(Wi-f)I Fold: A Proposal for Origami-Inspired Antenna Reflector Designs for Enhanced Wi-Fi Reception

Seohee Han

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This study proposes a novel approach to amplifying Wi-Fi signals through the construction of a 3-dimensional spherical reflector employing origami-based principles and hexagonal tessellation. Inspired by the segmented mirror design as evinced by the construction of the James Webb Space Telescope and the concept of the Dyson Sphere, the reflector consists of 19 hexagonal reflective panels arranged into three main groups that maximize signal gain and optimize focal volume. The optimal focal volume produced by the suggested design is evaluated using ray-tracing and geometrical modeling, through the analysis of incident and reflected rays across the three-panel groups each with specific angular configurations. Doing so, the study identifies the focal volume for the reflector based on the adjustment of the angles formed by each panel and proposes the optimal antenna placement location given the focal volume.
Keywords: Dyson Sphere, Origami-inspired Design, Antenna Reflector, Wi-Fi Booster

Introduction

Article 19 of the Universal Declaration of Human Rights stipulates that access to the internet is a fundamental human right. The estimated economic value generated using Wi-Fi technology alone will reach $4.9 trillion by 2025[1]. In 2020 Rwanda, anti-epidemic robots connected via Wi-Fi were responsible for monitoring patients, delivering food, and medication to help individuals in remote areas combat COVID-19[2]. Evidently, access to the internet is a prerequisite to survival for modern mankind.

The initial recognition by the United Nations that internet access constitutes a human right was seen as ambitious and far-fetched. However, in the status quo, it has become increasingly clear that this recognition was not only warranted, but also essential. Access to the internet is now widely acknowledged as a gateway right: one that unlocks further basic prerequisites in todays world, such as education, healthcare, employment opportunities, and housing. Furthermore, the internet aids in spreading important health information, public health initiatives, and the capability to monitor and address health emergencies instantly. For most, the internet is a crucial connection that closes the distance between being isolated geographically and accessing necessary medical care, as done for Nigerians using free e-consultation tools to self-assess infection risk for COVID-19[2]. In fact, the importance of internet access was dramatically illustrated during the Arab Spring in 2010[3]. The initial impetus for these revolutionary movements demanding democratic reform was significantly bolstered by social media platforms, particularly Twitter. In Tunisia, regions with internet access saw the birth of a unified movement that spread rapidly and gained global attention. This evidently shows the internets power to mobilize and unify individuals in the task of forming sufficient political capital.

Despite the widespread recognition of the importance of internet access, the practical provision of Wi-Fi infrastructure remains severely limited in many parts of the world. As of 2023, only 35% of individuals have access to Wi-Fi network connections in Least Developed Countries (LDCs), contributing to the statistic of only 65% of the world being connected online in this hyper-connected society[4]. Granted, various efforts have been made to improve network connectivity. To illustrate, in Sub-Saharan Africa, the road towards digitalization faces numerous obstacles, with one of its greatest being the fact that download speeds in the region are on average, more than 3 times slower than in the rest of the world[5]. Moreover, granting underserved areas with internet access requires large, long-run infrastructure investments across borders, which currently governments that are offline tend to lack the financial and political capital to do so. In Africa alone, these projects are expected to cost about $100 billion over the next 10 years[6]. As such, existing solutions frequently fall short in terms of scalability and speed of implementation, leaving many areas underserved. The digital divide remains a severe problem, with underserved regions and marginalized communities facing significant barriers to accessing reliable internet services.

In light of these challenges, this study proposes a novel approach to enabling easier and more efficient Wi-Fi access for all stakeholders involved. That is, the study proposes a design of a parabolic Wi-Fi reflector antenna inspired by the principles of origami, a form of traditional Japanese art through the folding of paper, and regular hexagonal tessellation. The proposed design is a 3-dimensional structure with 19 hexagonal reflective panels that when assembled, succeeds to create an efficient focal region where when placed, the Wi-Fi antenna receptor is able to receive and transmit signals with frequencies in the 2.4 GHz and 5 GHz bands, current standards for Wi-Fi technology[7]. Doing so, the study aims to contribute to the existing body of academic literature on Wi-Fi technology and address the current lack of research and practical implementation of such origami-inspired designs.

Existing Methodology

What are antennas and how do they work?

Today, antennas enable communication unbounded by distance and time. Antennas are energy conversion devices that radiate and receive radio signals in wireless communication systems. This is done by a transmitting antenna receiving electrical signals from a transmission line and changing them into radio waves, transmitted out in all directions. On the other hand, receiving antennas allows radio signals from space and generates current, dependent on the strength of the signals, and changes them into electrical signals and provides them to a transmission line. In both instances, antennas produce electromagnetic waves composed of oscillating electric and magnetic fields that travel perpendicularly to each other and to the direction of propagation. The antenna generates electromagnetic waves when an alternating current flows through a conductive material such as a metal wire. This current creates a magnetic field, inducing a corresponding electric field. These alternating fields together form an electromagnetic wave that propagates outward from the antenna. The frequency of the generated wave depends on the frequency of the input signal, and antennas are typically designed to operate within specific frequency ranges to optimize transmission and reception[8].

To facilitate effective communication, antennas interact with modulated signals, which are altered to encode information. There are three forms of modulation: frequency modulation (FM), amplitude modulation (AM), and phase modulation (PM). In FM, the frequency of the carrier wave is varied in proportion to the message signal while the amplitude remains constant which makes it ideal for radio broadcasting and communication systems. In AM, the amplitude of the carrier wave is modulated to reflect the message signal while maintaining a constant frequency, making it a standard in AM radio broadcasting and aviation communication. PM, on the other hand, varies the phase of the carrier wave based on the message signal, keeping both frequency and amplitude constant. This method is particularly useful in advanced digital communication systems, such as satellite communications and cellular networks[9].

