International Journal of Electrical and Computer Engineering (IJECE)
Vol. 10, No. 3, June 2020, pp. 2579~2588
ISSN: 2088-8708, DOI: 10.11591/ijece.v10i3.pp2579-2588

Performance assessment of antenna array for an unmanned air vehicle

Ameer H. Ali, Mohannad A. M. Al-Ja'afari, Saif H. Abdulwahed
Najaf Technical Institute, Al-Furat Al-Awsat Technical University, Iraq

Article Info

Article history:

Received May 10, 2019
Revised Nov 17, 2019
Accepted Nov 26, 2019

Keywords:

Antenna Array Element
GPS
Phase Array
Switched Beam
UAV

ABSTRACT

In this paper, the performance of Linear Antenna Array Element (LAAE) has been evaluated at the Base Station (BS) with a different number of elements for Unmanned Air Vehicle UAV application. The Switched Beam (SB) and Phase Array (PA) have been used as a steering beam mechanism. The beam steering tracker is based on the GPS points of the UAV and the BS. In addition, the Misalignment angle has been analyzed for SB and PA corresponding to the maximum speed of the UAV. The compression between SB and PA in term of Bit Error Rate (BER) vs. Signal to Noise Ratio (SNR) and BER vs. Misalignment angle have been examined by using Matlab. The results show that the PA has better performance than SB in both terms under Additive White Gaussian Noise (AWGN) channel with an interference signal. When the number of the elements is eight provides longer distance than four by the factor (1.5 in SB case and 2 in PA case) and wider Misalignment angle range than twelve by factor (2 in SW case and 3 in PA case). Therefore, it is becoming a useful option for many applications.

Corresponding Author:

Ameer H. Ali,
Najaf Technical Institute,
Al-Furat Al-Awsat Technical University,
31001 Al-Najaf, Iraq.
Email: inj.ame7@atu.edu.iq

1. INTRODUCTION

The rapid growths in electronics and mobile communications in term of the low cost of manufacturing and operating makes the UAVs are high flexibility in various military and civilian applications such as search, rescue, surveillance, cargo delivery and aerial mapping [1-3]. In addition, it can be exchanged for the communications infrastructure in critical areas such as the battlefield and environmental disasters. Most UAV-based applications rely on traditional communication techniques for data exchanging which lessen the susceptibility of the UAVs. As well as, the electro-mechanical tracking systems have low reliability and high cost [4, 5]. therefore, it is vital to appoint an advanced techniques. Consequently, the use of the Antenna Array (AA) system in the UAV communication system helps to improve the Signal to Interference plus Noise Ratio (SINR), where the AA provides/receipt signal power through the efficient beam-steering capabilities [6]. Many researchers have accompanied various studies in the field of UAV. Y. Zhang in 2018 presents a circularly polarized microstrip antenna array to increase the bandwidth in S-band for UAV ground to air transmission [7]. M.Asghar Khan et al in 2018 used the directional AA in Flying Ad-hoc Networks architecture to deliver data exchange services among UAVs efficiently and range enhancement [1]. Derek Campbell and C.J. Reddy in 2017 introduce a numerical analysis to a radiation pattern to electronically steered AAs applied in UAV wing using FEKO software [6]. Syed Muslim Shah and Raza Samar in 2011, used bit-interleaved coded modulation to exchange data control across 3-UAVs improve the power consumption at different configurations [8]. Sameir Deif et al in 2015, designed a feed network for a 12-element planer AA beam on UAV wing to improve the video transmission link [9].

Jiahui Li et al in 2017, introduce an analog beam tracking based Cram´Er-Rao Lower bound algorithm to provide high tracking speed and data rate for UAV [10]. P. Ngamjanyaporn et al in 2017, presents an SB using 3-element circular array of two Yagi-Uda antennas, which gives 7-beams to cover the 0-180 degree azimuth plane with increasing gain to 7 dBi [11]. John C. Porcello, in 2013, builds a smart antenna for high bandwidth UAV communication based on Lagrange Interpolation using FPGA [12]. Yan Shi et al. in 2018 used the Software Define Radio platform on UAVs to obtain air to ground wireless characteristics at different scenario and frequencies [13]. Lei Shi et al in 2013 used AA at the receiver side to detect the Angle of Arrival (AoA) to the target [14]. Benjamin Nuss et al in 2017, used Multiple-Input, Multiple-Output Orthogonal Frequency-Division Multiplexing (MIMO-OFDM) radar to detect flying UAVs under the coverage area [15]. Wei Zhou et al in 2018 used Channel State Information to detect and identify the UAVs [16]. Oliver Biallawons Jens Klare and Lars Fuhrmann in 2018 used virtual MIMO to detect and identify the UAVs [17]. group of researchers concentrate to improve the capacity such as using beamforming and scheduling between multi-antenna UAV and single antenna UAVs [18], massive MIMO BS to serve many single antenna UAVs [19, 20]. Jiri Pokorny et. al, in 2018, build a prototype aerial BS using UAV as a 5G ECO system. The connectivity between a UAV and a BS is made by mechanical steering to a directional microwave link [21]. In this work, two types of scenarios have been considered: i- SB and ii- PA to enhance the SINR value. The beam steering algorithm is based on the GPS coordinates of the UAV that received by low frequency and long-range channel.

