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A Multiple Beam LTE Base Station Antenna with Simultaneous Vertical and Horizontal Sectorization

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***Abstract*—**A low wind-load light-weight broad-band multi-beam base station antenna has been developed. It can generate any required number of beams with the required beamwidths. It can have horizontal and vertical sectorization at the same time. Vertical sectorization doubles the overall number of beams. It will be very valuable in LTE-A and 5G. It can be used to serve vertically split inner and outer cells, which improves system performance. The intersection between the beams of the proposed multi-beam antenna can be controlled by optimizing the design parameters of the antenna. The gain at the points of intersection between the beams, the null filling and the overlap between the beams can all be modified. The proposed multi-beam base station antenna can cover an unlimited number of wireless applications, regardless of their frequency bands. It can simultaneously cover all, current and future, wireless technology generations such as 2G, 3G, 4G (LTE), --- etc. For example, in LTE, it covers the bands 450-470 MHz, 690-960 MHz, 1.4-2.7 GHz and 3.3-3.8 GHz. It has at least 2 ports for each band in each beam for ±45° polarizations. It can include up to 72 ports or even more, which could facilitate any further needed capacity expansions.

***Keywords*—**Base station antenna, multi-beam antenna, smart antenna, vertical sectorization.

I. Introduction

THE most common configuration for the wireless communication network plan is the three sectored solution which involves a base station serving three hexagonal shaped cells or sectors as shown in Fig. 1 (a). In a three-sector configuration, a given base station antenna serves a 120° sector. Three of these 120° sectors cover 360°. Other sectorization configurations may also be used. For example, Fig. 1 (b) shows a six-sector configuration in which each antenna serves a 60° sector.

In order to increase the system capacity, the number of sectors has to be increased such that each antenna serves a smaller area. For example, the performance analyses in coverage and capacity of Universal Mobile Telecommunications System (UMTS) show that the number of simultaneous users increases by increasing sectors. Furthermore, it is known that for higher data rates, the coverage will be smaller when cell area is considered without sectors. But increasing sectors with same parameters makes extensive coverage for higher data rates [1].

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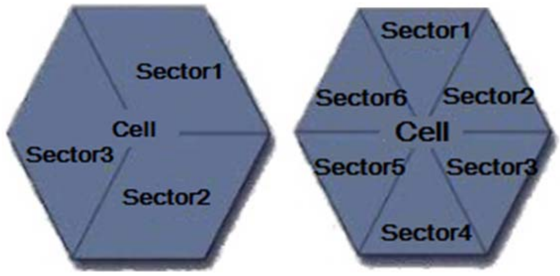


(a) Three sectors (b) Six sectors

Fig. 1 Different cell sectorization schemes

Sectorization could be horizontal (in azimuth plane) and vertical (in elevation plane) as shown in Fig. 2. Vertical sectorization doubles the number of the horizontally sectorized beams. It can also eliminate the need for the complicated vertical tilting. Vertical Sectorization can be used to serve vertically split inner and outer cells, which improves system performance. It is very useful for users that may be at high elevations as shown in Fig. 3. However, with the currently used base station antenna phased array technology, covering narrow sectors requires more radiating elements than antennas covering wider sectors. Thus, costs, weight and size requirements increase as a cell is divided into a greater number of sectors. Therefore, multi-beam base station antennas have been proposed.

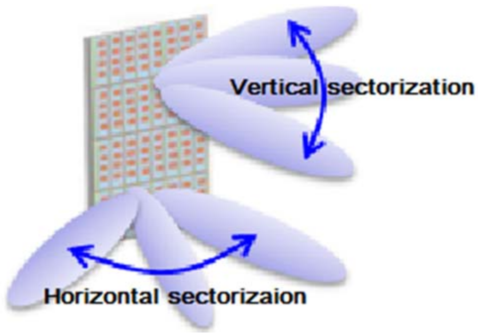
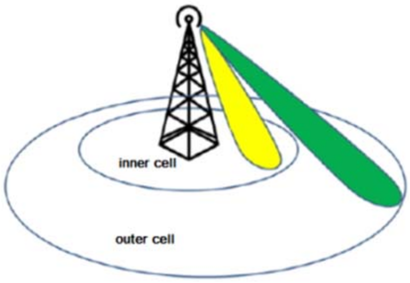
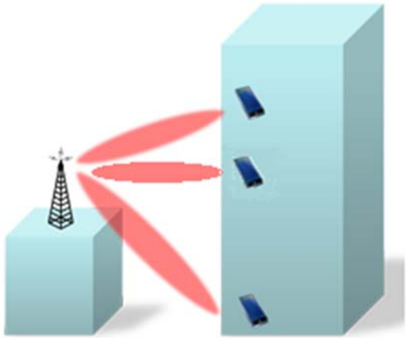


