ICDT 2024

The Nineteenth International Conference on Digital Telecommunications

May 26 - 30, 2024

Barcelona, Spain

ICDT 2024 Editors

Dragana Krstic, University of Niš, Serbia

Stan McClellan, Texas State University - San Marcos, USA

ICDT 2024

Foreword

The Nineteenth International Conference on Digital Telecommunications (ICDT 2024), held between May 26-30, 2024 in Barcelona, Spain, continued a series of special events related to telecommunications aspects in multimedia environments. The scope of the conference was to focus on the lower layers of systems interaction and identify the technical challenges and the most recent achievements.

High quality software is not an accident; it is constructed via a systematic plan that demands familiarity with analytical techniques, architectural design methodologies, implementation polices, and testing techniques. Software architecture plays an important role in the development of today's complex software systems. Furthermore, our ability to model and reason about the architectural properties of a system built from existing components is of great concern to modern system developers.

Performance, scalability and suitability to specific domains raise the challenging efforts for gathering special requirements, capture temporal constraints, and implement service-oriented requirements. The complexity of the systems requires an early stage adoption of advanced paradigms for adaptive and self-adaptive features. Online monitoring applications, in which continuous queries operate in near real-time over rapid and unbounded "streams" of data such as telephone call records, sensor readings, web usage logs, network packet traces, are fundamentally different from traditional data management. The difference is induced by the fact that in applications such as network monitoring, telecommunications data management, manufacturing, sensor networks, and others, data takes the form of continuous data streams rather than finite stored datasets. As a result, clients require long-running continuous queries as opposed to one-time queries. These requirements lead to reconsider data management and processing of complex and numerous continuous queries over data streams, as current database systems and data processing methods are not suitable. Event stream processing is a new paradigm of computing that supports the processing of multiple streams of event data with the goal of identifying the meaningful events within those streams.

We take here the opportunity to warmly thank all the members of the ICDT 2024 technical program committee, as well as all the reviewers. The creation of such a high quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and effort to contribute to ICDT 2024. We truly believe that, thanks to all these efforts, the final conference program consisted of top quality contributions.

We also thank the members of the ICDT 2024 organizing committee for their help in handling the logistics and for their work that made this professional meeting a success. We hope that ICDT 2024 was a successful international forum for the exchange of ideas and results between academia and industry and to promote further progress in the domain of digital telecommunications. We also hope that Barcelona provided a pleasant environment during the conference and everyone saved some time to enjoy the historic charm of the city

ICDT 2024 Chairs:

ICDT Steering Committee
Stan McClellan, Texas State University - San Marcos, USA
Bernd E. Wolfinger, University of Hamburg, Germany
Amalia Miliou, Aristotle University of Thessaloniki, Greece

ICDT Publicity Chairs

Laura Garcia, Universidad Politécnica de Cartagena, Spain

Sandra Viciano Tudela, Universitat Politecnica de Valencia, Spain

ICDT 2024

Committee

ICDT Steering Committee

Stan McClellan, Texas State University - San Marcos, USA
Bernd E. Wolfinger, University of Hamburg, Germany
Amalia Miliou, Aristotle University of Thessaloniki, Greece

ICDT 2024 Publicity Chairs

Laura Garcia, Universidad Politécnica de Cartagena, Spain
Sandra Viciano Tudela, Universitat Politecnica de Valencia, Spain

