next-generation wireless communication system. Smart antennas are mainly employed to minimize the system-level requirements by increasing the overall performance of the communication system [1]. The smart antennas have become one of the significant technologies to attain higher efficiency in wireless communication systems. Smart antennas have gained an increasing research interest due to its ability to adjust the network interference

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and target the end-user [3]. Smart antenna technology has recently made a significant impact on the quality optimization, network configuration and transparent operation, and spectrum efficiency.

2. Background

Smart antennas were initially developed for military applications. They are initially used to eliminate the interference signals. Smart antennas will often appear as a multi-beam technique, which leverage its performance mainly in CDMA, FDMA and TDMA networks. The major difference between smart antenna and traditional reconfigurable antenna is the inclusion of antenna array instead of single antenna element [2]. Figure 1 shows the first developed smart antenna architecture.

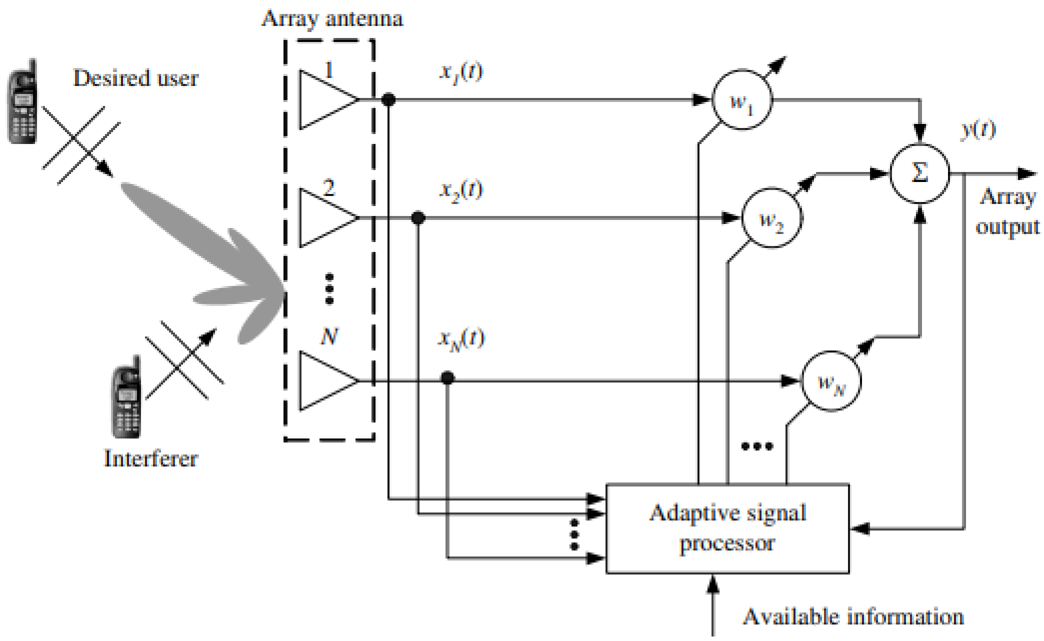

Figure 1. Smart Antenna Architecture [5]

Smart Antennas are currently implemented in a wide-range of wireless communication applications. Based on the antenna theory the smart antennas are generally classified as switched beam and adaptive beam array. Further, the switched beam is divided into two different types as unidirectional antenna and multi-directional antenna. The adaptive beam array is further differentiated into two different types as single-user based beam forming and multi-user based beam forming. The switched beam type utilizes the switching mechanism between general array and discrete array, whereas the adaptive beam array involves in assessing the received number of signals [6].

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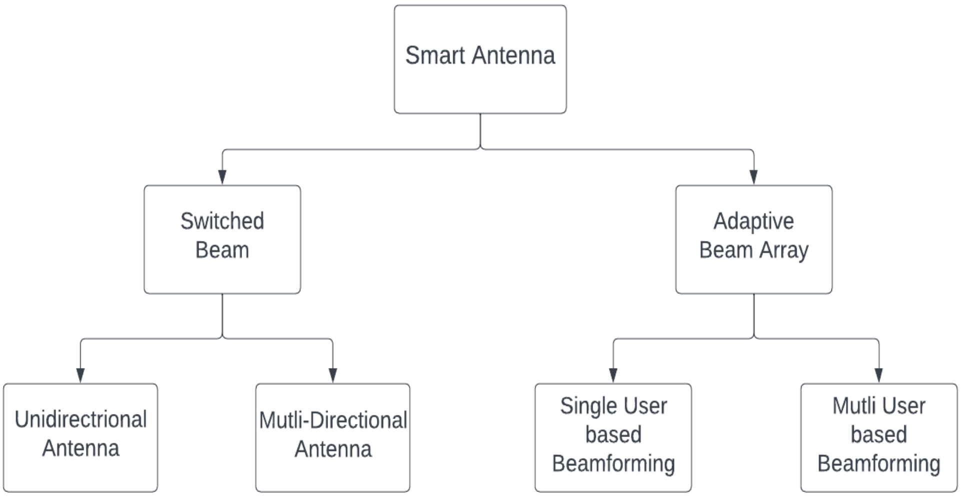