Fig. 2 Vertical and horizontal sectorization

In this paper, a low-cost light-weight broadband multi-beam base station antenna configuration is proposed. It provides simultaneous vertical and horizontal sectorization over the whole LTE Spectrum. It can be used in Full Dimension Multiple Input Multiple Output (FD-MIMO) systems which is a key enabling technology in the Advance Long Term Evolution (LTE-A) and the 5G [2], [3]. The multi-beam base station antenna technology is a good candidate for switched beam smart antennas since every user will always be near to the peak of a beam.



(a) Serving inner and outer cell



(b) Serving different floors of high-rise buildings

Fig. 3 Vertical sectorization in different configurations

II. Current Multi-Beam Base Station Antenna Technology

A single multi-column array may be driven by a feed network to produce multiple beams from a single aperture. Very complicated antennas have been developed using multi-beam forming networks driving planar arrays of radiating elements, such as the Butler matrix [4]. Efforts have been made to make amplitude distribution in antenna array depending on frequency either by using filters (which adds complexity and about three times more components), or frequency dependent power dividers (which significantly reduces the bandwidth). Other classes of multi-beam antennas based on a classic Luneburg cylindrical lens have been tried [5]. The Luneburg lenses are composed of layered structures of dielectric concentric shells, each of a different refractive index. The cost of the classic Luneburg lens is high and its production process is very complicated. Furthermore, these antenna systems have narrow frequency bandwidth.

The currently used multi-beam technologies use several frequency dependent components and, therefore, they have low frequency bandwidths. Furthermore, they do not provide a clear way of adding massive MIMO configurations. In the currently available multi-beam base station antennas, all beams must be tilted in the vertical plane by the same vertical tilt angle. In some of the available multi-beam antennas, the vertical tilt angle is even fixed such that all beams are either not tilted in the vertical plane or they are all tilted by a fixed specific tilt angle.

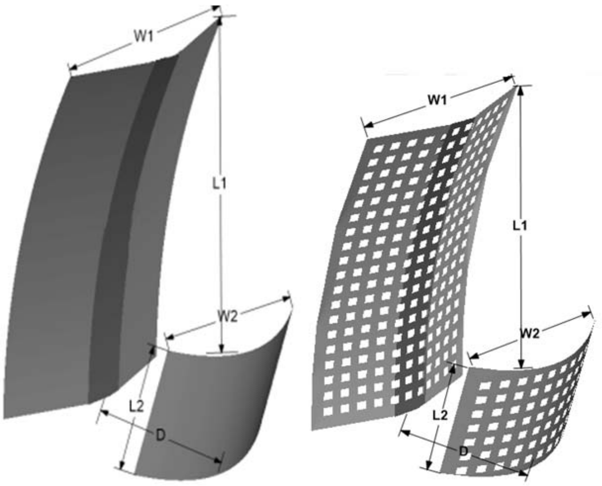
III. Multi-Beam Base Station Antenna Technology

A multi-beam base station antenna providing simultaneous vertical and horizontal sectorization has been developed. It consists of two parabolic cylindrical reflectors and a set of small size broadband resonant feeds [6]. A large number of these feeds operating at different frequency bands can be simultaneously used with the same base station antenna. Hence, the proposed base station antenna can be easily upgraded to any new generation wireless technology by only replacing the feeds instead of replacing the whole antenna. The basic concept of dual parabolic cylindrical reflector antennas and their broadband resonant feeds can be found in [6].

Multi-beam technology can be easily applied to the dual parabolic cylindrical reflector antenna by adding multi-feeds and slightly modifying the dimensions of the main reflector and the sub-reflector. This process is simple and adds much less weight and size than the conventional antenna technology does. The proposed main reflector consists of three intersecting parts having different tilt angles with the horizontal axis as shown in Fig. 4. The proposed sub-reflector covers the three parts of the main reflector. Shifting any feed away from the focus of the sub-reflector will result in tilting the beam that is generated by this feed. So, shifting the feed vertically and/or horizontally will result in tilting the generated beams vertically and/or horizontally. With the determined locations of the multiple feeds, the dimensions of the three parts of the main reflector and the angles between them are then optimized according to the required number of beams and their required beam-widths.

