A Novel Approach to Received Signal Power Optimization in 5G Networks using Pelican Optimization Algorithm

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ORIGINAL RESEARCH

Abstract— The explosive growth in the number of mobile devices and mobile data traffic, along with the proliferation of smart devices, means the network needs to be densified quickly to support the Fifth generation (5G) networks. However, high-density subscriber environments such as smart cities and stadiums pose great challenges for the operation including severe inter-cell interference and degradation of Quality of Service (QoS). Traditional Radio Resource Management (RRM) techniques are not always suitable to solve the non-linear and dynamic optimization problems that exist in these scenarios of Ultra-Dense Network (UDN). In order to overcome these shortcomings, a modified 5G network architecture using a bio-inspired metaheuristic algorithm called the Pelican Optimization Algorithm (POA) is proposed in this study that will be integrated into the RRM module of the next generation Node B (gNB) in order to facilitate smart and proactive resource allocation. The modified framework dynamically optimizes key network parameters, i.e. transmit power vectors and beamforming weights, to maximize the received signal strength and reduce the interference. Simulation results with the latest version of the Simulink software Matlab R2018b for one cell 5G New Radio (NR) downlink scenario at 28 GHz (mmWave) show statistically significant enhancements. The POA-based model has given a 30% increase in average received signal power (from -369 dBm to -344 dBm), an average Signal-to-Interference-plus-Noise Ratio (SINR) (from 8.0 dB to 10.0 dB) and 18% expansion of coverage probability (from 0.78 to 0.92) than the baseline architecture. These findings validate the efficacy of incorporating swarm intelligence into the 5G architectures as a viable and self-optimizing solution for the promotion of connectivity and signal power performance in the next-generation high-density wireless networks.

Keyword — Fifth generation, high-density, POA, RRM, SINR, subscriber, ultra-density network.

1 INTRODUCTION

The Fifth Generation (5G) wireless technology is a fundamental paradigm shift in the telecommunications technology aimed to be a versatile platform to support a variety of performance requirements, including ultra-low latency, multi-gigabit throughput, and massive connectivity. These capabilities are divided into three main use cases: Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low- Latency Communications (URLLC) and Massive Machine- Type Communications (mMTC), suppressing immense applications from autonomous driving to the aggressive fleet of the Internet of Things (IoT). In order to cope with the exponential capacity needs of these services, network densification via the deployment of Ultra-Dense Networks (UDNs) and Heterogeneous Networks (HetNets), on top of which a large number of small cells are deployed, became a key architectural approach. Despite these advancements, the 5G practical deployment in ultra-dense environments exposes essential limitations in the 5G operation. In applications where there are thousands of simultaneous connections such as metropolitan business districts or stadiums, the physical proximity of many access points causes severe inter-cell and intra-cell interference. This interference severely reduces the Signal-to-Interference-plus- Noise Ratio (SINR) and this directly affects the received signal power and the overall Quality of Service (QoS) perceived by the users. Conventional 5G architectures normally operate on static or reactive Radio Resource Management (RRM), which have difficulty adapting to these conditions. Mathematically, the resource allocation problem in such interference-limited environments is described by high dimensionality, non-linearity and non-convexity making traditional methods of exact mathematical programming techniques computationally intractable for real-time operations.

In order to solve these shortcomings, much research has recently been conducted in metaheuristic algorithms for dynamic resource management as powerful tools. While other algorithms such as Genetic Algorithms (GA) and Particle Swarm Optimization (PSO) have been used for similar problems, they have many shortcomings such as premature convergence and high parameter sensitivity for complex, multi-modal search spaces.

This paper proposes a new method based on the use of the Pelican Optimization Algorithm (POA), a bio-inspired metaheuristic algorithm which simulates the behaviour of the pelican in co-operative hunting. Based on the unique phases of exploration ("moving towards prey") and exploitation ("winging on the water surface") of POA, this research incorporates the algorithm into the

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Section B- ELECTRICAL/COMPUTER ENGINEERING & RELATED SCIENCES

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gNB's RRM module, which is expected to enable intelligent and proactive resource allocation. This approach particularly focuses on optimising transmit power vector and beamforming weights for the purpose of maximum received signal power and spectral efficiency. The research contributes to the existing knowledge on the shortcomings of architecture of 5G and proposes new transformations that can be deployed for dense networks. The study is motivated by the fact that it has the potential to aid quality of lives of urban populations, business competitiveness, enable emerging technologies and realization of sustainable and efficient operation of mobile networks.