Main types of antennas

Largely, antennas can be classified into three main categories: omnidirectional, directional, and semi-directional antennas. Primarily, an omnidirectional antenna sends out signals in all directions with equal strengths, producing a 360 degree radiation pattern around the antennas axis with nominally constant signal magnitude within a plane. Compared to directional antennas, it has a wider coverage area; however, this comes at the cost of the antenna dissipating the signal in all directions, resulting in its directivity ranging from 2 dBi and 9 dBi, which is weaker than those of directional antennas[10]. Due to its lower signal strength and wider radiation coverage, omnidirectional antennas are mostly used in mobile data transmissions, where the location of the receiver need not be fixed. For instance, omnidirectional antennas are used at base stations or cell towers mounted at a height in order to provide coverage to mobile devices in all directions within a certain radius. Furthermore, omnidirectional antennas can also be used in a network's router or access point in houses and office settings as it provides central communication capabilities to all surroundings. The broad coverage it provides allows clients to move without losing signal. Omni-directional antennas can exist in different forms, such as the whip antenna, horizontal loop antenna, and vertical dipole antennas. Despite differences, they all share the characteristic of radiating waves in all azimuthal directionsthat isin the direction perpendicular to the antennas axis. However, the whip antenna is usually vertically oriented, meaning that it radiates vertically polarized waves. The length of the whip antenna is normally half of the wavelength which allows the antenna to resonate with the incoming or outgoing waves, thereby maximizing the efficiency of energy transfer[8].

On the other hand, directional antennas transmit or receive signals in a specific direction only, making it an ideal device to be used for transmission of signals to fixed receivers. Directional antennas usually use dipole and parabolic dishes, whose physical design of narrower angular coverage focuses the beam of radio frequencies, producing a narrow beam of radio frequency signal strength. This allows it to transmit and receive signals in a specific direction.

Contrasting to the circular radiation pattern of omnidirectional antennas, directional antennas focus radiofrequency (RF) energy in a certain direction, producing a cigar-shaped radiation pattern which has a radius of around 45 to 90 degrees, also referred to as a lobe (refer to Figure 1). Due to their higher directivity, they have a more focused beam designed to concentrate more energy in a single direction, making them more conducive for long distance transmission[11]. Thus, larger signal coverage makes directional antennas the ideal type for point-to-point communication where a strong signal is needed over a specific path such as satellite communication and long distance wireless networking. Directional antennas also come in various

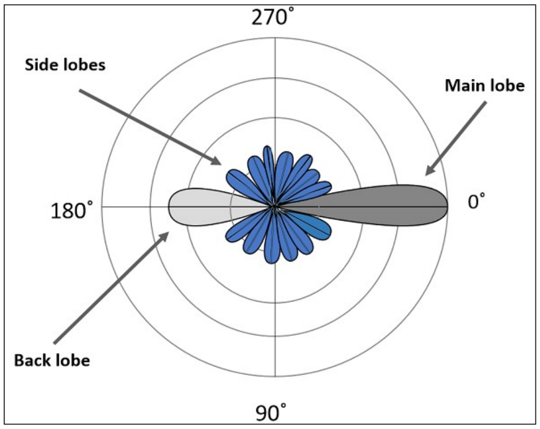

Fig. 1 Radiation pattern of a dipole antenna with main lobe, side lobes and a back lobe

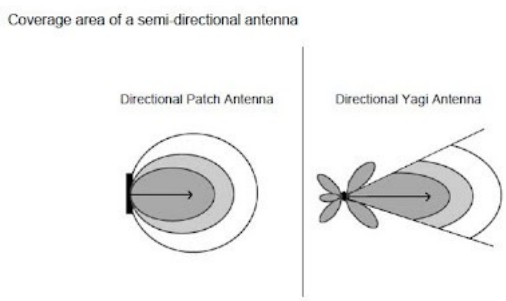

Fig. 2 Coverage area of a semi-directional antenna

shapes, sizes and designs, such as the folded dipole antenna, ground plane antenna, and YAGI antenna. Amongst these, the folded dipole antenna consists of two parallel conductive elements each of equal length connected at both ends to form a closed loop. It displays the advantage of easier impedance matching with transmission lines due to its high input impedance of 300 , which is four times that of a standard dipole[12]. Its ability of impedance matching allows folded dipole antennas to be frequently employed in dipole arrays.

The third type of antennas are semi-directional antennas. These direct the energy from the transmitter significantly more in one particular direction radiating in a hemispherical or cylindrical coverage pattern as can be seen in Figure 2. This characteristic allows the antenna to be suited for short and medium range transmissions.

Limitations and necessity for novel research

Various types of antennas exist; however, one of the most crucial uses of the antenna nowadays is to create an operating network to allow Wi-Fi connection. Despite the widespread popularity of Wi-Fi technology in the status quo, it is not without limitations. Wi-Fi, by virtue, is a wireless network consisting of wireless network adapters the client device responsible for receiving signal transmissions from the access point and access points (APs) a bridge between traditional wired local networks and wireless local networks. As a direct consequence of this, a successful Wi-Fi network relies heavily upon whether the transmissions between network adapters and APs via antennas are undisturbed. Despite the consistent development of antenna technology to minimize this interference, transmission distortion remains as one of the major setbacks to Wi-Fi technology.

One scientific breakthrough in this front was the multiple in, multiple out (MIMO) antenna. MIMO antennas use multiple antennas at both the transmitter and receiver ends to enhance data throughput and reliability. This technology takes advantage of multipath propagation, where signals bounce off walls, ceilings, and other surfaces to reach the receiver via multiple paths[13]. By using multiple antennas, MIMO systems can process these multiple paths to improve signal strength and quality, leading to better performance in terms of speed and reliability.