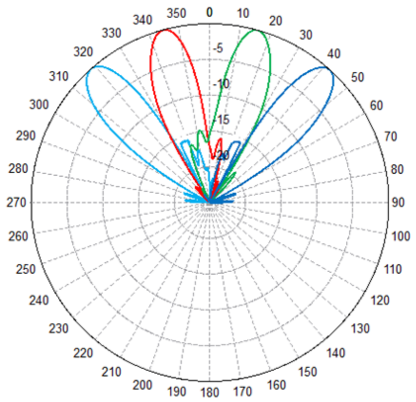
The proposed multi-beam base station antenna can cover all wireless generations and applications regardless of their frequency bands. The whole LTE frequency band (0.45-3.8 GHz) can be covered by a single antenna. The reflectors of the proposed antenna are easy to form from flat sheets with a very high surface accuracy. So, they can be shipped and stored in a form of flat sheets of metal. To significantly reduce the weight of the proposed reflectors, several holes can be punched in their surfaces and also in their radomes as shown in Fig. 4. These holes also make the metallic sheets transparent. Punched antennas are not significantly affected by strong winds and they require simple lightweight towers.

A sample configuration of the proposed multi-beam base station antenna was selected to be a reference design. It is a quad beam configuration, the length L1 of the main reflector is 250 cm while its width W1 is 130 cm. The width of the central part is 50 cm, while the widths of the other two parts are 40 cm each. The length L2 of the sub-reflector is 43 cm while its width W2 is 98 cm. The distance between the sub-reflector and the main reflector D is 76 cm. The focal length of the main reflector is 72 cm, and the focal length of the sub-reflector is 16.1cm. The angle between the intersecting parts of the main reflector is 15.2°.

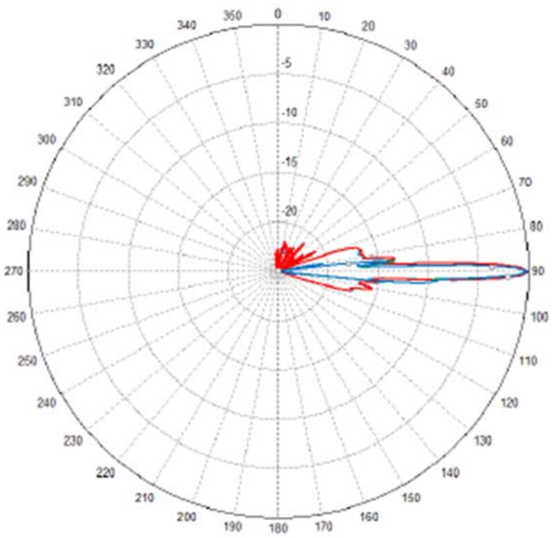


(a) Solid reflectors without punching (b) Punched reflectors

Fig. 4 Base Station antenna drawings



(a) Azimuth plane



(b) Elevation plane

Fig. 5 Radiation patterns of a quad beam antenna covering 120° at 1.8 GHz

Fig. 5 shows the calculated radiation patterns in the azimuth and elevation planes at a sample frequency 1.8 GHz. These patterns were calculated using GTD. A GTD software code was written, especially, for dual parabolic cylindrical reflectors and its accuracy was verified experimentally several times with different configurations [7]. Furthermore, it was specifically verified with some configurations of this proposed base station antenna in the South African National Antenna Test Range, Pretoria, South Africa [8], with the support of Vodafone, in February 2016. Moreover, this base station antenna technology was verified by testing a basic single beam configuration in Vodafone's network.

The electrical specifications of the proposed quad beam antenna are summarized in Table I while the mechanical specifications are listed in Table II. As understood from Table I, two different feeds operating at two different frequency bands have been used together to cover the whole LTE frequency band (600-3800 MHz). The first feed is working from 600 MHz to 960 MHz, while the second one is working from 1400 MHz to 3800 MHz. On the other hand, another feed covering the 450 MHz band can be added to the antenna if needed.

