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Review

Recent Advances of 5G Technology Based on Patch Antenna: A Literature Review

Rhen John Rey R. Sacala [1,*] and Edwin R. Arboleda [2]

[1] Department of Computer, Electronics, and Electrical Engineering, Cavite State University – Don Severino Delas Alas Campus, Indang, Cavite, Philippines, e-mail: rhenjohnsacala@gmail.com
[2] Department of Computer, Electronics, and Electrical Engineering, Cavite State University – Don Severino Delas Alas Campus, Indang, Cavite, Philippines, e-mail: edwin.r.arboleda@cvsu.edu.ph
* Correspondence: rhenjohnsacala@gmail.com

Abstract: For their speed in data processing, low heights and cheapness, patch antennas are important to 5G networks. While there have been improvements in the area of bandwidth and size reduction; however, there are still problems that need to be fixed with regards achieving high data rates as well as wideband operation and compact sizes for 5G applications. In the coming years researchers should concentrate on materials optimization and feeding methods so that they can work efficiently at shorter wavelengths for next-generation systems while still covering all necessary bands.

Keywords: patch antennas; substrate; MIMO; antennas; 5G

I. Introduction

5. G, also known as the fifth generation of wireless mobile communication technology, is a game-changer in telecommunications [1]. What is unique about this invention is that it provides for incredibly fast data transfer rates as well as low latency and high connectivity which can revolutionize many fields such as transportation system or environmental protection campaign [2]. The technical features comprise ultra-high speeds, capacity and very low delay compared to its predecessor 4G LTE thus enabling IoT applications development among others like AI, self-driving cars or VR devices [3]. In the framework of Connected-and-Automated Mobility (CAM), different bands are allocated within the frequency spectrum used by 5G; these are: mm-Wave; mid-band; low-band. They offer various speeds and coverage areas where mm-Wave has the highest speed but covers only few meters around each base station [4].

For this technology, one of the types of antennas that are usually used is patch antenna. Patch antenna is an important part in radio systems and it has been widely applied in many areas such as smartphones, radar or satellite communication terminals [5]. These days we need new kinds of antennas because radios keep changing all the time [6]. This meant that patch antennas can work at wide frequency ranges which allows the support of multiple technologies concurrently which in turn reduces weight, size as well as cost of devices greatly. It can also be made to have certain features like very narrow beams for V2X communication in remote areas where objects are hard to detect. Moreover, patch antennas can be customized for different uses such as putting radiation elements together with protecting layers on spacecrafts too.

Patch antennas are important for 5G technology because they can satisfy the high-data rate and low latency requirements of these types of networks. Different papers stress their relevance to various areas of 5G applications. Various research papers highlight the significance of patch antennas in different aspects of 5G applications. For instance, a study by Nassr and Khamiss proposed a patch antenna at 38 GHz with enhanced gain and reduced side lobes to meet the demands of 5G communication [7]. Additionally, Jusoh's research demonstrated the design of a novel patch antenna operating at sub-6 GHz and sub-7 GHz bands, showcasing wider bandwidth and improved gains compared to conventional designs [8]. Yoo and Son introduced a millimeter-wave patch antenna that

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integrates a capacitive proximity sensor, enabling detection of hand grip states for 5G mobile terminals while maintaining stable gain and proximity sensing capabilities [9].

This literature review will explore the basics of patch antennas and its significance on the implementation of 5G technology. Moreover, the literature review will also explore the development of patch antennas over time and the advancements it made towards the present state it has in the 5G technology.