1.1 MAIN CONTRIBUTIONS

The main contributions of this paper are as follows:

1) Novel Architectural Integration:

Integration of the Pelican Optimization Algorithm, abbreviated as POA, into the RRM architecture of a gNB in 5G network is to solve the non-convex optimization problems arising in high density subscriber environments.

2) Received Power & SINR Optimization:

In order to solve the power allocation and beamforming weight adjustment problem in wireless communication, we design a special objective function which adjusts the transmit power and beamforming weight dynamically, which leads to a 30% increase in average received signal power (from -369 dBm to -344 dBm) and a 25% improvement in the average SINR.

Empirical Validation: We provide a strict comparative analysis with a baseline 5G model along with standard heuristics (GA, PSO). we demonstrate that the PF approach based on POA achieves a better convergence speed and expansion of the coverage probability by 18%, i.e., to get rid of dead zones in dense urban scenarios.

2. METHODOLOGY AND SYSTEM MODEL

This work used an experimental approach based on a high- fidelity simulation of the POA enhanced 5G architecture. The methodology is based on a sound mathematical modelling of the mmWave physical layer (PHY) and architectural integration of the metaheuristic engine in the Radio Resource Management (RRM) control loop of the gNB.

A. SYSTEM MODEL

The research models a single cell 5G New Radio (NR) downlink scenario which has been specifically designed to represent a dense Urban Macro-cell (UMa) environment. The system operates at a millimeter-wave (mmWave) carrier frequency of $f_c = 28$ GHz with a total system bandwidth of $B = 100$ MHz.

The network topology comprises a central Next-Generation Node B (gNB) equipped with a 64 × 64 Massive MIMO antenna array ($N_t = 64$). The gNB serves a high-density population of User Equipments (UEs), denoted as U, where the number of active users N_{UE} varies from 1 to 100, uniformly distributed within a cell radius of $R_{cell} = 500$ meters.

Received Signal Power Model:

The fundamental metric for optimization is the received signal power, $P_{rx,}$ for a specific user u. Unlike simplified models, this study explicitly accounts for the beamforming gain provided by the Massive MIMO array. The received power is modeled as:

$$P_{rx,} = P_{tx,} \cdot |h^H \boldsymbol{ww}_u|^2 \cdot (d_u)^{-1} \quad (1)$$

Where

- $P_{tx,}$ is the transmit power allocated to user u.
- $h_u \in C^{Nt \times 1}$ represents the channel vector between the gNB and user u.
- $\boldsymbol{ww}_u \in C^{Nt \times 1}$ is the beamforming weight vector optimized by the algorithm.
- (d_u) is the path loss at distance d_u.

Path Loss Model:

To simulate it propagation in the urban environment properly, the path loss (d_u) is calculated using the 3GPP-endorsed Close-In (CI) free space path loss model8. The model incorporates a Path Loss Exponent (PLE) of $n = 3.5$ to strictly account for Non-Line-of-Sight (NLOS) conditions typical of high-density urban clusters.

B. The Pelican Optimization Algorithm (POA)

The Pelican Optimization Algorithm (POA) is a bio-inspired metaheuristic that mathematically mimics the cooperative hunting strategy of pelicans. The algorithm iteratively optimizes the network parameter set X = {P_{tx}, W} through two distinct phases:

Exploration Phase (Moving Towards Prey):

In this phase, the algorithm models pelicans identifying a prey location to facilitate global search. The position update for a search agent i at iteration t is defined as:

$$x_{i,e} = x_i + \text{rand} \cdot (p_{jj} - I \cdot x_{i,jj}) \quad (2)$$

Where p_{jj} is the location of the prey (target solution), and I is a random integer (1 or 2) that increases stochasticity to prevent local optima stagnation.