Smart antennas, on the other hand, utilize directional signal transmission to optimize signal strength and reduce interference. These antennas can dynamically adjust their beam patterns to focus on specific users, thereby improving the overall performance of the network. This adaptive approach not only enhances signal quality but also reduces interference from other sources, making smart antennas particularly useful in crowded environments such as urban areas or large buildings[14].

To further boost performance, recent research has focused on techniques such as beamforming and phased array antennas[15]. Beamforming involves directing the transmission and reception of signals in specific directions to enhance signal strength and reduce interference. This technique is particularly useful in environments with high levels of interference or where precise control over signal direction is required.

If previous efforts were concerned with reducing the information loss as information was transmitted via a central network, recent successes have taken a more systematic approach to enhancing overall network connectivity by creating an ad hoc network system[16]. To illustrate, a mobile ad hoc network (MANET) is a multihop network where communication from the source to the destination occurs via intermediate nodes, with routing protocols determining the path. Devices in an ad hoc network can access each other's resources directly through basic peer-to-peer (P2P) or point-to-multipoint modes, eliminating the need for central servers. This further reduces the risk of information loss across long distance information transmission[17]. Despite progress in MANET technology, various issues and challenges persist. For example, in an ad hoc network, communication depends on mobile nodes, meaning that a single delineation of a node from the network range will result in the failure of communication[18].

Nevertheless, currently one of the most innovative methods for addressing the limitations of earlier antenna technologies is the utilization of optical beams in wireless communication. Optical wireless communication offers significant benefits:

1. Transmitted beams can stay narrow over long distances, making them ideal for linking satellites in outer space.
2. The confinement of an optical beam allows it to be directed only to the intended users, providing better privacy and energy efficiency compared to wider radio beams.
3. High directivity ensures a higher fraction of signal power reaches the user, improving the signal-to-noise ratio (SNR).

However, optical wireless communication requires comprehensive phased array antenna structures supported by complex signal processing. This technology can achieve high directivity with a simple passive optical device, but it needs a clear line-of-sight (LoS) between the transmitter and receiver. This requirement is a disadvantage compared to radio wireless links operating at low to moderate frequencies, such as wireless LAN systems at 2.5 and 5 GHz[19].

Origami Inspired Antennas

Not only limited to the application of origami techniques in construction of the JWST, scientists have engaged in a number of endeavors to develop aerospace engineering in terms of efficiency of transportation or energy supply, through origami methods. The most notable contributions made in this field of literature are mainly four, according to Nasirs work on Origami Technology for Antennas and Devices in Different Fields[20].

Primarily, the origami microstrip antenna was designed by Gerard Hayes and his research team from North Carolina State University which uses origami techniques to create self-folding 2D SMP (shape memory polymers) antennas that transform into 3D antennas when exposed to a light source. Doing so, the conventional microstrip transmission line transforms into a monopole antenna and a microstrip patch antenna into a monopole antenna[21].

The second type is the origami spring antenna. This antenna, developed by Yao, was capable of changing its transmitted radio frequencies through changing its height by folding and unfolding the array antenna. This was done by a dielectric substance with the help of a spring[22]. To illustrate, when the pressure was applied to the spring, the antenna folded and then unfolded when the spring was released.

Third, the tetrahedron origami antenna developed by Shah and Lim consisted of a triangular monopole antenna, a couple of parasitic strips on paper, and reflectors. By introducing the different configurations of folded shapes the antenna could take, Shah explained the different methods to maximize the gain and directivity of the antenna through adjusting its directors, reflectors, and also origami[23].

Finally, the origami Yagi loop antenna was developed as a simple alternative that yielded comparable high levels of gain to a conventional dish antenna, making it useful for point-to-point and radio communication. Xu and her team designed a bi-directional loop antenna array using magic cube origami[24]. The antenna resulted in having a high gain loop and a bi-directional radiation pattern with minimal volume due to folding and easy transport and handling.

Hexagonal tessellation

Another method used to construct antennas in the status quo is tessellation. Tessellation is defined as a pattern of geometric shapes that fit together perfectly on a plane, without any gaps or overlaps and can repeat in all directions infinitely. The term is derived from the Latin word tessera a small, tile-like stone cube used to make tessellata, which are mosaic pictures that form tilings in Roman buildings. In particular, hexagonal tessellation is widely regarded as the optimal geometric structure for applications requiring efficiency in space utilization and mechanical stability. The Keck telescope is one instance where this can be observed: its primary mirror employs hexagonal tessellation due to its geometric properties of maximizing surface area while minimizing perimeter, which is crucial for optimizing reflectivity and production efficiency. Compared to square or triangular tessellations, hexagonal structures are superior regarding packing density, ensuring no gaps or overlaps in the arrangement of reflective surfaces. It operates with a sensitive 10 meters wide primary mirror system comprising 36 smaller hexagonal segments working as one. The hexagonal design allowed the mirror quadruple the size in surface area despite the same weight as the Hale Telescopes mirror, which is a parabolic primary mirror.

Beyond packing efficiency, hexagonal tessellation plays a critical role in weight optimization. This is significant because the successful construction of the Keck telescopes mirror relies on dealing with the mechanical and structural challenges of maintaining alignment under varying gravitational forces. The precision of the Keck telescopes mirror is maintained through an adaptive optics system consisting of 108 actuators and 168 relative position sensors. These components ensure that each hexagonal segment remains perfectly aligned to correct for distortions caused by thermal expansion, mechanical stress, or external forces such as gravity. Overall, the sensors continuously monitor the alignment of the hexagonal segments, while the actuators make micro-adjustments in real time, ensuring the mirror retains its intended curvature. In particular, when a single hexagonal segment becomes misaligned, the position sensors first identify deviations in the segments alignment relative to its adjacent segments. Second, the sensors relay this data to the central control system, which then the actuators precisely move the affected segments back into alignment as micro-adjustments. Finally, the sensors confirm the correction, ensuring that the mirror maintains its intended curvature[25].