2. RANGE MEASUREMENT FORMULA

The Friis transmission formula is used to compute the received power (Pr)(watt) at the terminals of a receive antenna when another antenna some distance away transmitting a known amount of power (Pt)(watt), separated by a distance R (meter), and operating at frequency f (Hz). This formula is presented by (1) [22, 23].

$$\mathrm{P_r} = \frac{\mathrm{P_t G_t G_r c^2}}{(2\pi \mathrm{df})^2} \quad (1)$$

where $\mathrm{G_t}$ and $\mathrm{G_r}$ are the transmitter and receiver gain respectively, c is the speed of light.

It can be seen that the received power is decreased, where R and F are increased and it is increased where Pt, Gt and Gr are increased. Therefore, when the distance is doubled, the forth of received power is required. So that, the efficient choice to increase the range is by increasing the Gr or/and Gt of the antenna. The best way to do this is by using the Antenna Array Elements (AAE).

3. ANTENNA ARRAY MODEL

The linear antenna array elements (LAAE) system is shown in Figure 1. Which M presents the number of AAE and separated by distance d. each antenna connected by analog weight to adjust the beam steering direction. The weight values are determined according to the desired direction. As shown in (2) present expression of the array factor (AF) of the arrived signal [24].

$$AF(\theta) = 1 + e^{j\Psi} + e^{2j\Psi} + \cdots + e^{(M-1)j\Psi} \quad (2)$$

where array phase function (Ψ) = $kdsin(\theta) + \beta$ and the propagation constant(k) =$\frac{2\pi}{\lambda}$, λ is the wavelength, β is the phase angle between element and θ is the desired AoA of the arrived signal. β Is the control parameter which steering antenna beam among broadside and end fire. In other word, when β = zero then θ= 90o (broadside case), and when β = 180 o θ= 180o (end fire). As shown in (2) gives the increasing element lead to increasing directivity of the main loop especially in broadside case that makes it suitable for long haul communication. The AF in (2) can be expressed in a closed form, which is more convenient for pattern analysis [25]:

$$AF(\theta) = \frac{\sin(\frac{M\Psi}{2})}{\sin(\frac{\Psi}{2})} \quad (3)$$

The directivity of such an array is equal to M. For a uniform broadside linear array of M isotropic elements spaced at any-wavelength apart, the beam width is given by (4).

$$BW = \frac{51\lambda}{Md} \quad (4)$$

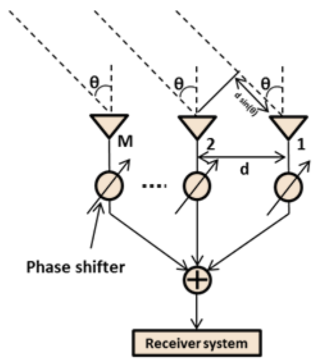

Figure 1. Linear antenna array model

4. STEERING SYSTEM ALGORITHM

The mechanism of computing the steering beam angle (β) of the LAAE in the BS toward the UAV coordinate is depended on the GPS information of the UAV and the BS. In each time slot, the GPS is providing the location coordinate of the UAV to the BS by a telemetry communication system that works at low frequency (long range channel). The longitude and latitude coordinates are assigned as (X_0 and Y_0) and (X_1 and Y_1) to the UAV and the BS respectively. A single omnidirectional antenna has been considered for the UAV and LAAE for the BS as illustrated in Figure 2. By keeping in mind these considerations, the algorithm of updateing β has the following procedure:
Read the UAV coordinate X_0,Y_0
Read the BS coordinate Y_1, X_1
Compute the ΔX and ΔY

$$\Delta X = (X_0 - X_1) * cos(Y_1)) * Ʀ \quad (5)$$

$$\Delta Y = (Y_0 - Y_1) * 111.19 \quad (6)$$

where X in radian and Y in degree, Ʀ is the Earth radius in Kilometer.
Compute the β angle

$$\beta = -tan^{-1}(\frac{\Delta Y}{\Delta X}) \quad (7)$$

The beam steering has been adjusted by the beamformer coefficients (W) as explained in the next sections. The W vector can express in (8).