II. Patch Antennas Basics

A patch or microstrip antenna is a flat, low-profile antenna which in its basic form consists of a flat plate over a ground plane [10]. Such an antenna typically consists of several key components. These include a thin, flat metallic patch printed on a dielectric substrate, a ground plane attached on the opposite side of the patch, and a feeding mechanism such as a coaxial cable or a microstrip transmission line [11]. In some advanced designs, additional elements like meander line unit cells for polarization conversion and artificial magnetic conductor structures can be incorporated to enhance antenna performance and reduce radar cross-section [12]. Furthermore, features like F-shaped probes, metal columns, and folded defected ground structures can be added to create radiation nulls and improve out-of-band suppression in filtering patch antennas. Additionally, patch antennas can be optimized with unclosed annular strip-line radiators excited via coplanar lines to achieve specific performance characteristics like return loss, gain, and polarization control [13].

Common shapes of patch antennas include rectangular, circular, elliptical, hexagonal, diamond, stepped, triangle (right, obtuse, isosceles and equilateral) [14] [15] [16]. Such shapes are utilized in various designs to achieve specific performance characteristics such as dual and triple frequency capabilities, improved gain, radiation patterns, front-to-back ratio, and electric field distribution for various applications ranging from wireless communications to ultra-wideband (UWB) systems. The choice of shape can impact the antenna's bandwidth, impedance matching, radiation efficiency, and overall performance, making it crucial to select the appropriate shape based on the desired specifications and operational requirements.

Typically made of a metal such as copper, a patch antenna uses a radiating patch component to send and receive radio waves efficiently. A ground plane is the name for this patch element in combination with a dielectric material circuit board. In other words, they behave like a resonant cavity system. When the antenna is energized by applying radio frequency (RF) energy through a feed line connected to the patch, electromagnetic (EM) waves are emitted from it. These waves mainly propagate outwards from the broadside of the antenna, perpendicular to its surface area. The height of the dielectric substrate and size of conducting patches determine what frequency it will resonate at which in turn controls which specific types of radio wave can be most efficiently transmitted or received by this antenna system

Patch antennas are known for their simplicity, cheapness, light weight and better radiation performance [17]. Therefore, it is a universal type of antenna which is widely used in different areas including mobile phones, base station antennas, WLAN, radars, satellite communication terminals and other scientific applications [5]. The patch antenna is especially useful when wideband applications require a single antenna to cover several frequency bands thus eliminating the necessity for realization of an antenna covering the same frequency bands.

Patch technology has changed a lot over the years to keep up with modern radio systems. In the beginning, wide bandwidth coverage and simple pattern characteristics for radiation were some of the reasons why patch antennas were so popular [18]. Even though this didn't seem like much at first, it found its way into many different applications like radio telescopes, wireless communication devices, mobile phones as well as radar systems. Then came improvements such as putting slots into the design which could better VSWR and return loss [19]. These changes also made wider bands possible by introducing symmetrical slots onto edges of patches so that they could control resonances better [20]. Modifying them in other ways like cutting holes in the radiating patch itself or using a defected ground structure near it while feeding power through proximity led to higher gain, larger bandwidths, less error reflection voltage standing wave ratio (VSWR), sharper directivity patterns;

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thus making these antennas compact and low profile [21]. For example within nano satellite space based operations where there is no atmosphere attenuation problem; S band operation optimized version were made available which showed significant improvement in terms of return loss VSWR and gain [22]. The growth of patch antennas with improved performance characteristics is the result of many changes. These changes have produced wideband patch antennas which can efficiently cover multiple frequency ranges, reduced device size, weight and cost [23]. Also, new designs for particular uses such as 5G mobile phones have been created by automatic antenna design systems that use evolutionary algorithms showing what can be achieved in antenna synthesis by intelligent computer programs [24]. Feeding methods like Micro Strip Line, co-axial and aperture coupled feeds used at different points in time have also increased the efficiency at which microstrip patch antennas work at various frequencies.