Unlike traditional continuous mirrors, such as the Hale Telescope, which operates using a single massive glass component, the Kecks hexagonal mirror segments allow for the distribution of weight. Hence, this significantly reduces the overall mass the mirror structure has to bear while maintaining structural integrity. This difference in design also impacts optical efficiency. A continuous parabolic mirror provides an unbroken reflective surface, ensuring that incident light is focused with minimal diffraction and scattering. This results in high optical throughput, as nearly all collected light is directed precisely toward the focal point, maximizing image sharpness and brightness. In contrast, segmented mirrors, while capable of achieving a similar effective aperture, introduce diffraction effects at the boundaries between segments. These gaps, though minimal, can slightly reduce the overall efficiency of light collection by causing minor scattering and interference. Additionally, maintaining optimal alignment across multiple segments requires active optical control, as even small deviations can degrade image resolution. Nevertheless, tessellated designs compensate for these limitations by incorporating adaptive optics, which dynamically adjust individual segments to correct for distortions, ultimately improving resolution and contrast in real-time observations.

However, the trade-off is that a significant mechanical challenge of maintaining alignment in a hexagonal tessellated mirror under varying gravitational forces is the differential stress across the structure. Unlike a single, continuous mirror, segmented mirrors must account for tiny shifts in individual panels due to load distribution. Nevertheless, engineers mitigate these issues by using a semi-rigid support system that allows for controlled flexibility while preserving alignment. Furthermore, the individual segments can be fabricated from ultra-lightweight materials such as beryllium and low-expansion glass composites, which are highly stable and durable under extreme heat. For the Keck telescope in particular, it utilizes a low-expansion glass ceramic material, minimizing distortion due to temperature fluctuations. The backing structure consists of a honeycomb lattice that reduces weight contributing to its long-term durability in outer space, but also ensuring high optical accuracy.

Proposed Design

Recognizing these limitations and past attempts, this study proposes a multi-panelled spherical Wi-Fi signal reflector designed to enhance reception efficiency while maintaining structural feasibility.

The overall design is as follows:

As indicated above, the overall structure consists of 19 regular hexagonal reflective panels, forming a tessellated surface. To construct this structure, regular hexagonal tessellation has been used as compared to other regular polygons due to its high packing density, optimal perimeter-to-area ratio, and superior stress distribution properties, making it the ideal option to construct large, lightweight, and durable reflective structures. One of the key challenges in Wi-Fi signal reflection is ensuring maximum surface area for signal redirection while minimizing weight and structural complexity. Traditional parabolic reflectors, which rely on a smooth curved surface to focus signals to a single point, offer high gain, but are susceptible to misalignment issues, weight constraints, and directionality limitations. In contrast, a multi-panel hexagonal reflector provides broader and more even signal distribution. This is because a hexagonal tessellated reflector distributes reflections across multiple angles, improving signal reach and mitigating dead zones in environments with obstacles or interference compared to parabolic reflectors which focus signals towards a single focal point and thus requires precise positioning and limited signal coverage. Furthermore, this design allows the reflector to be folded, reducing its size by more than 60%, as shown in Figure 4. Out of a total of 19 hexagonal cells, the central 7 cells remain a fixed block, while the remaining 12 cells are connected by hinges that allow them to fold back and forth, creating a very simple structure as shown in Figure 5.

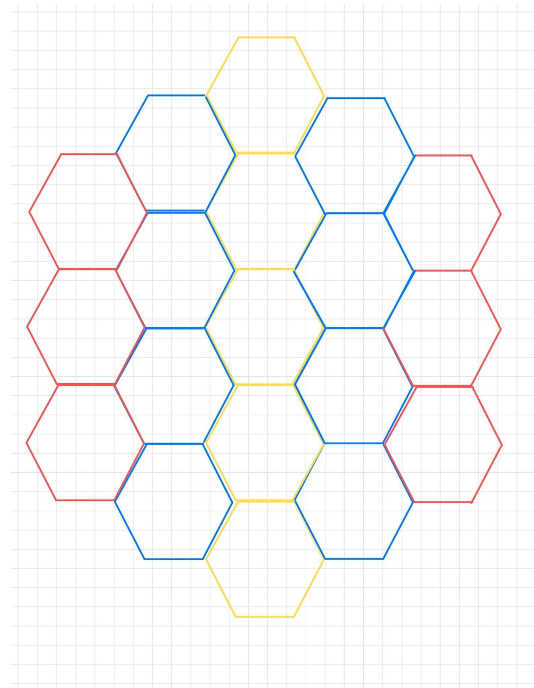

Fig. 3 Design Layout

This enhances portability, making it easier to transport to remote locations and install for improved Wi-Fi signal reception.