$$W_j = [\omega_{1j}\ \omega_{2j} \dots \omega_{Mj}]^T \quad (8)$$

where j presents the time slot for the GPS reading UAV coordinates. The output of the combined weighted signal is calculated as (9) [26]

$$y = \sum_{i=1}^{M} w_{ij}^{*} x_i = W_j^H X \quad (9)$$

where X is the incoming signal which is a combination of the received information signal (s(t)), the Interference signal (I(t)) and a zero mean noise signal (v(t)) in AAE as expressed in (10) [27].

$$X = AF(\theta_s)s(t) + AF(\theta_I)I(t) + v(t) = [x_1 x_2 \dots x_M]^T \quad (10)$$

The accuracy of the algorithm depends on the GPS update rate that it is between 1 -10 Hz. This algorithm directs the beam pattern towards the reallocation of the UAV, even if there is an obstacle between them. In this research, two methods have been used in the steering process: SB and PA systems,

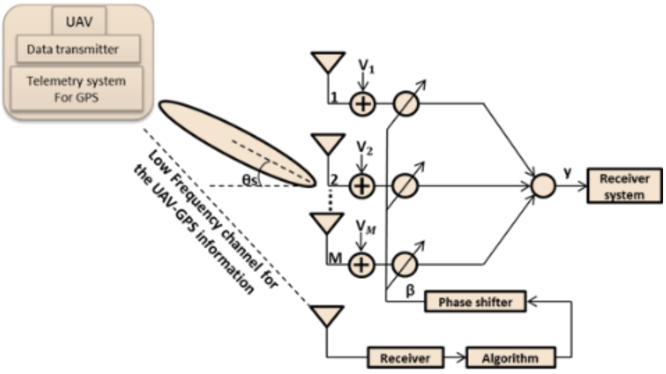

Figure 2. System arcitecture block diagram

4.1. Switching beam system

This method selects the relating beam to the angle β, which computed by (7), based on the (11) within any coverage angle (ɣ). The Figure 3 shows a block diagram of this scenario.

$$n = \mu\beta + c \tag{11}$$

where n represents the beam selected number, and the parameters (µ,c) are calculated based on the value of M-elements and K-Beams. In this work, the M values are (4, 8 and 12) and the K values are (7, 13 and 25) respectively within ɣ= [-32.5 o to 32.5o]. Therefore, µ and c values are optimized and listed in Table 1.

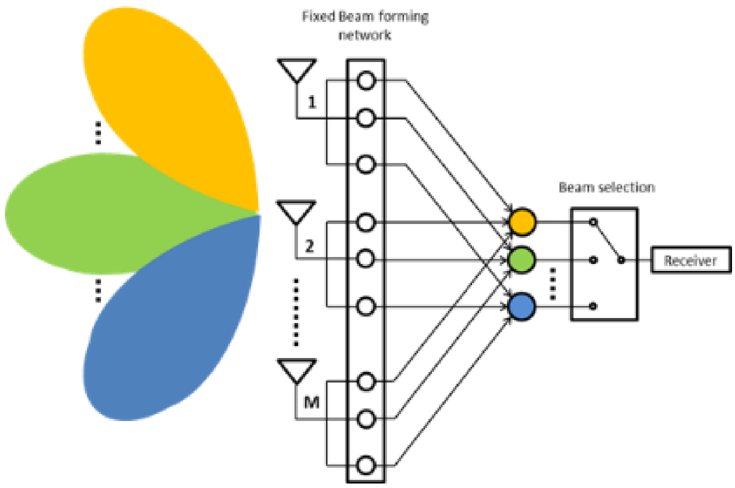

Figure 3. Swtiched beam system

Table 1. Beam selection parameters

M	N	μ (b in rad)	c
4	7	-6.057	3.5
8	13	-11.4	6.5
12	25	-16.7	9.5

As mentioned in (3) and (4), the increase in M leading to increase the directivity and decrease the BW respectively. The number of beams in each given array has been chosen to provide an appropriate performance. The radiation patterns of each given AA have been illustrated in Figure 4. In each beam, the Wn vector has been assigned to adjust the beam direction at a proper angle. The flow chart of this system has been presented in Figure 5.