ICDT 2024 Technical Program Committee

Arsalan Ahmad, National University of Sciences and Technology, Islamabad, Pakistan / Trinity College Dublin, Ireland
Ayad Al-Adhami, Plymouth University, UK / University of Technology, Iraq
Babak Barazandeh, University of Southern California, USA
Ilija Basicevic, University of Novi Sad, Serbia
Pierre Beauseroy, Université de Technologie de Troyes, France
Larbi Boubchir, University of Paris 8, France
Vittorio Curri, Politecnico di Torino, Italy
Abhishek Das, Aliah University, Kolkata, India
Somaieh Davar, Concordia University, Canada
Laura-Maria Dogariu, University Politehnica of Bucharest, Romania
Tan Do Duy, Ho Chi Minh City University of Technology and Education, Vietnam
Zakaria Abou El Houda, University of Montreal, Canada
David Espes, Université de Bretagne Occidentale, France
Mário Ferreira, University of Aveiro, Portugal
Mohamed Fezari, Annaba University, Algeria
Rita Francese, Università di Salerno, Italy
Felix J. Garcia-Clemente, University of Murcia, Spain
Benedict R. Gaster, University of West of England, UK
Pantea Nadimi Goki, TeCIP Institute Scuola Superiore Sant'Anna, Italy
Carlos Guerrero, University of Balearic Islands, Spain
Makhlouf Hadji, Technological research Institute SystemX, France
Ruimin Hu, Wuhan University, China
Yishan Jiao, Pearson Education, USA
Mohammed Jouhari, Mohammed VI Polytechnic University, Benguerir, Morocco
Maria Kallionpaa, Hong Kong Baptist University, Hong Kong
Fazia Karaoui, University of Science and Technology Houari Boumediene of Algiers, Algeria
Wen-Hsing Lai, National Kaohsiung University of Science and Technology, Taiwan
Jan Lansky, University of Finance and Administration, Czech Republic

Moonjin Lee, Korea Maritime and Ocean University / University of Science & Technology Korea / Research Institute of Ship and Ocean engineering, Korea
Isaac Lera, University of the Balearic Islands, Spain
Peng Liu, Prometheus Computing / National Institute of Standards and Technology, USA
Xiaoli Liu, University of Helsinki, Finland
Jaime Lloret Mauri, Polytechnic University of Valencia, Spain
Vladimir Lyashev, Huawei Technologies Co. Ltd. - Moscow Research Center, Russia
Min Ma, Google speech, USA
Adnan Mahmood, Macquarie University, Australia
S. Manoharan, University of Auckland, New Zealand
Alexandru Martian, University Politehnica of Bucharest, Romania
Stan McClellan, Texas State University, USA
Weizhi Meng, Technical University of Denmark, Denmark
Amalia Miliou, Aristotle University of Thessaloniki, Greece
Ioannis Moscholios, University of Peloponnese, Greece
Dmitry Namiot, Lomonosov Moscow State University, Russia
Khoa Nguyen, Carleton University, Canada
Morteza Noshad, University of Michigan, USA
Patrik Österberg, Mid Sweden University, Sweden
Constantin Paleologu, University Politehnica of Bucharest, Romania
Euthimios Panagos, Perspecta Labs Inc., USA
Liyun Pang, Huawei Germany Research Center, Germany
Maciej Piechowiak, Kazimierz Wielki University, Poland
Luca Potì, Universitas Mercatorum | CNIT, Italy
Andy Reed, The Open University, UK
Eric Renault, IMT-TSP, France
Ravikant Saini, Indian Institute of Technology Jammu, India
Abdel-Badeeh M. Salem, Ain Shams University, Cairo, Egypt
Ana Serrano Tellería, University of Castilla La Mancha, Spain
Akbar Sheikh-Akbari, Leeds Beckett University, UK
M. Estela Sousa-Vieira, University of Vigo, Spain
Cristian Lucian Stanciu, University Politehnica of Bucharest, Romania
Da-Wen Sun, University College Dublin, Ireland
Christopher Tegho, Calipsa, London, UK
Giorgio Terracina, Università della Calabria, Italy
Tony Thomas, Indian Institute of Information Technology and Management - Kerala, India
Božo Tomas, University of Mostar, Bosnia and Herzegovina
Laszlo Toth, University of Szeged, Hungary
Scott Trent, IBM Research - Tokyo, Japan
Ming Tu, JD AI Research, Mountain View, USA
Adriano Valenzano, CNR-National Research Council, Italy
Rob van der Mei, Centre for Mathematics and Computer Science (CWI), Amsterdam, Netherlands
P. Vijayakumar, University College of Engineering Tindivanam, India
Calin Vladeanu, University Politehnica of Bucharest, Romania
Sergey V. Volvenko, Peter the Great St. Petersburg Polytecnic University, Russia
Haoxin Wang, Toyota Motor North America R&D InfoTech Labs, USA
Lei Wang, University of Connecticut, USA
Bernd E. Wolfinger, University of Hamburg, Germany