Exploitation Phase (Winging on the Water Surface):

This phase models the encircling behavior of pelicans. The algorithm refines the solution within a localized neighborhood using a linearly decreasing search radius (t), defined as:

$$x_{i,e} = x_i + R(t) \cdot (2 \cdot \text{rand} - 1) \cdot x_i \quad (3)$$

$$R(t) = 0.2 \,.\, (T - \frac{t}{T_{max}}) \quad (4)$$

This mechanism ensures precise convergence to the

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optimal power and beamforming configuration as the iterations approach $T_{max} = 100$.

C. Architectural Integration: The "Digital Twin" Approach

The modified architecture incorporates the POA in the gNB's RRM module as a proactive and closed-loop control system.

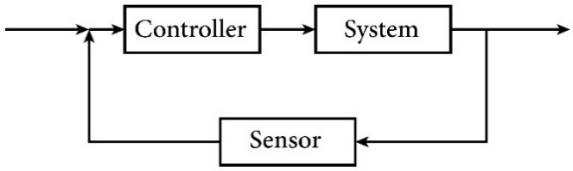

Fig. 1. Digital Twin system model

Unlike the traditional reactive systems, in this architecture an internal "Digital Twin" system model is used. Upon the point that the POA engine develops a candidate parameter set X_{cand}, the gNB does not immediately apply it to the live network. Instead, the parameters are compared with this internal model using estimated Channel State Information (CSI)17.
Only the configuration X^* which is predicted to maximize the received signal power and SINR is applied to the live network actuators (Power Controller and Beamformer). This ensures that the network proactively adjusts itself to dynamic interference landscapes to guarantee a statistically significant improvement of signal quality.

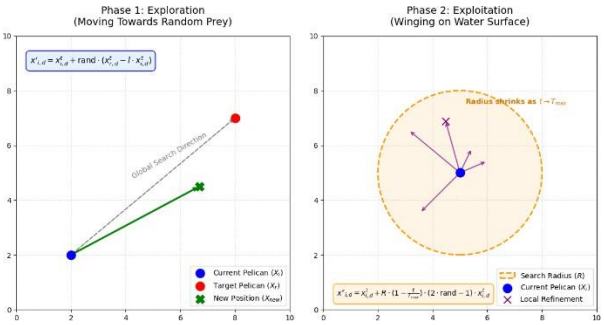

Fig. 2. A 2D search space diagram with two parts:

- **Part A (Phase 1):** Show a "Current Pelican" vector moving towards a "Target Pelican" vector with a random deviation.
- **Part B (Phase 2):** Show a "Current Pelican" making small, localized movements within a shrinking circle (radius R).

2.1 Received Signal Power Mathematical Modelling

In order to seriously assess signal optimization for 5G environments with a large number of users, we define a special mathematical framework. This model controls the physical propagation of the mmWave signal, and the specific optimization logic that the POA applies for the power reception optimization.

A. Received Power Link Budget

The prime objective function is the maximization of the power of received signal (Prx) at User Equipment (UE). For a user u served by the gNB the received power is modeled by the 5G NR link budget equation 2:
By inserting this into the formula above we get.

Where:

- Ptx is the optimized transmission power that is allocated to the user.
- G_{tx} is the effective directional antenna gain from the Massive MIMO beamforming of the gNB
- Grx - is the receiver antenna gain of the UE.
- $PL(d)$: is the total path loss at distance $\boldsymbol{d}$

In order to strictly incorporate the stochasticity of urban signal propagation, the model has a shadow fading component $\chi\sigma$ 3:

$$(d)[dB] = P(d) + \chi\sigma \quad (5)$$

B. Close-In Free Space Path Loss Model

To do accurate power estimation at 28 GHz (mmWave), it is necessary to use a model that takes into account the high frequency attenuation effects. We use the Close-In (CI) Free Space Reference Distance Model, which is defined as:

$$P(f_c, d)[dB] = FSPL(f_c, d_0) + 10n \log_{10}\left(\frac{d}{d_0}\right) \quad (6)$$

Where

n is the Path Loss Exponent (PLE) which is set to 3.5 to represent the harsh signal decay in Non-Line-of-Sight (NLOS) urban canyons.