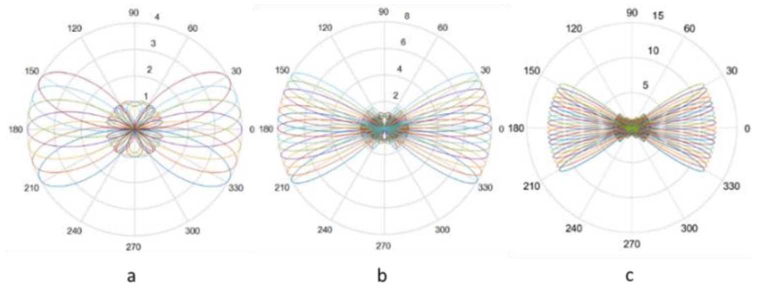

Figure 4. The radiation pattern for LAAE: a- at M=4, b- at M=8, c- at M=12

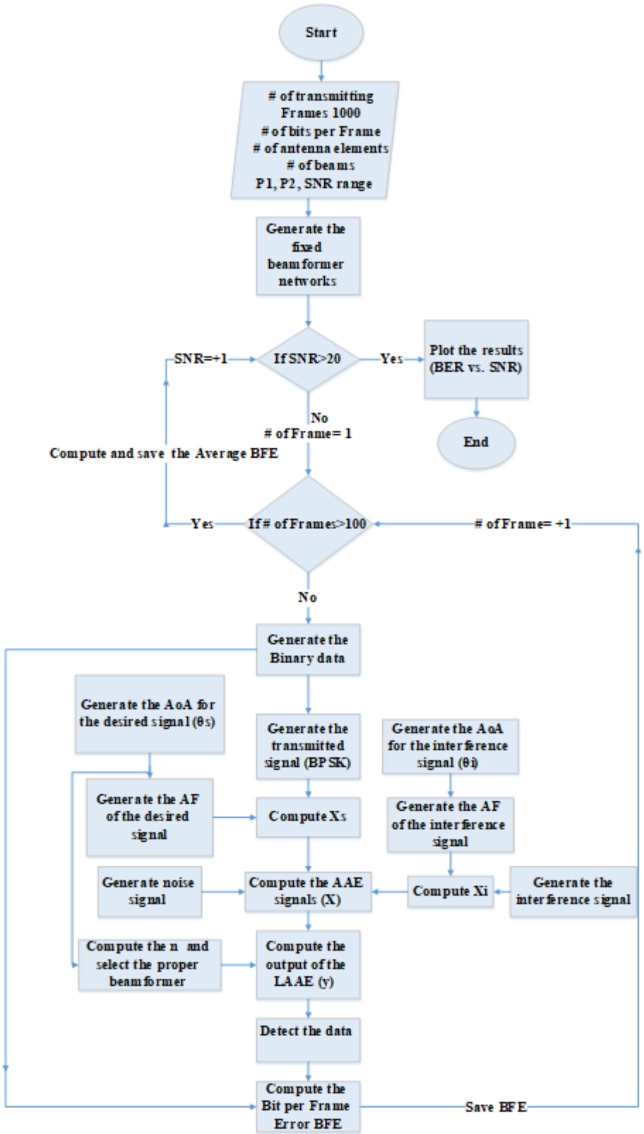

Figure 5. The flowchart of the switched beam scenario

4.2. Phased array system

In this scenario, after the β has been computed, it will deliver to the phase shifter component. Therefore, the beam is steered at angle β over a given time slot. The flowchart of this scenario is similar to switched beam with replacing the beamformer selection block by the phase shifter controller and removing the generate the fixed beamformer networks.

4.3. Misalignment angle analysis

The GPS receiver update-rate determines the delay time of display itself. The update-rate of the foremost GPS systems is refreshed at each 1Hz. The value of the update rate is considered for an application requirement. When the update rate is high, the measurement capability is improved but the power consumption is increased. The analysis of the update rate for antenna beamforming has been introduced for the UAV application. The misalignment angle (∇θ) between the current position (θ) and the arrived position (θ̂) of the UAV at the update rate = 1 Hz has been chosen. The AAE performance is degraded whereas the ∇θ is increased because of the directivity is maximum at the center of the beam. So that, the ∇θ derivation is required to choose the appropriate number of AAE. Consider the beam is directed toward the angle θ̂ of the horizontally moving UAV at speed S, until the next update is coming to redirect the beam as in Figure 6. Where R the range and r is the distance between the estimated and the current position. Therefore, it can be driven the ∇θ and S by (12-14).

$$r = S.T \tag{12}$$

Then,

$$\nabla\theta = \tan^{-1}(\frac{ST}{R}) \tag{13}$$

$$S = \frac{R}{T}\tan(\nabla\theta) \tag{14}$$

from (13), the ∇θ is related proportionally to the S and T. Also, it is inversely proportional to R.

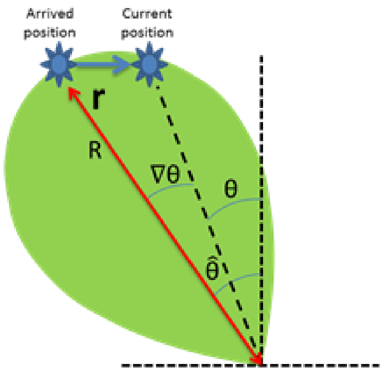

Figure 6. Air to ground scenario of the misalignment angle derivation

5. RESULTS AND DISCUSSION

In this section, the BER performance of the SB and the PA system has been evaluated versus SNR and misalignment angle under AWGN channel using Matlab. As well as, uniform distributed AoA to a uniformly random interference signal has been existed to investigate the SINR enhancement that each M will give. The summary of simulation parameters has been listed in the Table 2.