III. Requirements and Challenges in 5G

In order to make an antenna 5G compatible, considerations should be made on both the system and the antenna itself for optimum performance. Among the factors that must be taken into account by such antennas include wider network coverage, reduced latency time, support for massive devices connection, faster data rates, small size in terms of dimensions and weight which can easily fit into any available space or even carried around, cost efficiency in terms of production or installation expenses incurred during manufacture stage as well as operational cost savings realized over its lifetime span among others like bandwidths having higher gains thus minimum radiation losses while using flexible materials for shrinking them down more so when putting together with other parts using such elements like metals sheets; these should have been clad with light weight insulating material around it [25][26]. Antennas should also meet dynamic technological advances, become smaller sizes suitable for next generation equipment and work with Gateways/Routers/Wireless Access Points (WAPs)/ HD streaming capable devices like smartphones /tablets/laptops/netbooks etc., Handheld Devices (HHDs) used in various activities such as gaming consoles where players need wide range mobility over large geographical areas while connected wirelessly through MIMO enabled Public Transportation networks for example buses/taxis/trains/planes/boats/submarines etc.. For this reason alone at high frequencies bands there is need of designing antennas having wider impedance bandwidths coupled with high gains because according to path loss calculation models; it shows that most signals will not be able reach their intended destinations unless they are reflected back towards them from another point on earth surface which may have objects blocking direct line sight between source destination hence causing multi-path fading effect resulting into signal degradations experienced at receiver end points so far encountered along wave front propagation past obstacles. Building suchlike aerials can get complicated due many variables involved though artificial intelligence methods may help optimize design process where necessary through use surrogate functions-based optimization techniques aimed at dealing with computational complexity [27].

In 5G systems, different difficulties are faced by Patch Antennas. More bandwidth and radiation efficiency are required [28] [29]; this is one challenge among others. Also, in designing antennas for high frequency operation at 28GHz band while maintaining simple geometry with mass manufacturability [30], it becomes another problem to solve them easily. Moreover, growing mobile networks need massive connectivity which should be accompanied by advanced security features that will also increase network capacity but still maintain low-latency requirements [31]. These issues indicate how complex it can be to design patch antenna for meeting the strict needs of 5G system such as wideband, efficient, frequency selective and overall performance matching with other systems or devices.

IV. Recent Advances

Advancements in Patch Antennas as a basis for 5G technology, that have been made in recent years are mainly due to development in terms of their small sizes and the materials used as well as varied manufacturing methods. Progresses include; compact broadband patch antennas with ball grid array (BGA) packaging for 5G millimeter wave applications [32], low-profile broadband multi-mode patch antennas designed for fifth generation mobile with high efficiency and broad bandwidth [33], wideband differentially fed dual polarized magnetoelectric (ME) dipoles for millimeter-wave applications having stable radiation patterns and high isolation [34] as well as dual-function periodic slotted patch antennas for vehicular 5G communications which offer dual-band functionally and large frequency ratio design [35]. These developments indicate continuous attempts at improving performance, efficiency, and versatility of Patch Antennas within the evolving landscape that is brought about by 5G technology.

To achieve 5G technology implementation, various ways have been used to reduce the size of patch antennas. An interesting method is to change the antenna by using metamaterial shapes such as circular or pentagonal negative media which makes it smaller and enables it operate on many frequency bands [36]. Another way includes loading shorting pins onto the edge of the patch, employing interdigital structure and differentially feeding this antenna that can realize about 90.6% size reduction compared with conventional square patches [37]. Besides proposing Artificial Magnetic Conductor (AMC) surfaces for reducing vertical and horizontal profiles of radiator, size of antenna patch may be reduced by up to 22.04% while ground plane can be made smaller by 29.6% [38] [39]. These improvements represent new approaches to miniaturize patch antennas without sacrificing their performance or even making them work better.

Recently, the materials used in the manufacturing process of patch antennas have shown considerable improvement. Additive manufacturing technology has made it possible to create complex shapes for electronic devices such as conductive Acrylonitrile Butadiene Styrene (ABS) materials for 3D-printed antennas [40]. Also, additive manufacturing air gap techniques have been used to investigate low dielectric constant substrates for patch antennas with tunable dielectric properties. Furthermore, radomes made out of PTFE and silica have been studied as a way to enhance antenna performance; these materials not only protect the antenna but also improve gain and directivity [41]. These developments demonstrate that there is always something new happening in terms of both materials and methods used in making patch antennae; this therefore provides more options when it comes to design flexibility for different applications while at the same time ensuring increased functionality.