Qilian (Vision) Yu, University of California, Davis, USA

Zbigniew Zakrzewski, UTP University of Science and Technology, Poland

Ligang Zhang, School of Engineering and Technology - Central Queensland University, Australia

Piotr Zwierzykowski, Poznan University of Technology, Poland

Copyright Information

For your reference, this is the text governing the copyright release for material published by IARIA.

The copyright release is a transfer of publication rights, which allows IARIA and its partners to drive the dissemination of the published material. This allows IARIA to give articles increased visibility via distribution, inclusion in libraries, and arrangements for submission to indexes.

I, the undersigned, declare that the article is original, and that I represent the authors of this article in the copyright release matters. If this work has been done as work-for-hire, I have obtained all necessary clearances to execute a copyright release. I hereby irrevocably transfer exclusive copyright for this material to IARIA. I give IARIA permission or reproduce the work in any media format such as, but not limited to, print, digital, or electronic. I give IARIA permission to distribute the materials without restriction to any institutions or individuals. I give IARIA permission to submit the work for inclusion in article repositories as IARIA sees fit.

I, the undersigned, declare that to the best of my knowledge, the article is does not contain libelous or otherwise unlawful contents or invading the right of privacy or infringing on a proprietary right.

Following the copyright release, any circulated version of the article must bear the copyright notice and any header and footer information that IARIA applies to the published article.

IARIA grants royalty-free permission to the authors to disseminate the work, under the above provisions, for any academic, commercial, or industrial use. IARIA grants royalty-free permission to any individuals or institutions to make the article available electronically, online, or in print.

IARIA acknowledges that rights to any algorithm, process, procedure, apparatus, or articles of manufacture remain with the authors and their employers.

I, the undersigned, understand that IARIA will not be liable, in contract, tort (including, without limitation, negligence), pre-contract or other representations (other than fraudulent misrepresentations) or otherwise in connection with the publication of my work.

Exception to the above is made for work-for-hire performed while employed by the government. In that case, copyright to the material remains with the said government. The rightful owners (authors and government entity) grant unlimited and unrestricted permission to IARIA, IARIA's contractors, and IARIA's partners to further distribute the work.

Table of Contents

Experimental Investigations to Combat Fading in the NR of 5G Applications with Antenna Pattern Diversity

Abdelkader Mosbah and Mustafa Benssalah
Ecole Militaire Polytechnique, EMP
Algiers, Algeria
e-mail: aek_mosbah@yahoo.fr, benmusta@gmail.com

Ali Mansoul
Telecom Division, CDTA
Algiers, Algeria
e-mail: amansoul@cdta.dz

Abstract — **This work presents a new design and implementation of an Antenna Array with two different elements, to combat interference and multipath effects that occur in the NR of 5G applications. In fact, communication systems impose severe constraints in terms of channel capacity and transmission quality, while keeping the interference and multipath levels low. In this paper, we propose a new approach to combat fading phenomena without requiring any statistical knowledge of the propagation channel parameters. This new design uses two different elements array that adjust the signal phase shifter to maximize the combined received power proportionally to its gradient magnitude. The proposed architecture was implemented on a Universal Software Radio Peripheral (USRP) to perform experimental measurements and examine the performance of this approach. From the obtained results, we can note a 3 dB improvement over the basic approach that was with two identical antennas.**

Keywords-Antennas; Antenna Array; Fading; Diversity; Multi-path; wireless communication; USRP.