Table 2. Simulation parameters

Parameters	Description
Modulation	BPSK
Frame size	10Kbits
Number of frames	100
channel	AWGN
SNR range	0-20 (dB)
Angle of the sector	65°
No. of AA (M)/ No. of beam(K)	4/7,8/13 and 12/19
Antenna element	isotropic
Misalignment angle range	0-0.08 (rad)
Angle of arrival to interference signal	Random and uniform distributed between (-32.5° -32.5°)
Transmission mode	Down link
Propagation channel	Line of Sight (LoS)

5.1. Performance of BER versus SNR

Figures 7 and 8 present the BER vs SNR comparison of the PA and SB at M= 4, 8 and 12 respectively. As expected, the BER of M=12 deliverers the best performance at all SNR values. The PA considerably outperforms the SB by 1.8, 1.9 and 0.4 dB at M=12, 8, 4 respectively. From Figures 7 and 8, Table 3 presents the SINR improvement between the different value of M. The SINR of the PA is better than SB in all cases. It can be seen that the SINR Improvement of 12 over 4 has the best value and 12 over 8 has the lowest value. While the case of 8 over 4 gives the tradeoff between the complexity and the performance.

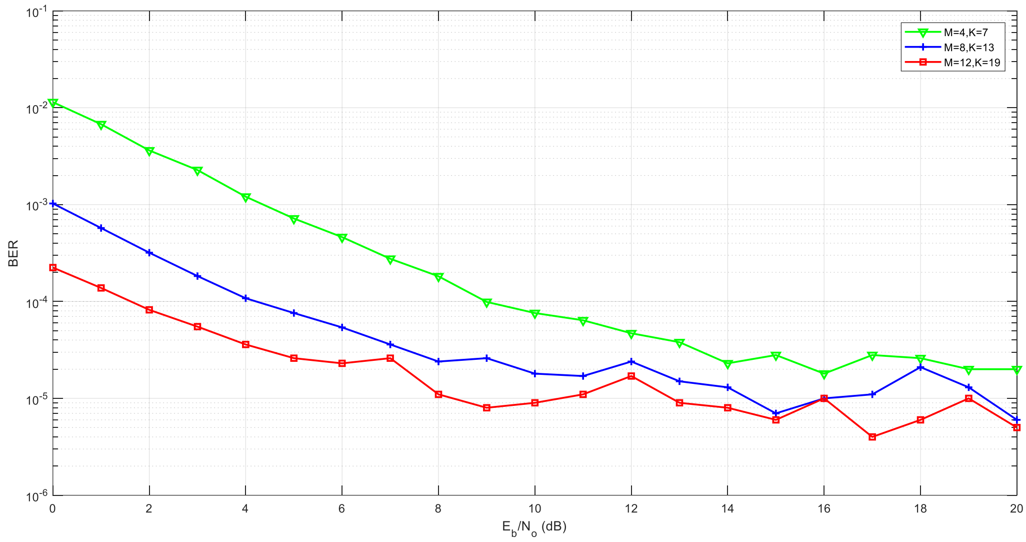

Figure 7. BER vs SNR for SB system

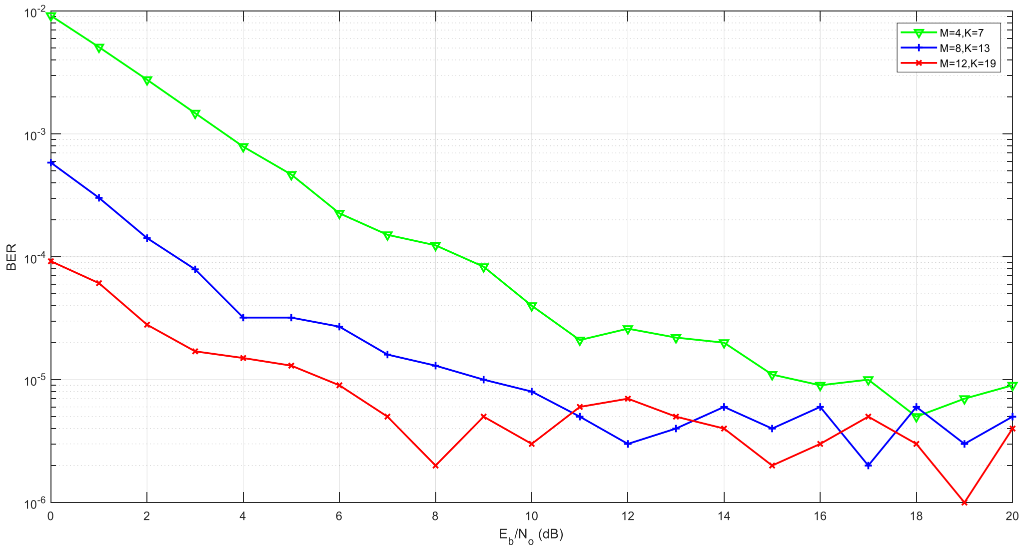

Figure 8. BER vs SNR for PA system

Table 3. SINR comparison

SINR improvement for SB			SINR improvement for PA		
12 over 8	12 over 4	8 over 4	12 over 8	12 over 4	8 over 4
2.6 dB	7.4dB	4.8 dB	2.75 dB	8.8 dB	6 dB

5.2. Performance of misalignment angle

The misalignment angle has been evaluated for SB and PA at SNR=8 dB. For PA, M=12 outperforms the others until the ∇θ>0.021 rad, whereas M=8 outperforms M=4 until ∇θ>0.065 rad as illustrated in Figure 9. For SB M=12 gives the best for ∇θ>0.0165 rad and M=8 overcome M=4 for ∇θ>0.0347 rad as illustrated in Figure 10. Another notation that can be seen, ∇θ has a wider range for PA than SB. at these angles ∇θ, the maximum horizontal speed allowed for each case has been compared for M=12 and 8 in Table 4.