Since its creation, beamforming for patch antennas has undergone a considerable number of improvements. Some of these include the ability to form beams that are self-adjusting and capable of adapting to any shape [42]. Furthermore, using dielectric materials with higher values like ROGER 3003 in combination with microstrip patch antenna arrays can lead to compact size as well as high gain which makes them suitable for communication applications beyond 5G [43]. Another observation made from research is that altering the configuration of an array's antennas greatly affects its gain and beamwidth; various configurations give different results [44]. These developments demonstrate how much beamforming techniques have changed over time by combining machine learning with difficult problem-solving methods while meeting modern communication system requirements.

The advancements in MIMO applications of patch antennas in recent years have led to the development of mechanical dual-band, dual-polarized antennas for 5G MIMO systems with high cross-polar discrimination and isolation, which can be mass-produced [45]. Moreover, there is a two-port circular patch antenna design that has decoupling structure for MIMO, which provides compact dimensions, good radiation performance and high port isolation. In addition to this invention is a patch antenna design with C slots that are double offers multi-directional transmission pattern wide beamwidth large bandwidth recommended for 5G OFDM systems with 5G standards according to Keerthana, [46] thus making it meet the requirements for MIMO. Furthermore, these developments improve efficiency, bandwidths as well as performance levels of patches utilized within different wireless communication systems employing MIMO detection techniques.

Various operations can be performed on patch antennas due to the integration of RF modules, making it more functional and effective than ever before. For example, with a use of MEMS switches and bias network in patch antennas, switchable slots that work at several frequencies with acceptable return losses and directivities are achieved [47]. Another approach is to place RFIC inside the inner cavity of antennas-in-package (AiP) which increases bandwidth by arranging ground vias appropriately thus improving overall performance [48]. Moreover, highly integrated tunable triple-bandpatch antennas are designed containing U-slots as well as varactor diodes that enable them to achieve three bands performance individually tune their operational frequencies compact size and practicability [49]. These developments demonstrate how much impact has been brought about by integrating RF modules into patch antennas where flexibility, better performance and wider frequency range coverage have been realized.

V. Performance Evaluation

Evaluation of patch antennas in performance involves considering S-parameters, VSWR, axial ratio, bandwidth and operating frequency among other key features. Among other things the studies have used finite element method (FEM) for accurate calculation and design factor evaluation [50]. Moreover, the distance between the ground plane and the patch significantly affects impedance and radiation properties thus influencing return loss, frequency shift, gain, directivity as well as radiation pattern [51]. In addition to this, research has also shown different gains and directivities of flexible substrates for Polyester materials such as Polyethylene terephthalate (PET), Polyimide at 24GHz [52].

Aside from performance appraisals, different simulation techniques are used for patch antennas. Electromagnetic-thermal co-simulation is done by the discontinuous Galerkin time domain (DGTD) method and finite element time domain (FETD) method, which considers thermal effects on radiation patterns [53]. Moreover, CST Microwave Studio and COMSOL Multiphysics as simulation software are employed in designing and simulating passive wireless strain sensors based on microstrip patch antennas where COMSOL software has shown better accuracy as well as linear response for strain sensing [54]. The scattering problem of incident fields on antenna patches is solved by a mathematical model that incorporates finite element Galerkin method so that antenna characteristics can be computed without reducing cell sizes near excitation points [55].