TABLE I
ELECTRICAL SPECS OF THE PROPOSED QUAD BEAM BASE STATION ANTENNA

Frequency Band, MHz	600-960	1400-3800
Gain, dBi	17.3-20.5	19-26
Horizontal Beamwidth, degrees	19-22	12-17.5
Vertical Beamwidth, degrees	8-10	3-5
Front-to-Back Ratio at 180°, dB	≥25	≥25
Return Loss, dB	≥12	≥12
Isolation, ±45°polarizations, dB	≥18	≥18
Isolation between bands, dB	≥25	≥25
Isolation between beams, dB	≥25	≥25
Polarization	±45°	±45°
Impedance	50 ohm	50 ohm

TABLE II
MECHANICAL SPECS OF THE PROPOSED QUAD BEAM BASE STATION ANTENNA

RF Connector Quantity, total	32
Length	250 cm
Width	130 cm
Net Weight, without mounting kit	30.0 kg

IV. CONTROLLING THE OVERLAP BETWEEN THE MULTI-BEAMS

The intersection between the beams can be controlled by optimizing the focal lengths of the sub and main reflectors and also the angles between the three intersecting parts of the main reflector. For example, the gain at the points of intersection between the quad beams that was shown in Fig. 5 can be increased (null filling) as shown in Fig. 6. Of course, this results in more overlap between the beams.

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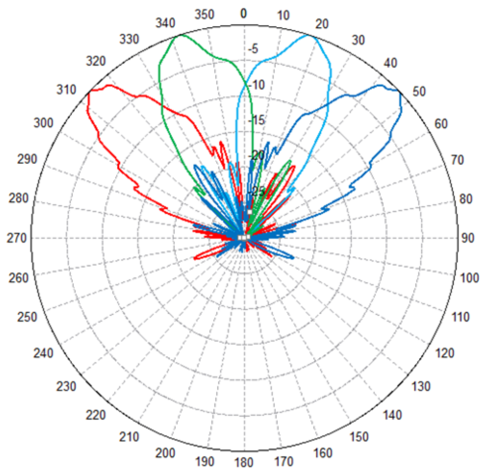


Fig. 6 Radiation patterns of a quad beam antenna with an increased intersection between the beams at 1.8GHz

V. Simultaneous Horizontal and Vertical Sectorization

The quad beam base station antenna configuration was then modified such that it simultaneously generates horizontal and vertical sectorization, which doubles the overall system capacity, as shown in Fig. 7, which is a key enabling technology in LTE-A and 5G. Vertical sectorization can also eliminate the need for the complicated vertical beam tilting. Vertical sectorization can be used to serve vertically split inner and outer cells, which improves system performance. It is very useful for users that may be at high elevations. The azimuth and vertical radiation patterns of the proposed configuration are shown in Fig. 8 at a sample frequency 1.8 GHz. The electrical specifications of the proposed quad beam antenna with vertical and horizontal sectorization are summarized in Table III while the mechanical specifications are the same as listed before in Table II.

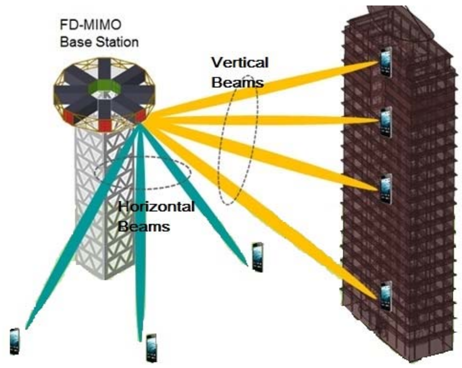
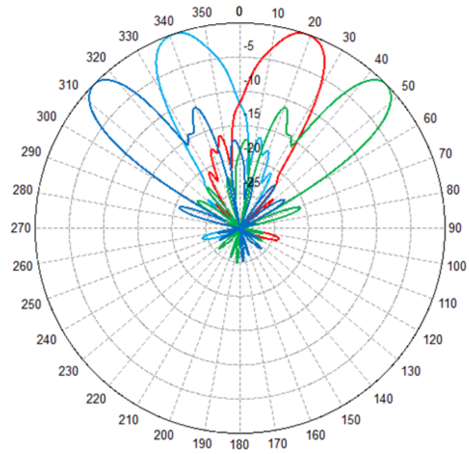
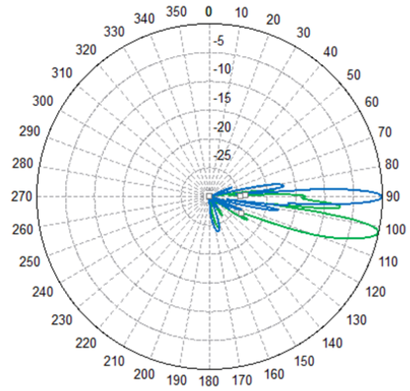