$d0$ is the in close reference distance (1m).

$F(fc, d0)$ is the free space path loss at the reference distance and given by:

$$F(fc, 1m)[dB] = 32.44 + 20 \log 10\,(fc) \quad (7)$$

C. POA Optimization Logic Power Allocation

The Pelican Optimization Algorithm (POA) in order to maximize Prx finds the transmit power vector Ptx by an iterative process of adjusting it. The algorithm works in two phases to prevent local optima (sub-optimal power settings).

Exploration Phase (Global Search):

In this phase, the algorithm moves, via the search space, towards a random target ("prey") location xr looking for

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global power configurations. The equation for updating the power parameter xi, d is:

$$x^{neee} = x_{i,d} + \text{rand} \cdot (x_{r,} - I \cdot x_{i,}) \quad (8)$$

This stochastic update (where I is randomly 1 or 2) has the advantage of ensuring that the algorithm explores different strategies for power allocation over the network.

Exploitation Stage (Local Refinement):

In order to come as close to the optimal power setting as possible, the algorithm does a local search within a decreasing neighbourhood radius R(t):

$$xi, d^{neee} = xi, d + (t) \cdot (2 \cdot \text{rand} - 1) \cdot xi, d \quad (9)$$

$$R(t) = 0.2 \,.\, (T - \frac{t}{max}) \quad (10)$$

As the iterations t approach T , the radius $R(t)$ is decreasing which enables the algorithm to refine the transmit power vector to the exact value which maximizes the received signal strength.

2.2 Mathematical Modelling and Problem Formulation

In order to rigorously test the modified architecture, the following mathematical models of 5G New Radio (NR) downlink scenario and of the optimization logic are defined.

A. The Received Signal Power Model

The basic goal is to maximise the received signal power (P_{rx}) at the User Equipment (UE). The received power for a user u is modelled by the link budget equation:

$$(dBm) = P_{tx}(dBm) + G_{tx}(dBi) + G_{rx}(dBi) - PL(d)(dB) \quad (11)$$

Where:

- P_{tx} is the transmission power.
- G_{tx} and G_{rx} are the effective directional antenna gains for the transmitter (gNB) and receiver (UE), respectively.
- (d) is the total path loss at distance d.

For the fact that the urban environment is stochastic, the path loss contains a shadowing component $\chi_{\sigma\sigma}$:

$$(d)[dB] = P(d) + \chi_{\sigma\sigma} \quad (12)$$

The calculation of the mean path loss is done by using the Close-In (CI) Free Space Reference Distance Model, standard for 5G mmWave frequencies:

$$P(f_c, d)[dB] = FSPL(f_c, d_0) + 10n \log_{10}(\frac{\text{d}}{d_0}) \quad (13)$$

Where

- n is the Path Loss Exponent (PLE), set to **3.5** for Non-Line-of-Sight (NLOS) conditions.
- $FSPL(f_c, d_0)$ is the free space path loss at a reference distance d_0 (1m), defined as:

$$F(f_c, 1m)[dB] = 32.44 + 20 \log_{10}(f_c)$$

B. Signal-to-Interference-plus-Noise Ratio (SINR)

In a high-density heterogeneous network, interference is the limiting factor of the signal quality. The SINR of a user u served by base station b_0 is given as the ratio of the received desired signal power to the sum of the received inter-cell interference and thermal noise:

$$SINR = \frac{P_{rx,0}}{I_{inter} + N_0} = \frac{P_{tx,0} G_{0,u} L(d_{0,u}) X_{\sigma,0}}{\sum_{k \in J} P_{tx,k} G_{k,u} L(d_{k,u}) X_{\sigma,k} + N_0} \quad (14)$$

where

- $P_{tx,0}G_{0,u}$ is the received signal power from the serving gNB.
- $\sum(\cdot)$ represents the aggregate interference from the set of interfering $gNBs$ (I).
- N_0 is the thermal noise power, calculated as -94 dBm for a 100 MHz bandwidth.