Moreover, mathematically, hexagonal tessellation maximizes surface coverage and minimizes material usage as when

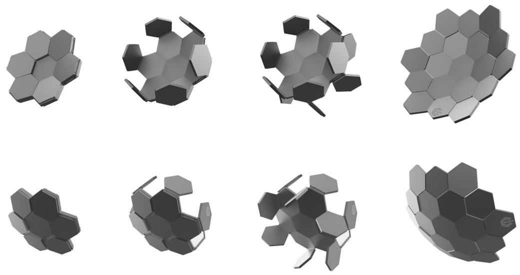

Fig. 4 Folding Mechanism

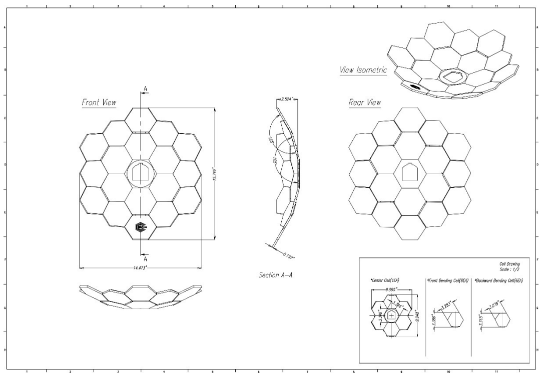

Fig. 5 Outline Drawing

hexagons tessellate a plane, they cover the area without any gaps or overlaps, resulting in a packing density of 100%. While squares and triangles also produce a complete packing density, they have higher perimeter-to-area ratio compared to hexagons, meaning more shapes are needed to cover the same area, making it inefficient in terms of material cost. Perfect packing density also means that the hexagonal tessellation can distribute mechanical stress, reducing the need for additional reinforcements and minimizing deformation risks due to temperature changes. As seen in Figure 6, amongst the different forms of regular tessellations created using the four possible regular polygons hexagonal, kagome, square, and triangular it is seen that the hexagonal tessellation faces the least stress strain. This characteristic is particularly significant to antenna installations on walls or ceilings, which require reflectors to be resilient to weight constraints and space utilization. The reflector can be grouped into 3 groups: A, B, and C. Group A refers to the columns formed by 3 vertically adjacent panels as colored red in Figure 7. Group B refers to the columns formed by 4 vertically adjacent panels as colored blue in Figure 8. Group C refers to the column formed by 5 vertically adjacent panels as colored yellow in Figure 9. Together, the panels form a 3-dimensional structure which acts as a de facto parabolic reflector. For the purpose of this paper, let us denote that each panel has a vertical length of l, and is attached to the adjacent panel which together, form an angle of θ.

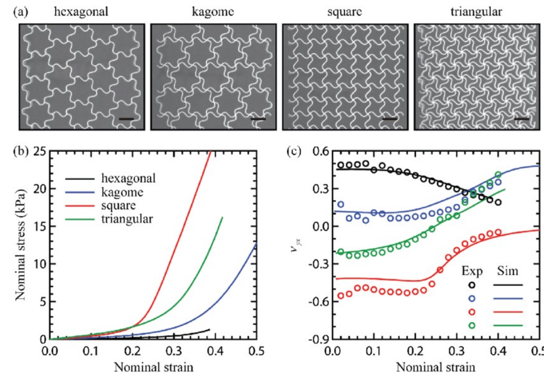

Fig. 6 Stress-strain relations of hexagonal, Kagome, square, and triangular tessellation topology

When assembled together, each group receives a series of light rays traveling at a direction parallel to the surface of which the structure is laid upon. The rays of these, when observed strictly laterally from the surface to the reflector, are as follows. However, taking into consideration the fact that the three groups come together to form one 3-dimensional structure, one must also account for the direction the rays travel when the structure is viewed vertically upwards. Considering this, the top view of the structure shows the three groups of panels in different colors: panels pertaining to Group A are marked as red; Group B blue; and Group C yellow. Likewise, incident rays and reflected rays originating from each of the panels are also marked in the corresponding colors. From this figure, one crucial condition must be satisfied: that the points O and S, which are the intersections of rays reflected by all groups that are a part of the structure and thus the range of possible positions at which an antenna can be placed, must lie further out from the vertical line that forms from the two points P and Q. The reason for this is because taking into account the arrangement of the 5 panels, the closer you approach the panels or the vertical line that forms from the two points P and Q, the antenna faces greater interference from the panels.

Keeping in mind the need to satisfy this condition, the approximate values for θ are as follows:

a. Figure 7: $\theta = 170^\circ$

b. Figure 8: $\theta = 167.5^\circ$

c. Figure 9: $\theta = 165^\circ$

d. Figure 10: $\theta = 165^\circ$

e. l=5

The rationale behind this estimate stems from the fact that a smaller value of theta would pose difficulties in constructing the structure. This is because the condition of having to lie further out from the vertical line that forms from the two points P and