Figure 2. Types of Smart Antenna

3. Smart Antenna Approaches

The primary objective of smart antennas is to identify the spatial characteristics, which plays a major role in calculating the beamforming vectors to locate the target antenna beam. As discussed in section II, the smart antennas have two main approaches based on the radiation pattern, they are

- Switched Beam Approach
- Adaptive Beamforming Approach

While utilizing the spatial characteristics, there are some instances where the signal of interest cannot be indicated accurately as represented in fig 2(a). In such cases, the adaptive beam pattern is used by altering the antenna elements into an adaptive system to offer beam formation in all the directions by defining the Signal of No Interest direction to reduce the antenna radiation in undesired direction as represented in fig 2(b). Smart antenna systems are highly used in the real-time applications such as RADAR, cellular communication (LTE, 5G) and acoustic signal analysis.

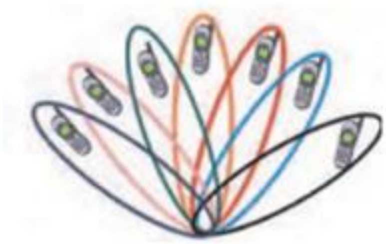

Figure 2(a). Switched Beam Approach [4] **(b).** Adaptive Beamforming Approach [4]

The major advantage of smart antennas is its ability to gradually increase the number of usable signals and decrease the signal interference. Smart antennas can remove the background noise by clearly transmitting and receiving the critical signals. The major challenge observed in smart antennas is its data learning and analysis process.

4. Related Research Works on Smart Antenna Systems

Smart antennas has the ability to enhance the network connectivity and channel capacity of wireless mobile networks and communication system. Smart antennas extend the network coverage among base station and mobile units by incorporating multiple antenna elements. The proposed study has discussed about the challenges and opportunities with respect to the following parameters:

1. Coverage and Connectivity
2. Quality of Service
3. Energy Efficiency and Routing

4.1 Coverage and Connectivity

The increased coverage and communication range is the most notable advantage of smart/adaptive antennas. The beam forming or antenna array gain of smart antennas represent the gradual increase in receiver-end signal power by developing an intelligible combination of signals from multiple antenna elements [7]. Further, it proportionally scales to the total number of Rx antennas by leveraging an extended battery life [9].

While sampling the smart antennas based on spatial domain, different signal diversity forms are obtained viz. spatial, temporal, code and frequency. The higher-order spatial diversity is equal to the combination of the number of transmitting and receiving antennas. The multiple transmitting antenna diversity is achieved by implementing a novel coding and modulation schemes [8]. The receiving antenna diversity is achieved by implementing an arrangement of independent signal fading dimensions.

The diverse smart antenna gain is achieved by obtaining the independent duplications of the antenna signal by fading the signal components independently [10]. Based on the probability, at least one or more than one components will not remain in the deep fade, the existence of more independent signal dimensions will reduce the antenna signal fluctuation effectively.

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Table 1. Coverage, Localization and Connectivity in Smart Antennas

References	Problem Addressed	Technique used	Outcome
Jeng et. al [7]	Coverage	Coverage probability Analysis	Extended the maximum transmission range
Thi et. al [8]	Localization	Smart Switched Beam Antenna	Developed Low-cost and simple localization system
Yuchen et. al [9]	Coverage	Self-Sensing Smart Antenna	Flexible radio wave coverage based on the user position
Anupama et. al [10]	Deep fading	Tchebysheff based antenna array distribution	Reduced antenna side lobe and beamforming level for different fading conditions

4.2 Quality of Service (QoS)

The main challenges associated with designing a communication link for smart antenna is to consider the inherent characteristics of the implemented network and also to design develop and implement required QoS for the traffic flow. The adoption of smart antenna beam forming techniques enables a significant reduction in the use of network resources for each individual transmission by employing angular separation of different flow paths. This effect is predicted to boost network throughput. The recent research works proposed in this domain are:

Li et.al have implemented smart antennas for optimizing the OFDM network's radio resources in order to deliver an enhanced Quality of Service (QoS). Smart antennas implemented in this network also assists in eliminating the co- and inter-channel interferences. From the simulation results it is evident that the desired output has been obtained by using the smart antennas [11].

TG et. al [12] have utilized smart antennas and adaptive resource allocation method along with the OFDM systems to fulfil the futuristic wireless communication requirements by reducing the network complexity. The proposed work satisfies the QoS requirement of different users by considering different performance metrics such as delay, bit rate, and data traffic. In the case of OFDM, the adaptive beamforming method causes difficulties in constructing the medium access layers by making the adaptive resource allocation as a more complex process. Hence, Kim et. al [13] have utilized different smart antenna mechanisms to meet the requirements of various users in terms of Quality of Service.

In order to improve the QoS in V2X applications, a smart antenna array with high antenna gain and targeted selection of transmission direction has been used by Ubler et. al [14]. An analysis has been made to increase the transmission distance and also the proposed smart antenna has implemented an automatic switching mechanism based on the geo-location information. From the simulation results it is evident that the smart antenna array has established a robust and efficient communication link with an increased transmission distance.