I. INTRODUCTIONH

Mobile communication systems have been evolving steadily in recent years. It has experienced different generations of technology developed from the first generation (1G) to the fourth generation (4G). However, the future looks much brighter for the next fifth-generation (5G) technology, offering better services and supporting more devices with new applications. [1]-[4]. The transmission channel in communication systems is undergoing at the different physical phenomena like scattering, diffusion and diffraction, resulting in interference and multipath effects in wireless communications, while keeping these effects low [5][6]. The fading affects the Quality of Service (QoS) in advanced wireless communication systems. To combat this phenomenon, different approaches have been proposed in the literature, such as increasing the power of emitting or using diversity techniques. Nevertheless, power is expensive, but diversity techniques remain the widely used to improve system performance, which can be divided to space diversity, polarization diversity, frequency diversity and diagram diversity [7][8]. The idea behind these approaches is to modify the different multipath component phases to avoid destructive combinations. The diversity techniques are based on the principle that several versions or statistically independent copies of the transmitted signal arrive at a receiver, each carrying the same information. They are then combined so that the resulting signal will be with less fading [7][8]. Having another antenna in space implies a diversity of

space; the different paths phases arriving at the second antenna are different due to the difference in the physical path lengths. By varying the electromagnetic wave polarization (polarization diversity), the direction of the electromagnetic field components is modified; it varies the reflection, diffraction and scattering mechanisms, which result in a difference in the different path components, so different phases. According to change in the electromagnetic waves frequencies (frequency diversity), the wavelength is changed, causing the electrical lengths of the different paths to vary, resulting in different phases. By differentiating the kind of antenna, the electromagnetic waves will undergo different diagrams. To succeed pattern diversity, it is necessary that the shapes of the antenna radiation patterns will be different; i.e., each antenna will therefore capture a maximum of power in different directions and then probably independent. Since signal fading varies according to the direction of arrival, the diagram diversity is easily exploitable and interesting. This technique has been applied and compared to the space diversity with the identical antennas on the base stations in mobile communications. The results showed that two types of diversity give comparable performances in urban areas [7][8]. In general, diagram diversity is usually combined with spatial diversity.

In this work, we present in Section II a new approach based on space and diagram diversity to combat the fading effect based on the improvement of the adaptive algorithm published in [9]. Section 3 explains the system studied which consists of a set of two different elements with a digital phase shift introduced at one of the two antennas of the array to combine the signals received in order to maximize the output power of the array, without the need for channel statistics. Therefore, in section IV, experimental measurements are carried out by implementing the new approach on Universal Software Peripheral Radio (USRP) of National Instruments.

II. THE PROPOSED APPROACH

In order to combat fading effect and improve the received signal quality, the receiver power must be maximized to be exploited. The proposed approach is based on the work presented in [9]. For this aim, a 2-elements array spaced with a distance d is used in a feedback loop that adjusts the phase of one of the two signals based on the proportional adaptive phase-shift system, as shown in Figure 1.
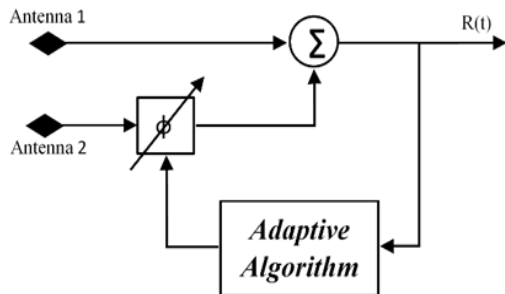
Figure 1. The proposed diversity approach

For simplicity, the same assumptions of [9] are made here and the received signal at antenna 1 is expressed as follows:

$$r_1(t) = A\,cos(\omega t + \theta) \quad (1)$$

and the received signal at the antenna 2 is given as follows:

$$r_2(t) = A\,cos(\omega t + \theta + \rho) \quad (2)$$

Where A is the amplitude considered here to be constant and the same at the two antennas, ω is the central angular frequency, $\rho = 2\pi d / \lambda$ and θ is a random variable uniformly distributed between 0 and 2π rad.