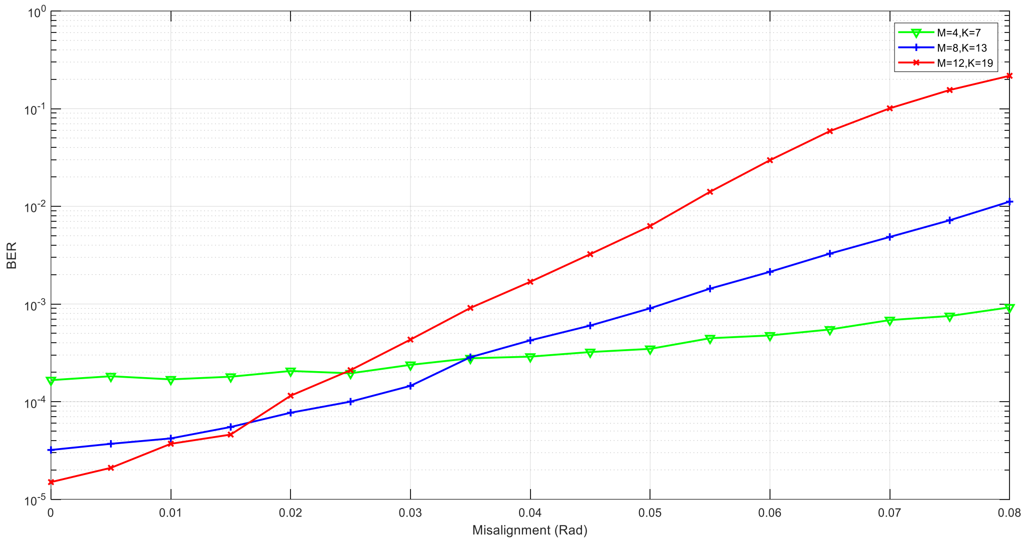

Figure 9. BER vs misalignment for SB system

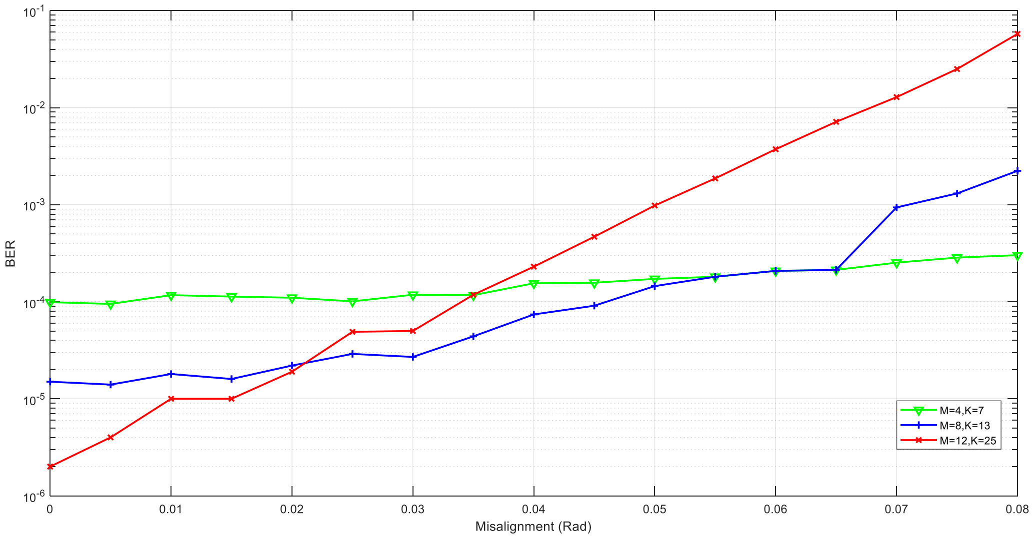

Figure 10. BER vs misalignment for PA system

Table 4. Misalignment angle comparison

	SB		PA	
M	$\nabla\theta$ (rad)	S_{max} (m/sec)	$\nabla\theta$ (rad)	S_{max} (m/sec)
12	0.0165	0.0165d	0.021	0.021d
8	0.0347	0.03468d	0.065	0.065d

6. CONCLUSION

In this paper, electronically steering beam system of different LAAE lengths have been considered at the BS to keep the beam direction always alignment to UAV coordinate. The simulation of this system has been investigated under AWGN channel and interference signal using Matlab. The BER vs SNR and BER vs misalignment angle performances of SB and PA have been evaluated for UAV at BPSK modulation. The steering mechanism of this system is based on the coordinate received from the GPS of the UAV. The result shows the BER vs SNR performance of PA is outperform the SW by 1.8 dB, 1.9 dB and 0.4 dB for M=12, 8, 4 respectively. The SNR values of the PA shows the M=8 deliver double distance, while M=12 deliver double and a half than M=4. The PA can provide wider misalignment than the SB. In addition, M=4 provide sufficient performance for close and fast UAV applications while M=12 is more suitable for far and slow speed application due to their beam width are wider and narrower respectively. The M=8 gives a comfortable case among them. In the future, we are going to merge the control signal of the steering beam with the main signal using stander IEEE 802.11 a.

REFERENCES

[1] Khan MA, Qureshi IM, Khan IU, Nasim A, Javed U, Khan W, "On the Performance of Flying Ad-hoc Networks (FANETs) with Directional Antennas," *2018 5th International Multi-Topic ICT Conference (IMTIC), IEEE*, 2018.

[2] Aswini N and Uma SV, "Obstacle avoidance and distance measurement for unmanned aerial vehicles using monocular vision," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 9(5), pp. 3504-3511, 2019.

[3] Debnath KS, Omar R, Abdul Latip NB, Shelyna S, *et al.*, "A review on graph search algorithms for optimal energy efficient path planning for an unmanned air vehicle," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 15(2), pp. 743-749, 2019.