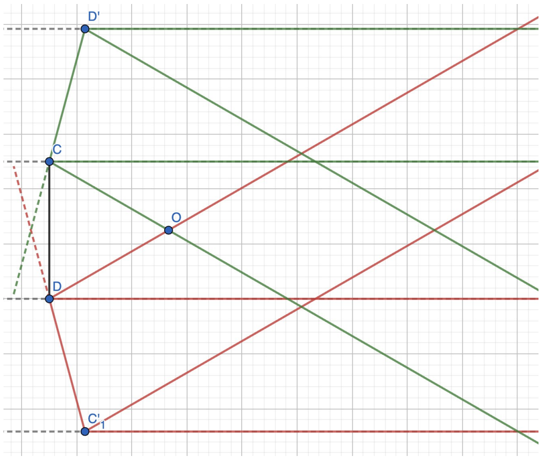

Fig. 7 Group A side view ray diagram

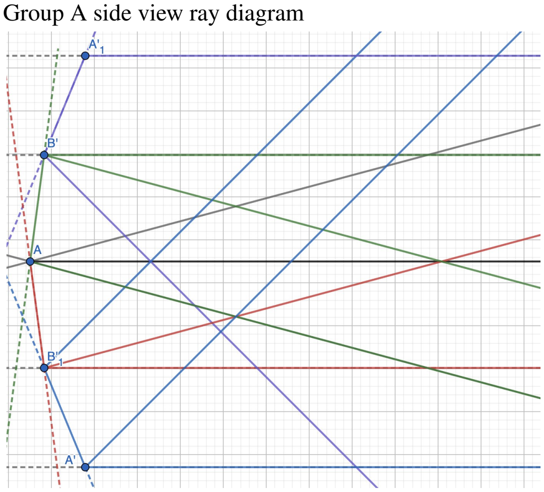

Fig. 8 Group B side view ray diagram

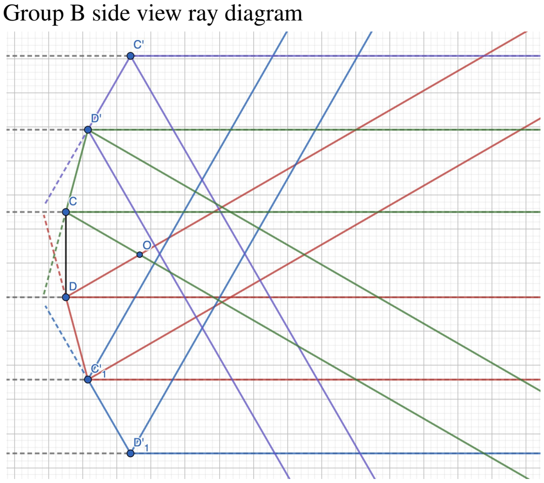

Fig. 9 Group C side view ray diagram

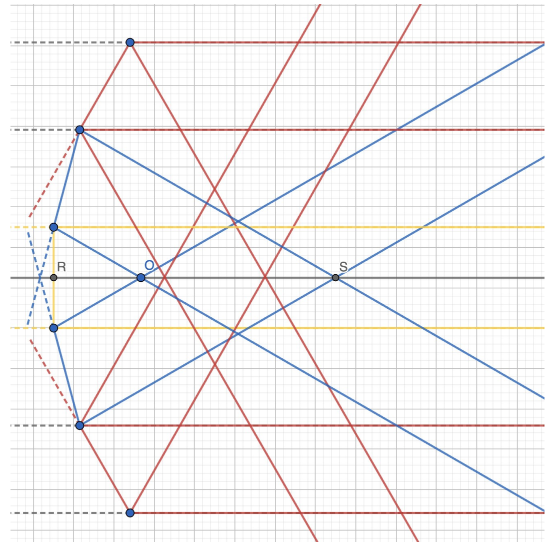

Fig. 10 Overall structure top view ray diagram

Q becomes increasingly challenging to meet once θ is smaller as the rays mostly intersect at a shorter distance from P and Q.

Furthermore, the reason for the differing values of theta is that each group has a different number of panels. Therefore, whilst Group A, having three panels, can have a larger value for θ, the maximum value of θ for Group C which has five panels, is naturally smaller than that of Group A.

As such, a closer look into the movements of rays reveal further characteristics that serve as useful tools to analyze the ideal antenna placement for the reflector to successfully receive Wi-Fi signals.

To better grasp which attributes of the structure will be the subject of inspection, let us refer to the side panel diagrams.

Group A

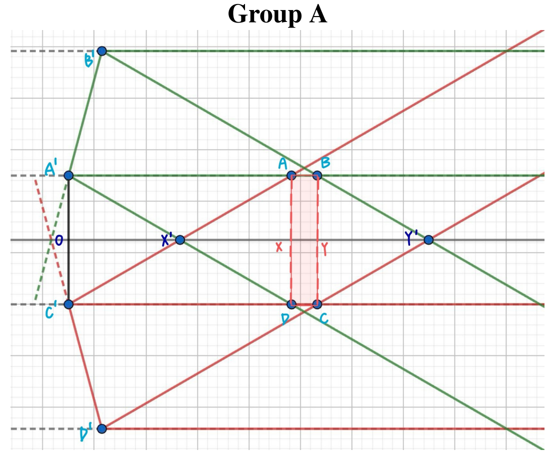

Fig. 11 Annotated Group A side view ray diagram

θ is the angle formed between the two adjacent panels in the diagram above. In this case, $\angle B'A'C'$ and $\angle A'C'D'$ are θ.

Points A and B have been selected as indicated on the figure to maximize the area that allows for antenna placement. This was done by locating the region where all rays overlap, since this would indicate that all Wi-Fi signals are being collected. The section inscribed by the surface and the points A and B is where the vertical height is maximized, optimizing antenna placement.

For x , as $\angle B'A'C = \theta$ and $\angle C'A'A = 90^\circ$, due to the ray entering the panel parallel to the normal line,

$$\angle B'A'B = \theta - 90^\circ \tag{1}$$

$$\text{Also}, \angle B'A'B = \angle BB'A', \text{making} \angle A'BB' = 360^\circ - 2\theta \tag{2}$$

$$\begin{aligned} \text{As } \angle A'AC' &= 360^\circ - 2\theta, \\ \angle AC'A' &= 180^\circ - (360^\circ - 2\theta) - 90^\circ \\ &= 2\theta - 270^\circ \end{aligned} \tag{3}$$

Therefore,

$$x = \overline{OX} = l\tan(2\theta - 270^\circ) \tag{4}$$

As $\angle X'Y'B$ and $\angle A'BB'$ are corresponding angles, they have identical values.