Table 2. Quality of Service and Application based Challenges in Smart Antennas

References	Problem Addressed	Technique Used	Outcome
Li et. al [11]	Quality of Service and Radio Resource Utilization	Smart Antenna Systems in OFDM Network	Eliminated co-and inter-channel interference
TG et. al [12]	Quality of Service	Smart Antenna based adaptive resource allocation	Reduces communication network complexity
Kim et. al [13]	Quality of Service	Different smart antenna mechanisms	Removes the complexities in constructing medium access layers
Ubler et. al [14]	Quality of Service Challenges	Smart antenna array targeted transmission direction selection	Automated switching based on geo-location

4.3 Routing Mechanism and Energy Efficiency

Luis et. al [15] have observed the potential of implementing smart antennas in the routing mechanism of WSNs and developed a location based routing protocol by utilizing the smart antennas to estimate the position of wireless sensor network nodes and deliver the routing decision and node position to the base station. The incorporation of smart antennas have greatly eliminated the network control overhead.

When it comes to multi-hop wireless networks, different challenges are observed in terms of energy efficiency and routing control overhead. To overcome this, Osama et. al [16] have discussed about the directional routing schemes in order to enable advanced network optimization and solve the emerging beamforming challenges.

From the perspective of energy efficiency, the wireless mobile networks are highly limited due to the network interference constraints. Hanaoui et. al [17] have integrated smart antenna systems in wireless mobile networks to improve the system capacity, power control and Quality of Service (QoS). The authors have compared the smart antennas' performance with omni-directional antennas and found that smart antennas have established a better communication channel between mobile sensor nodes. Further, Hailu et. al [18] have proposed an energy efficient MUSIC-RLS based DoA estimation and beamforming techniques to reduce energy consumption during beamforming process by generating narrow beam with reduced side-lobe level.

Table 3. Routing and Energy Efficiency in Smart Antennas

References	Problem Addressed	Technique Used	Outcome
Luis et. al [15]	Routing & energy restrictions	Smart antenna driven location based routing	Reduced network control overhead, increased energy efficiency
Osama et. al [16]	Routing & beamforming challenges	Smart antenna based directional routing scheme	Enhanced directional routing in multi-hop wireless networks
Hanaoui et. al [17]	Energy Efficiency	Smart antenna systems for WSN	Limited interference constraints
Hailu et. al [18]	Energy Efficiency	Energy efficient MUSIC-RLS based DoA estimation and beamforming	Reduced energy consumption during beamforming process by generating narrow beam with reduced side-lobe level

5. Existing Research Gaps and Challenges in Smart Antenna Systems

At present the smart antenna systems are deployed in one out of every 5 base stations. This increases the demand for smart antennas in the near future especially when utilizing the multi user wireless mobile communication systems. These systems demand more adaptive smart antennas especially in the unknown dynamic and adverse environment. The smart antennas should be even more advanced to steer the primary beam in the desired direction by nullifying the beamforming in the unwanted/undesired directions [19].

New intelligent algorithms should be developed to integrate smart antennas in futuristic wireless mobile networks in order to collect data and node information from the desired range to leverage smart decisions [20]. The challenges and opportunities in the following sub-domains and technologies of smart antennas require significant research attention - smart antennas in heterogeneous wireless networks; new approaches for enhancing the adaptive beamforming process; novel Direction of Arrival (DoA) estimation process; sensor based smart wearable antenna architectures; localization of active and passive targets;

adaptive nullified beam steering; implementation of smart antennas in acoustic underwater networks.

6. Conclusion

From the perspective of wireless communication systems, the adaptive beamforming capacity and resource allocation methods of smart antennas are used to incorporate effectiveness in the wireless communication network performance in terms of network bandwidth, efficiency and signal quality. Despite the hype, the adaptive beamforming process may also introduce complexity in the process of adaptive resource allocation. Thus, there is an increasing need to address the challenges in smart antenna resource allocations and implementing efficient Quality of Service (QoS). From the research study, it is evident that the smart antenna technology plays an essential role in wireless network communication. It is also observed that the smart antenna provides number of advantages such as enhanced network coverage, reduced network interference, increased spectrum utilization and efficiency, and enhanced data rate. This study has briefly discussed about the smart antenna architecture, types, techniques and challenges. A section describing the state-of-the-art research works in smart antenna has been included by categorizing it under 3 domains such as coverage & connectivity; Quality of Service (QoS); energy efficiency and routing. Finally, the existing research gap has been included by mentioning the sub-fields and technologies that require significant research attention in the near future.

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Author's biography

C Anand has completed B.E. in the field of EEE and M.E. in CSE. He has more than 12 years of teaching experience and has published more than five international journals on the field of wireless sensor networks. He has guided about 10 PG students and currently working as Assistant Professor in K.S.R. College of Engineering, Triuchengode, Tamil Nadu, India for the department of computer science and Engineering. He is a lifetime member of ISTE.