[4] Prakoso T, *et al.*, "Evaluation of skew-planar antenna for UAV communication at 2.4 GHz band," *IAES International Conference on Electrical Engineering, Computer Science and Informatics*, 2017.

[5] Boustani B, Baghdad A, Sahel A, and Badri A, "Performance analysis of direction of arrival algorithms for smart antenna," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 9(6), pp. 4873-4881, 2019.

[6] Campbell D, Reddy C, editors, "Optimal numerical analysis of electronically-steered arrays onboard electrically-large platforms. Antennas and Propagation & USNC/URSI National Radio Science Meeting," *2017 IEEE International Symposium on: IEEE*, 2017.

[7] Zheng JY, Zhou WX, and Chen W, "A Low-Profile Broadband Circularly Polarized Antenna Array for UAV Ground-to Air Communication," *Conference on: IEEE Asia-Pacific Conference on Antennas and Propagation (APCAP)*, 2018.

[8] Shah SM, Samar R, "Cooperative communication in 3-UAVs: Performance analysis with BICM transmission," *2012 9th International Bhurban Conference on Applied Sciences and Technology (IBCAST), IEEE*, 2012.

[9] Deif S, Sharawi MS, Nold B, Rawashdeh O, Aloi DN, editors, "Performance improvement of embedded planar fixed beam arrays in flying UAVs," *Antennas and Propagation & USNC/URSI National Radio Science Meeting, 2015 IEEE International Symposium on; IEEE*, 2015.

[10] Li J, Sun Y, Xiao L, Zhou S, Koksal CE, editors, "Analog beam tracking in linear antenna arrays: Convergence, optimality, and performance," *2017 51st Asilomar Conference on Signals, Systems, and Computers, IEEE*, 2017.

[11] Ngamjanyaporn P, Kittiyanpunya C, Krairiksh M, "A switch-beam circular array antenna using pattern reconfigurable Yagi-Uda antenna for space communications," *2017 International Symposium on Antennas and Propagation (ISAP), IEEE*, 2017.

[12] Porcello JC, "Designing and implementing multibeam smart antennas for high bandwidth UAV communications using FPGAs," *Aerospace Conference, IEEE*, 2013.