The combined signal is then:

$$R(t) = r_1(t) + r_2(t) \quad (3)$$

$$R(t) = A\,cos(\omega t + \theta) + A\,cos(\omega t + \theta + \rho - \phi) \quad (3.1)$$

The output power can then be written as:

$$P_R = E\{R^2(t)\} = A^2 + A^2 cos(\rho - \phi) \quad (4)$$
$$= A^2(1 + cos(\rho - \phi)) \quad (5)$$

where $E\{\}$ represents the mean value. To maximize the power P_R, it must be maximized $cos(\rho - \phi)$ implies that $(\rho - \phi) = 0$.

On the other hand, for large phase shifts between $r_1(t)$ and $r_2(t)$ (i.e., when $\rho - \phi = \pi$ or close to this value), the received power is around zero 0, causing important fading. Therefore, to maximize the received power, the phase shifter must provide a phase shift that makes the signals from two antennas in-phase.

Consequently, to maximize the received power PR applying the iterative algorithm of all or nothing, to the two-antenna network to adjust the phase, so one can write:

$$\phi(i+1) = \phi(i) + \vartheta * sign[(dP_R(t))/dt] \quad (6)$$

Where $\phi(i+1)$ and $\phi(i)$ are the phase shift at the $(i+1)^{th}$ and i^{th} iterations, respectively and ϑ is a weighting coefficient.

The key aspect of this algorithm is that it does not depend on the level of the received power and offers a good performance in terms of convergence speed. In [9], the phase

adjustment is done sequentially by incrementing or decrementing the phase shift with a constant step according to the gradient sign of the combined received power with the same antenna.

Therefore:

If $sign[(dP_R(t))/dt] > 0 \Rightarrow \phi(i+1) = \phi(i) + \vartheta \quad (7)$

If $sign[(dP_R(t))/dt] < 0 \Rightarrow \phi(i+1) = \phi(i) - \vartheta \quad (8)$

To apply this algorithm in a two-element antenna array, a single phase-shifter is used at antenna 2, as shown in Figure 1.

This approach has proven to be able to improve the received power but with limited performance. This limitation is due to the fact that the two antennas are identical so, for a deep fading in a given direction of radiation, the two antennas will be affected by its effect which will be able to weaken the received power by the system, and even if there will be power compensation will always be weak.

To overcome this problem, it is proposed to use two different antennas, implying two different patterns, which makes the probability of having both signals received in the same direction or at the same time small and insignificant.

III. IMPLEMENTATION

To test experimentally the proposed approach, the algorithm has been implemented on two pairs of Universal Software Radio Peripheral (USRP 2921 and 2932) platforms from National instruments [10]. These platforms are software programmable radio transceivers, programmable with NI LabView software and are suitable for physical layer communication systems prototyping. These modules have the ability to transmit and receive RF signals across the bands [0.4GHz - 4.4GHz] and [4.9GHz - 5.9GHz]. The clock synchronization aspect between the two platforms is carried out using wire synchronization, where two identical monopole antennas are used to acquire RF signals in two different frequencies of the Operating Bands in FR1 of 5G applications (ex : 2.5 GHz and 5.88GHz) transmitted from a Network Analyzer (as shown in Figure 2).
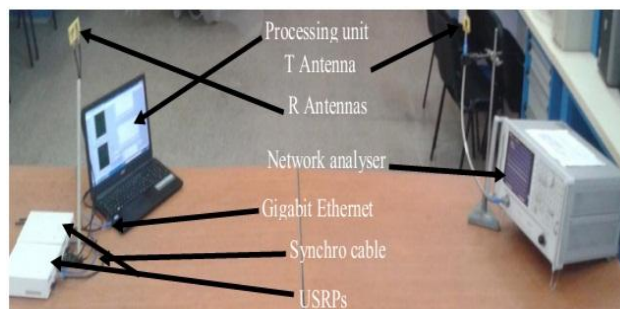

Figure 2. The adaptive dual-antenna array with the communication chain.