For the implementation of 5G technology, many case studies were carried out on patch antennas. One such study [56] simulated a 5G NR network at 2.3 GHz in Semarang City using the UMa path loss model to find out cell radius, number of sites required and signal strength parameters. Another study [57] made measurements on 28 GHz in a tropical climate and considered path loss models for LOS scenarios with co-polarization antennas. Furthermore, an antenna for millimeter-wave band at frequency 28 GHz was designed with wider bandwidth and higher efficiency for 5G systems [43]. Also, a low-profile slant ±45° polarized antenna was developed which can be used in MIMO system for wideband operation at base station working with 4G/5G [58]. These examples indicate different uses as well as development stages of path antennas aimed at improving performance of networks based on fifth generation technologies

VI. Future Directions

According to Kannadhasan et.al., [59], in patch antennas, conformal antennas have been developed for wireless body area networks (WBANs) for use with wearable devices. For different wireless communication standards including Wi-Fi, WiMAX and 5G, researchers are trying to increase bandwidth and efficiency through microstrip patch antennas (MPAs) [17] [60]. They are also investigating multi-band antennas that provide better transmission and reception performance in compact communications devices [61]. Gain can be increased by using metamaterial superstrate layers while adjusting antenna slots may vary gain so as to have wider band width; thus more techniques like changing substrate materials or feeding methods can also be employed in order to improve gain and band width [62]. The goal of these developments is overcoming problems associated with narrowband or low gain systems which need specific frequency bands within current wireless communication systems.

Different applications have been shown by patch antennas. Because of their being light weight, having a low profile and efficient radiation, they are being tried for 5G systems and even 6G communication [8] [63]. In medical diagnosis among other fields, patch antennas of dual bands are designed to work at specified frequencies like 2.4 GHz and 3.33 GHz through slot configuration [17]. On another note, these devices are also employed in wireless systems which operate under S and C bands where the quarter wave transformer width can be varied so as to tune it into triple band mode [64]. Also, some people are investigating microstrip patch antenna with partial ground plane approach to widen its bandwidth for different wireless communication standards including Bluetooth, WiMAX or RFID [65]. These multiple uses represent versatility and potentiality illustrated by patches within current and future communication/technology arenas.

Difficulties when using patch antennas include; high data rates, small size, all-direction radiation patterns, restricted specific absorption rate (SAR) and wide band needs [66]. Furthermore, MIMO patch antennas for wireless communication encounter challenges on isolation maintenance and diversity performance improvement [67]. Wearable antennas are problematic because they must be light weight with conformal designs made from textile substrates having good conductivity materials but should not degrade near body operations [68]. Biomedical application is beset by the need for high efficiency gain low return loss and SAR compliance which ensures accurate data transfer in wearable as well as implantable devices [69]. To tackle these problems, one has to look at physical parameters trade-offs between measures of effectiveness and new ways of making patch antennas more useful in different areas.

To improve the performance of a patch antenna, in future research, it is suggested to use metamaterial-based designs that might help with such features as antenna gain and directivity. Furthermore, efforts are concentrated on creating compact antennas having broadened bandwidth so as to cater for high-speed mobile internet during 5G communication era [70]. The growth of wireless communications particularly in 5G applications requires antennas capable of massive connectivity, enhanced network capacity and low latency thus making antenna design an essential area of investigation [71]. In order to enhance the design process and achieve desired antenna parameters for current 4G as well as upcoming 5G applications, new methods like generative adversarial networks together with optimization algorithms are used [30].

VII. Conclusion

Due to its ability to process large amounts of data quickly and with minimal delay, patch antennas are considered a vital part of the 5G network. Moreover, these types of antennas are known for being thin, cheap, and can be used in many different devices. Although the antenna has seen much development over time such as wider bandwidths or miniaturization through various materials or feeding techniques among other things; there are still challenges ahead like achieving high data rates or wideband design for 5G applications while also keeping it small enough. Researchers will therefore need to look into what kind of material should be used as well as how they can optimize this technology so that it works more efficiently on future networks which utilize shorter wavelengths than ever before while still ensuring proper coverage across all bands required by future mobile communication standards.

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