Using the sine rule in $\triangle BA'B'$,

$$y = \overline{A'B} = \overline{OY} = \frac{\sin(\theta - 90^\circ)}{\sin(360^\circ - 2\theta)} l \tag{5}$$

Group B

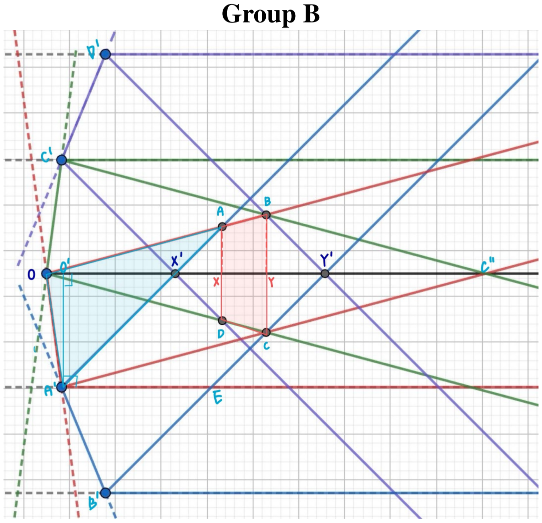

Fig. 12 Annotated Group B side ray diagram

When point O' is the foot of the perpendicular on $\overline{OY'}$ from point A', as $\angle A'OO' = \theta/2$,

$$\angle O'A'O = 90^\circ - \frac{\theta}{2}, \quad \angle EA'O = 90^\circ + 90^\circ - \frac{\theta}{2} = 180^\circ - \frac{\theta}{2} \tag{6}$$

As $\angle B'A'O = \theta$,

$$\angle B'A'E = \theta - (180^\circ - \frac{\theta}{2}) = \frac{3\theta}{2} - 180^\circ \tag{7}$$

As $\angle AA'O = \frac{5\theta}{2} - 360^\circ$ and $\angle AOX' = 180^\circ - \theta$ as the angle of incidence and reflection must be identical to each other,

$$\angle A'OA = 180^\circ - \theta + \frac{\theta}{2} = 180^\circ - \frac{\theta}{2} \tag{8}$$

Given such,

$$\angle OAA' = 180^\circ - \left(\frac{5\theta}{2} - 360^\circ\right) - \left(180^\circ - \frac{\theta}{2}\right) = 360^\circ - 2\theta \tag{9}$$

Thus, using the sine rule,

$$\begin{aligned} \overline{OA} &= \frac{\sin\left(\frac{5\theta}{2} - 360^\circ\right)}{\sin\left(360^\circ - 2\theta\right)} l, x = \overline{OX} = \frac{\sin\left(\frac{5\theta}{2} - 360^\circ\right)}{\sin\left(360^\circ - 2\theta\right)} \cos(180^\circ - \theta) l \\ &= \frac{\sin\left(\frac{5\theta}{2} - 360^\circ\right)}{2\sin(180^\circ - \theta)} l \end{aligned} \tag{10}$$

Also,

$$\angle XOC' = \frac{\theta}{2} \tag{11}$$

$$\angle BOX = 180^\circ - \theta \tag{12}$$

Due to the characteristics of the angle of incidence and reflection, the two angles formed in $\triangle OC'C''$ are identical, making $\triangle OC'C''$ an isosceles triangle.

Therefore,

$$y = \overline{OY} = \frac{\sin\left(\frac{\theta}{2}\right)}{2\sin(180^\circ - \theta)} l \tag{13}$$

θ is the angle formed between the two adjacent panels on the diagram above. In this case, $\angle PQR$ and $\angle QRS$ are θ.

$$\angle QRB = \theta - 90^\circ \tag{14}$$

Since $\angle Q'RB$ is a supplementary angle,

$$\angle Q'RQ = 180^\circ - (\theta - 90^\circ) = 270^\circ - \theta \tag{15}$$

The corresponding angle of $\angle Q'RQ$ is $\angle PQQ''$, meaning that the size of $\angle PQQ''$ is also $270^\circ - \theta$. In respect to $\triangle QQ''R$, $\angle Q'QR = 180^\circ - \theta$.

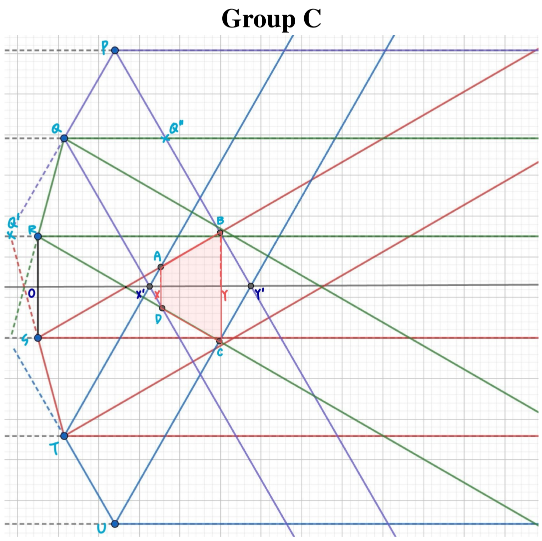

Fig. 13 Annotated Group C side view ray diagram

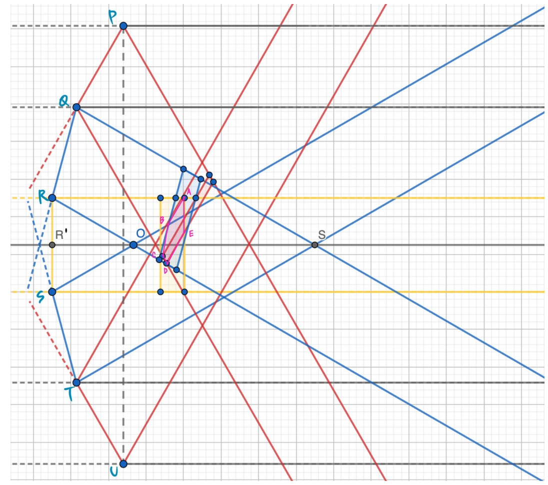

Fig. 14 Annotated top view ray diagram

Thus, using the sine rule,

$$x = \overline{OX} = \frac{\sin(270^\circ - \theta)}{\sin(2\theta - 270^\circ)} l \tag{16}$$