Fig. 7 Using horizontal and vertical sectorization in FD-MIMO



(a) Horizontal Radiation Pattern



(b) Vertical Radiation Pattern

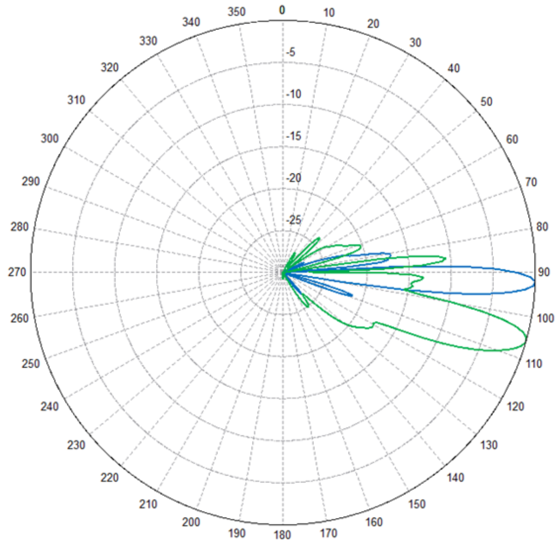
Fig. 8 Radiation patterns of the quad beam antenna at 1.8 GHz with vertical and horizontal sectorization

TABLE III
Electrical Specs of the Quad Beam Antenna with Vertical and Horizontal Sectorization

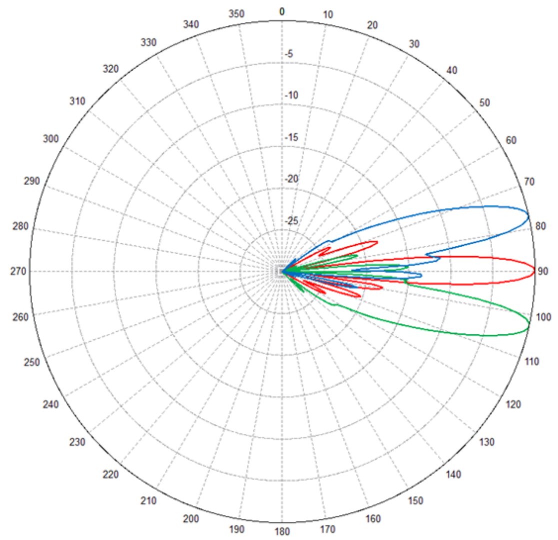
Frequency Band, MHz	600-960	1400-3800
Gain, dBi	16-19	18-24
Horizontal Beamwidth, degrees	20-22	12-17
Vertical Beamwidth, degrees	8-10	3-5
Front-to-Back Ratio at 180°, dB	≥25	≥25
Return Loss, dB	≥12	≥12
Isolation, ±45°polarizations, dB	≥18	≥18
Isolation between bands, dB	≥25	≥25
Isolation between horizontal beams, dB	≥25	≥25
Isolation between vertical beams, dB	≥20	≥22
Polarization	±45°	±45°
Impedance	50 ohm	50 ohm

VI. Different Configurations of Vertical Sectorization

The proposed base station antenna technology can be used to generate different configurations of vertical sectorization at the same time with the horizontal sectorization. For example, two vertically sectorized groups of the horizontally sectorized quad beams may be generated. Both groups of the quad beams may be vertically tilted downwards with two different tilting angles as shown in Fig. 9 (a). Of course, one of these two quad groups can have zero tilting angles as shown in Fig. 8 (b). Similarly, three vertically sectorized groups of the horizontally sectorized quad beams can also be generated. One of these three groups can be tilted downwards and another one can be tilted upwards, while the third group has zero tilting angle as shown in Fig. 9 (b).