[13] Shi Y, Enami R, Wensowitch J, Camp J, "Measurement-based characterization of LOS and NLOS drone-to-ground channels," *2018 IEEE Wireless Communications and Networking Conference (WCNC): IEEE*, 2018.

[14] Shi L, Allen C, Ewing M, Keshmiri S, Zakharov M, Florencio F, *et al.*, "Multichannel sense-and-avoid radar for small UAVs," *Digital Avionics Systems Conference (DASC), 2013 IEEE/AIAA 32nd: IEEE*, 2013.

[15] B. Nuss, L. Sit, M. Fennel, J. Mayer, T. Mahler, and T. Zwick, "MIMO OFDM radar system for drone detection," *2017 18th International Radar Symposium (IRS)*, Prague, pp. 1-9, 2017.

[16] Zhou W, Wang L, Lu B, Jin N, Guo L, Liu J, *et al.*, "Unmanned Aerial Vehicle Detection Based on Channel State Information," *2018 IEEE International Conference on Sensing, Communication and Networking (SECON Workshops): IEEE*, 2018.

[17] Biallawons O, Klare J, Fuhrmann L, "Improved UAV detection with the MIMO radar MIRA-CLE Ka using range-velocity processing and TDMA correction algorithms," *2018 19th International Radar Symposium (IRS): IEEE*, 2018.

[18] Chalise BK, Zhang YD, Amin MG, "Multi-beam scheduling for unmanned aerial vehicle networks," *2013 IEEE/CIC International Conference on Communications in China (ICCC), IEEE*, 2013.

[19] Chandhar P, Danev D, Larsson EG, "Massive MIMO as enabler for communications with drone swarms," *2016 International Conference on Unmanned Aircraft Systems (ICUAS), IEEE*, 2016.

[20] Chandhar P, Danev D, and Larsson EG, "Massive MIMO for communications with drone swarms," *IEEE Transactions on Wireless Communications*, vol. 17(3), pp. 1604-1629, Mar. 2018.

[21] Jiri Pokorny, *et al.*, "Concept Design and Performance Evaluation of UAV-based Backhaul Link with Antenna Steering," *Journal of Communications and Networks*, vol. 20(5), pp. 473-483, 2018.
[22] Schantz HG, Unden AH, Nikravan M, Kwon D-H, "Simple formulas for near-field transmission gain and fields," *Proc 2013 Antenna Appl Symp*, 2013.
[23] Rao KP, Vani RM, and Hunagund PV, "Planar Microstrip Patch Antenna Array with Gain Enhancement," *8th International Conference on Advances in Computing and Communication (ICACC-2018), Elsevier B.V*, 2018.
[24] Lo Y, Lee S, and Lee Q, "Optimization of directivity and signal-to-noise ratio of an arbitrary antenna array," *Proceedings of the IEEE*, vol. 54(8), pp. 1033-1045, 1966.
[25] Kummer WH, "Basic array theory," *Proceedings of the IEEE*, vol. 80(1), pp. 127-140, 1992.
[26] AL-Jaafari MAM, Ali AH, Abdulwahed SH, AL-Rikabi hmh, "Novel VSS-NLMS Algorithm for Adaptive Equalizer under Complex Dynamic Wireless Channel," *Journal of Theoretical & Applied Information Technology*, vol. 96(19), 2018.
[27] Al-Musawi RS, "A Novel Low-Complexity Sub-Block Nlms-Drmta Algorithm for Blind Multiuser Detection in Wcdma Systems," *Journal of Theoretical & Applied Information Technology*; vol. 83(3), 2016.

BIOGRAPHIES OF AUTHORS

Ameer H. Ali was born in Al-Najaf, Iraq in september of 1990. He received his B.Sc and M.Sc degrees in 2012 and 2015 respectively from University of Kufa and University of Technology, Iraq. He is an assistant Lecture at the Department of Electronic and Communication Technologies,Najaf Technical Institute,Al-Furat Al-Awsat Technical University, Al-Najaf, Iraq. His area of interest includes FPGA, Robotic system and intelligent systems.

Mohannad A.M. Al-Ja'afari was born in Najaf, Iraq, in 1989. He received the B.S. degree from the University of Kufa, Najaf, in 2011 in electrical engineering and the M.S. degree from the University of Technology, Baghdad, in 2014 in communication engineering. His research interests include, Adaptive Signal Processing, Neural Network Algorithms, Wireless Communication, Optimization and Wavelet

Saif H. Abdulwahed was born in Baghdad in 9/1/1991, he had a master degree in communication engineering / University of technology / Baghdad, member of the Society of Scientific & Technical Competencies and member in the IRAQI ENGINEERS UNION.