The communication chains implemented at the USRP's both start with an amplifying stage where the gains are adjusted to get signals of the same strength of the two antennas. The phase shift is performed directly at the RF side, and not the IF, using a Virtual Instrument of LabView.

Furthermore, to ensure that the measurement setup fulfills the far field condition, the transmitter is separated by a distance greater than $D2/\lambda$, where D is the largest dimension of the antenna and λ is the signal wavelength. The measurements have been done indoor a Lab room of 10 x 5 meters with a lot of equipment inside.

Two different measurement setups have been used. In the first one, the reception is done with the same antenna (monopole). In the second setup, the reception is done with a different antenna (monopole radiate horizontally and Vivaldi radiate vertically upwards). These antennas are simulated with CST (Computer Simulation Technology) [11] software and then designed and fabricated shown in Figure 8. We present in the next paragraph theirs performance:
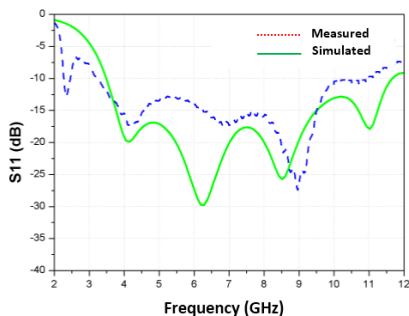
Figure 3.   The S11 parameter of realized Vivaldi antennas.
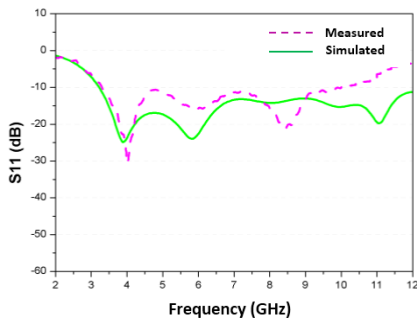

Figure 4.   The S11 parameter of realized Monopole antennas.

The two antennas: Vivaldi and Monopole are ULB antennas that cover virtually the same band as shown in Figure 3 and Figure 4. These antennas are designed with a minimum of mutual coupling or the S12 and S21 parameters are identical to see the isolation and they are less than -15 dB over the operating frequency band as shown in Figure 5.
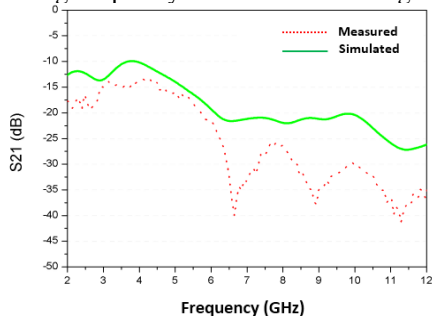

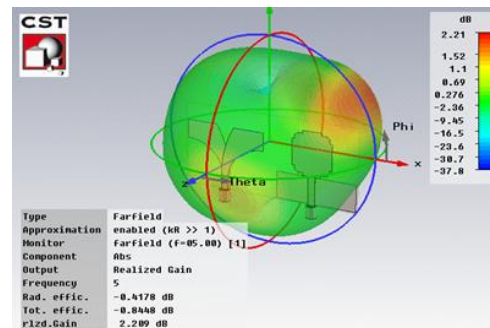Figure 5.   The S11 parameter of realized Monopole antennas.

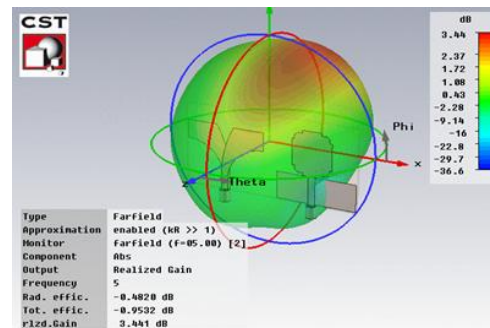Figure 6.   Radiation patterns of Vivaldi antenna.