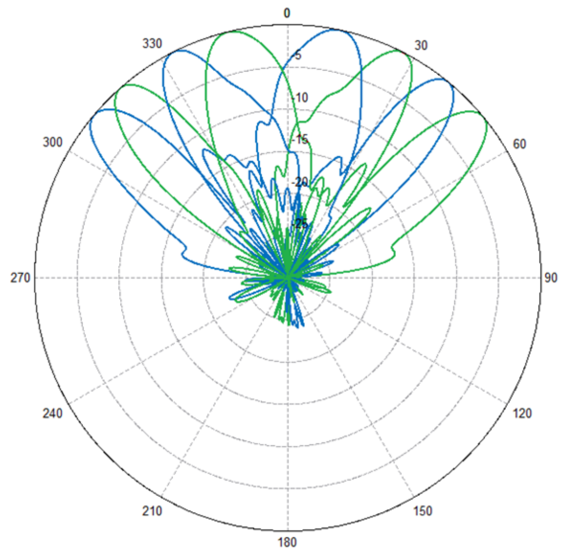
(a) Vertical patterns of two vertical groups of horizontally sectorized beams



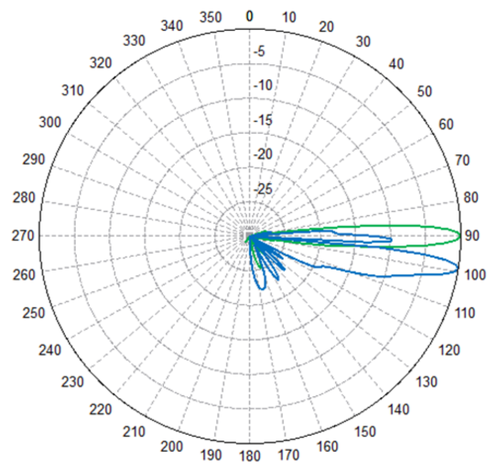
(b) Vertical patterns of three vertical groups of horizontally sectorized beams

Fig. 9 Different configurations of vertical sectorization at 1.8 GHz

The proposed multi-beam base station antenna technology is a good candidate for switched beam smart antennas. With simultaneous vertical and horizontal sectorization, the number of beams can be doubled. For example, a quad beam antenna can generate eight beams covering 120° in two vertical groups. The peaks and the nulls of the beams in the two vertical groups are uniformly distributed as shown in Fig. 10. Similarly, the quad beam antenna can generate 12 beams covering 120° in three vertical groups with different vertical tilt angles. Hence, three quad beam antennas can be used, to cover 360° with 36 beams in three vertical groups as shown in Fig. 11. Hence, every user will always be near to the peak of a beam.



(a) Horizontal Radiation Pattern



(b) Vertical Radiation Pattern

Fig. 10 Peaks of one vertical group of beams aligned above (or close to) nulls of the other group at 1.8 GHz

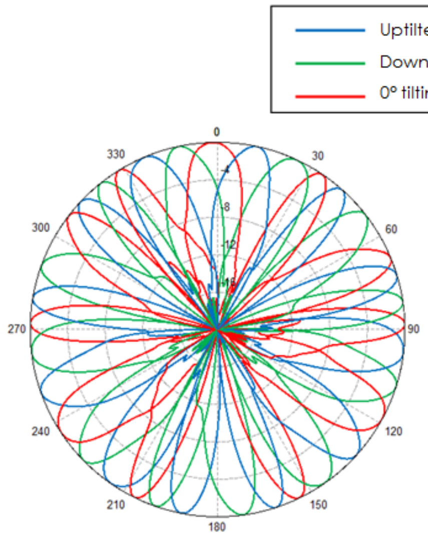


Fig. 11 Horizontal pattern of a configuration for switched beam smart antennas at 1.8 GHz

VII. Conclusion

A low-cost light-weight wide band multi-beam base station antenna has been developed. It could produce an arbitrary number of beams with arbitrary beamwidths. It could have simultaneous horizontal and vertical sectorization, which doubled the overall system capacity. It could be used in FD-MIMO, which is a key enabling technology in LTE-A and 5G. It is expected to drastically improve the system throughput beyond what is possible in conventional LTE systems. Vertical sectorization doubled the number of the horizontally sectored beams. It could also eliminate the need for the complicated vertical tilting. Vertical sectorization could be used to serve vertically split inner and outer cells, which improves system performance. It was very useful when serving users that may be located on different floors with different heights, especially if some of them were at very high floors. The proposed base station antenna technology could be used to generate different configurations of vertical sectorization with the quad horizontal sectorization. For example, two vertical groups and three vertical groups of the horizontally sectorized quad beams were generated.

The proposed base station antenna could include up to 72 ports or even more, which could facilitate any further needed capacity expansions. The proposed multi-beam base station antenna could cover all wireless applications and generations, regardless of their frequency bands. For example, it could cover the whole LTE frequency band (0.45-3.8 GHz) It had too many design parameters with too many degrees of freedom that can be optimized together to yield any desirable performance and any special requirements. The proposed multi-beam base station antenna technology could be used in smart antennas since every user will always be near to the peak of a beam.