For y, due to the characteristics of inflection and reflection angles of a light ray being the same in magnitude, $\triangle PQQ''$ has two identical base angles making it an isosceles triangle. As such,

$$\angle PQ''Q = 180^\circ - 2(180^\circ - 2\theta) = 720^\circ - 4\theta \tag{17}$$

Thus, in respect to $\triangle PQ'B$, using the sine rule,

$$y = \frac{\sin(2\theta - 270^\circ)}{\sin(720^\circ - 4\theta)}(x + l) \tag{18}$$

Given that

$$\begin{aligned} x = \overline{OX} &= \frac{\sin(270^\circ - \theta)}{\sin(2\theta - 270^\circ)} l, \text{we have} \\ y = \overline{OY} &= \frac{\sin(270^\circ - \theta)}{\sin(720^\circ - 4\theta)} l \end{aligned} \tag{19}$$

With the general formulae for values x and y introduced, let us apply the estimate values for both θ and l:

Primarily, for Group A, the values are as follows:

$$x = \overline{OX} = 5 \cdot \tan(2 \times 170^\circ - 270^\circ) = 5 \cdot \tan(70^\circ) = 13.737 \tag{20}$$

$$y = \overline{OY} = \frac{\sin(170^\circ - 90^\circ)}{\sin(360^\circ - 2 \times 170^\circ)} \times 5 = 14.397 \tag{21}$$

For Group B:

$$\begin{aligned} x = \overline{OX} &= \frac{\sin\left(\frac{5\times167.5}{2} - 360^\circ\right)}{\sin(360^\circ - 2 \times 167.5)} \cos(180^\circ - 167.5^\circ) \times 5 \\ &= \frac{\sin\left(\frac{5\times167.5}{2} - 360^\circ\right)}{2\sin(180^\circ - 167.5^\circ)} \times 5 = 9.875 \end{aligned} \tag{22}$$

$$y = \overline{OY} = \frac{\sin\left(\frac{167.5^\circ}{2}\right)}{2\sin(180^\circ - 167.5^\circ)} \times 5 = 11.482 \tag{23}$$

For Group C:

$$x = \overline{OX} = \frac{\sin(270^\circ - 165^\circ)}{\sin(2 \times 165^\circ - 270^\circ)} \times 5 = 5.577 \tag{24}$$

$$y = \overline{OY} = \frac{\sin(270^\circ - 165^\circ)}{\sin(720^\circ - 4 \times 165^\circ)} \times 5 = 5.577 \tag{25}$$

The significance of these values are as follows. For instance, in Group B, the antenna should be placed within the quadrilateral ABCD, for it to be placed in the reflectors focal region. The focal region is where the antenna delivering Wi-Fi signals should be placed for the reflector to be able to maximize its Wi-Fi signal transmission. The area of ABCD is dependent on the calculated values of x and y, where the antenna should be placed in a distance ranging from 9.875 to 11.482 unit lengths from the structure.

However, one must keep in mind that the height dimension to the reflector structure means that one should calculate the focal region accounting for this extra dimension. Given such, below is the previous top view ray diagram with the calculated focal regions for each group from a vertical perspective. Based on the vertical perspective, as shown in Figure 14, the area with the greatest number of overlap between the focal regions defined previously in the respective side view ray diagrams of each group is the polygon ABCDE. Therefore, if one were to account for the additional height dimension as well as the horizontal focal regions calculated, the Wi-Fi antenna should be placed at this given location. Doing so will maximize the chances of Wi-Fi rays being received as well as transmitted within the reflector, achieving the initial goal of the study to suggest a novel method to contribute to the existing attempts to improve Wi-Fi transmission.

Reflection

By designing a Wi-Fi reflector through the use of origami-inspired structures and hexagonal tessellation, the challenges and advantages of using tessellated reflective surfaces in optimizing Wi-Fi signal transmission became clearer. One of the most notable realizations was the significance of achieving precise angular configurations to ensure an effective focal volume. Small deviations in the angle between panels did in fact dramatically affect signal convergence, requiring meticulous design considerations. Additionally, the study shed light to the importance of finding the correct balance between structural feasibility and optical efficiency. While tessellation enhances portability and adaptability, ensuring the alignment of reflective surfaces remained a challenge, akin to the segmented mirror designs in astronomy.

Discussion

Despite this, the design is still not without limitations. To illustrate, the design could benefit from increasing the number of reflective panels featured in order to increase its directivity and aperture whilst collating signals. However, one must take the fact of rising construction costs and damage possibilities whilst making this design. This is particularly significant given the primary goal of this design being to help alleviate the hardships/problems associated with low Wi-Fi access for those in developing nations, who oftentimes lack the finances to fund such structures. Number of panels could be increased for better reflectivity of the design. Nevertheless, the unique elements of origami techniques that can be found in the design does make it particularly adept for versatile use. For instance, based on the radio or electromagnetic signals frequency that is being transmitted to the antenna, the reflector is capable of adjusting the angle adjacent panels form, θ, due to its flexibility. The foldability of the design may also result in an increased mobility for Wi-Fi signal, as wider regions which hitherto had weak to low signals can now improve their reception through said reflectors.

Conclusion

The proposed design does indeed function as a viable alternative to existing Wi-Fi signal reflectors given its new design techniques and efficiency. In particular, closely imitating the shape of a parabolic reflector, this design is superior to a parabolic reflector that is generally used to collate Wi-Fi signals in terms of focusing collimated light rays into a diffraction-limited spot. While parabolic reflectors can converge light rays into a single focal point, producing clearer signal with higher directivity, spherical reflectors converge light into several intersections within the focal volume as the rays that bounce off the central region focus farther away than the rays that reflect on the edges.

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