Figure 7.   Radiation patterns of Monopole antenna

The radiation of the two antennas are shown in Figure 6 and Figure 7.

IV.   EXPERIMENTAL VALIDATION

To evaluate the performance of the proposed approach, experimental measurements are carried out according to situations. The first one considers two identical antennas similar to the work published in [9] and the second adopts two different antennas (designed and fabricated in this work). Figure 9 illustrates the different received measured powers for the two identical and different antennas, respectively. As we can see, the received signals undergo the fading phenomenon. This is due to the multipath propagation, imposing destructive combinations of the received signal.

Figure 8.   Photo of the fabricated antenna array.

The power levels for antenna 1 and antenna 2 are low because they are on average of -71dBm with deep-fad

reaching -80dBm. As we can see in Figure 9, the proposed approach performance exceed those obtained with two identical antennas, such that we have, respectively, average values of -62dBm and -65dBm, as maximum values -60 dBm and -63 dBm and -66.5 dBm and -71 dBm as minimum values. So the proposed approach enormously improve the original approach by means of 3 dB, which itself improves the power [9].
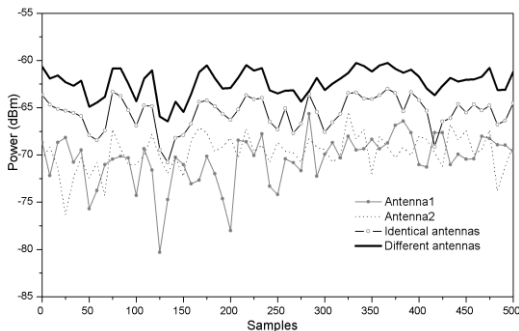

Figure 9.   Measured received powers.

However, the first approach behaves well in conditions where the two signals are uncorrelated; it can be observed that it achieves performance closer to those of the new approach. Nevertheless, the new approach results always surpass the other by an average value of 3 dB.

TABLE I.   DIFFERENT POWER VALUES

Feature (dBm)	Min value	Means value	Max value
Reception with antenna 1	-80.2	-71.9	-65.9
Reception with antenna 2	-76.45	-70.4	-65.8
Reception with identical antenna	-71.30	-65.8	-62.9
Reception with different	-65.41	-62.2	-60.2
Comparison	-5.89	3.6	2.7

Another performance criterion that can be used to compare the two approaches is the Cumulative Distribution Function (CDF), it gives the cumulative probability that the received power level is less than a given value. Figure 10 illustrates the CDF for antenna 1, antenna 2 and the applied algorithm in both cases of identical and different antennas.

As we can see in Figure 10, the algorithm with the proposed approach outperforms all the other ones.

For example, at -66 dBm, with the proposed approach, only 5% of the signal is below this value (95% of the signal is greater than this power level) while with the original approach 30% of the signal is lower at this value. For another reading, for example, the power level corresponding to 10% probability (90% of the signal is greater than this power level) is -64dBm for the algorithm with two different antennas and -67dBm with two identical antennas that gives about 3 dB difference.
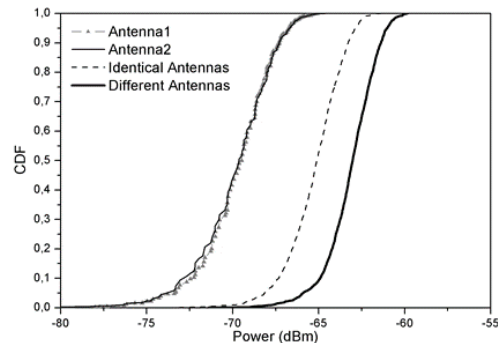

Figure 10.   Measured received powers.