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References

[1] A.K.M Fazlul Haque, Mir Mohammad Abu Kyum, Md. Baitul Al Sadi, Mrinal Kar and Md. Fokhray Hossain,"Performance Analysis of UMTS Cellular Network using Sectorization Based on Capacity and Coverage", (IJACSA) International Journal of Advanced Computer Science and Applications, Vol. 2, No. 6, 2011, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.622.6413&rep=rep1&type=pdf .

[2] Salam Akoum, Joydeep Acharya, Amitav Mukherjee, "Method of operating vertical sectorization in FD-MIMO systems", https://www.google.com/patents/WO2015152931A1?cl=en.

[3] Taeyoung Kim, "Enabling Massive MIMO in Cellular Systems: FD-MIMO in 3GPP LTE", Communications Research Team, DMC R&D Center Samsung Electronics Corp, http://www.kics.or.kr/storage/mailing/20140520/140520_174652526.pdf

[4] Chia-Chan Chang, Ruey-Hsuan Lee, and Ting-Yen Shih, "Design of a Beam Switching/Steering Butler Matrix for Phased Array System", IEEE Transactions on Antennas and Propagation, Vol. 58, NO. 2, February 2010, ieeexplore.ieee.org/iel5/8/5405121/05345749.pdf

[5] Robert Milne, "Dipole Array Lens Antenna", IEEE Transactions on Antennas and Propagation, Vol. AP-30, NO. 4, July 1982, ieeexplore.ieee.org/document/1142835.

[6] Mohamed Sanad, "A Novel Foldable/Deployable Base Station Antenna for All Generations of Wireless Applications including the Whole LTE Spectrum", Transaction on IoT and Cloud Computing, 2013, http://amantantennas.com/am/library/pdfs/2012/paper_N.pdf

[7] M. Sanad and L.Shafai, "Generation of Elliptical Beams of Arbitrary Beam Ellipticity and Low Cross-Polarization Using Offset Dual Parabolic Cylindrical Reflectors", Canadian Journal of Electrical Engineering, Vol.13, No.3, pp.99-105.

[8] http://www.paardefontein.co.za/. Accessed on 15/11/2017

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Dr. Sanad directed and achieved several research projects for some of the largest telecommunication companies in the USA and the world such as Nokia Mobile Phones, Texas Instruments, Amplica Inc, Metricom Inc, Snap Track Inc, Antennas America Inc, HiPoint Technology Inc, Aetherwire Inc and others. He established antenna research centers for some of these companies from scratch and He directed their technical strategic planning. Dr. Sanad is the one who invented the first internal (embedded) integrated microstrip antenna for cellular phones when he was leading the antenna development team at Nokia Mobile Phones in San Diego, California.

Recently, Dr. Sanad has invented another novel technology, which is a handset antenna that covers the whole LTE (4G) spectrum plus the WiMAX, 2G and 3G bands. A single passive antenna could cover all the important wireless applications without using any matching or tuning circuits. This makes it feasible to use the same handset everywhere in the world (global roaming) with all generations of wireless applications included (G2, G3, G4, ------ etc.). On the other hand, Dr. Sanad has invented a new multiple beam cellular base station antenna that can simultaneously cover an unlimited number of wireless applications, regardless of their frequency bands. This will significantly enhance the efforts to develop new wireless technologies and add new applications.

In March, 2012, Mohamed Sanad won the 2012 Innovation Prize for Africa, "IPA", (US$100,000) (http://www.innovationprizeforafrica.org/media.asp). "IPA" was awarded by the United Nation Economic Commission for Africa "UNECA" and the African Innovation Foundation "AIF" in recognition of one of his base station

antenna innovations.

Noha Hassan is an associate professor at the Department of Biomedical Engineering, Cairo University. Her research interests are focused on the interaction between electromagnetic waves and the human body as well as therapeutic applications of EMFs. She has published several papers in International journals and conferences about the interaction between antennas and the human body, antenna shielding techniques and antenna applications in biomedical instruments. Dr. Hassan was graduated from the Department of Biomedical Engineering, Cairo University. She got her Ph.D. degree from the Department of Biomedical Engineering, University of Nevada, Reno, USA. Her Ph.D. thesis was on the interaction of electromagnetic fields with biological cells as well as modeling the interaction with cell aggregates.