V.   CONCLUSION

In this paper, a new approach with an adaptive algorithm to combat fading phenomenon has been proposed with a two different (02)-element array. This technique allows adjusting the phase of one of the two antennas in proportion to the variation of the received power by the two different diagrams combined to maximize this power. To evaluate its performance, an experimental measurement was carried out to measure the power received and calculate the CDF in order to compare the results obtained with our approach that uses two different antennas with the two identical antennas. All the results show clearly that the approach used with enormously improves the received power making it recommended generally for advanced wireless communications and particularly for NR of 5G applications.

REFERENCES

[1] G. Baudoin, "coll., "Radiocommunications numériques/1: Principes, Modélisation et Simulation", ISBN 978-2-10-050514-2, Dunod Paris 2007.

[2] J. G. Andrews, et al., "What will 5G be?," IEEE Journal on selected areas in communications, vol. 32, pp. 1065-1082, 2014.

[3] A. A. R. Saad and H. A. Mohamed, "Printed millimeter-wave MIMO-based slot antenna arrays for 5G networks," AEU-International Journal of Electronics and Communications, vol. 99, pp. 59-69, 2019.

[4] Z. Ying, "Antennas in cellular phones for mobile communications," Proceedings of the IEEE, vol. 100, pp. 2286-2296, 2012.A. Aragon-Zavala, Antennas and propagation for wireless communication systems: John Wiley & Sons, 2008.

[5] J. D. Parsons and P. J. D. Parsons, "The mobile radio propagation channel," 1992.

[6] C. B. Dietrich Jr, K. Dietze, J. R. Nealy, and W. L. Stutzman, "Spatial, polarization, and pattern diversity for wireless

andheldterminals," Antennas and Propagation, IEEE Transactions on, vol. 49, pp. 1271-1281, 2001.

[7] R. G. Vaughan, "Pattern translation and rotation in uncorrelated source distributions for multiple beam antenna design," Antennas and Propagation, IEEE Transactions on, vol. 46, pp. 982-990, 1998.

[8] P. L. Perini and C. L. Holloway, "Angle and space diversity comparisons in different mobile radio environments," Antennas and Propagation, IEEE Transactions on, vol. 46, pp. 764-775, 1998.

[9] T. Denidni, D. McNeil, and G. Y. Delisle, "Experimental investigations of a new adaptive dual-antenna array for handset applications," Vehicular Technology, IEEE Transactions on, vol. 52, pp. 1417-1423, 2003.

[10] 10. USRP user guide https://labview.developpez.com/

[11] 11. CST User-guide, https://space.mit.edu/RADIO/Documentation/CST

[12] 12. Y. T. Lo and S. Lee, Antenna Handbook: theory, applications, and design: Springer Science & Business Media, 2013.

[13] 13. W. K. Toh, Z. N. Chen, X. Qing, and T. S. P. See, "A planar UWB diversity antenna," IEEE Transactions on Antennas and Propagation, vol. 57, pp. 3467-3473, 2009.

[14] 14. R. Arora, A. Kumar, S. Khan, and S. Arya, "Design Analysis and Comparison of HE and E Shaped Microstrip Patch Antennas," International Journal on Communications Antenna and Propagation, vol. 4, pp. 27-31, 2014.

[15] 15. S. Zhang and G. F. Pedersen, "Mutual coupling reduction for UWB MIMO antennas with a wideband neutralization line," IEEE Antennas and Wireless Propagation Letters, vol. 15, pp. 166-169, 2015.J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, pp.68–73, 1892,

[16] 16. M. Bithikh, R. Aksas, H. Kimouche, and A. Azrar, "New UWB antenna design for wireless communications," Microwave and Optical Technology Letters, vol. 54, pp. 692-697, 2012.

[17] 17. A. F. Molisch, Wireless communications vol. 34: John Wiley & Sons, 2012.

[18] 18. A. Goldsmith, Wireless communications: Cambridge university press, 2005.