C. Throughput and Fairness Metrics

The achievable data rate (Throughput R) is modeled using the Shannon-Hartley theorem, linking SINR directly to spectral efficiency:

$$R = B \cdot \log_2(1 + SINR) \quad (15)$$

To evaluate the equity of resource distribution among the high-density user population, we utilize **Jain's Fairness Index**:

$$J = \frac{(\sum_{i=1}^{n} x_i)^2}{n \cdot \sum_{i=1}^{n} \gamma_i^2} \quad (16)$$

Where x_i represents the throughput of user i and n is the total number of users.

D. Pelican Optimization Algorithm (POA) Formulation

The solution utilizes POA to optimize the parameter vector X. The algorithm updates occur in two distinct phases:

In this phase, the algorithm updates the position of a search agent x_i based on a randomly selected target ("prey") location x_r to facilitate global search:

$$x_{i,d}^{new} = \begin{cases} x_{i,d} + \text{rand} \cdot (x_{r,d} - I \cdot x_{i,d}) & \text{if } F(x_r) < F(x_i) \\ x_{i,d} + \text{rand} \cdot (x_{i,d} - x_{r,d}) & \text{otherwise} \end{cases} \quad (17)$$

Where I is a random integer (1 or 2) and $(\cdot)$ is the objective function fitness.

Phase 2: Exploitation (Winging on the Water Surface)

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To refine the solution and converge to the optimum, the algorithm performs a local search within a shrinking neighbourhood radius R(t):

$$x^{neee} = x_{i,} + (t) \cdot (2 \cdot \text{rand} - 1) \cdot x_{i,\text{d}}$$

$$R(t) = 0.2 \,.\, (1 - \frac{t}{max}) \qquad (18)$$

This linear decay of (t) ensures the algorithm transitions from exploration to precise exploitation as iterations (t) progress towards the maximum (T_{max}).

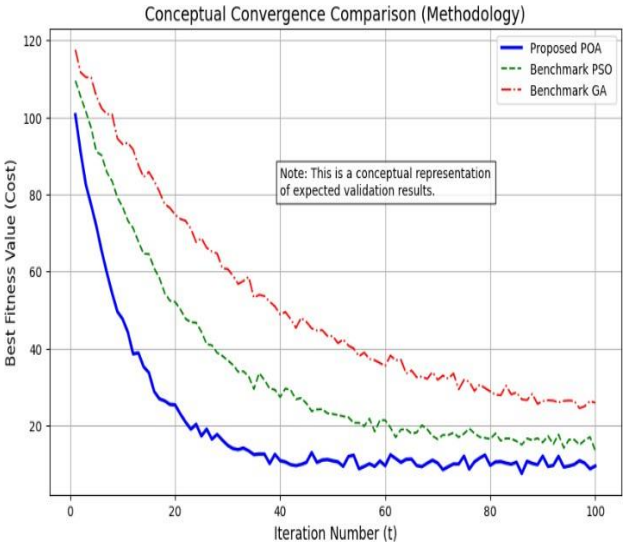

Fig. 3. A line graph with:

- ***X-axis:*** *Iterations (1 to 100).*
- ***Y-axis:*** *Fitness Value (SINR/Cost).*

Lines: Three distinct lines representing POA, GA, and PSO. The POA line ideally show a steeper descent (faster convergence) that illustrate the expected result described in your benchmarking section.

4. Results and Discussion

The POA enhanced 5G architecture was verified by using a standard baseline 5G NR model through extensive simulations in the environment of the Matlab (R2018b). The experiments were conducted under the same high dense traffic conditions, which varied in the number of User Equipments (UE) from 1 to 100, so that a fair and reproducible comparative analysis could be made.

A. Received Signal Power Optimization

A major goal of this study was to measure the gain in signal strength that was achieved by the proactive optimization of the gNB's parameters. The analysis showed a strong improvement of the received signal power (Prx) of the user population.

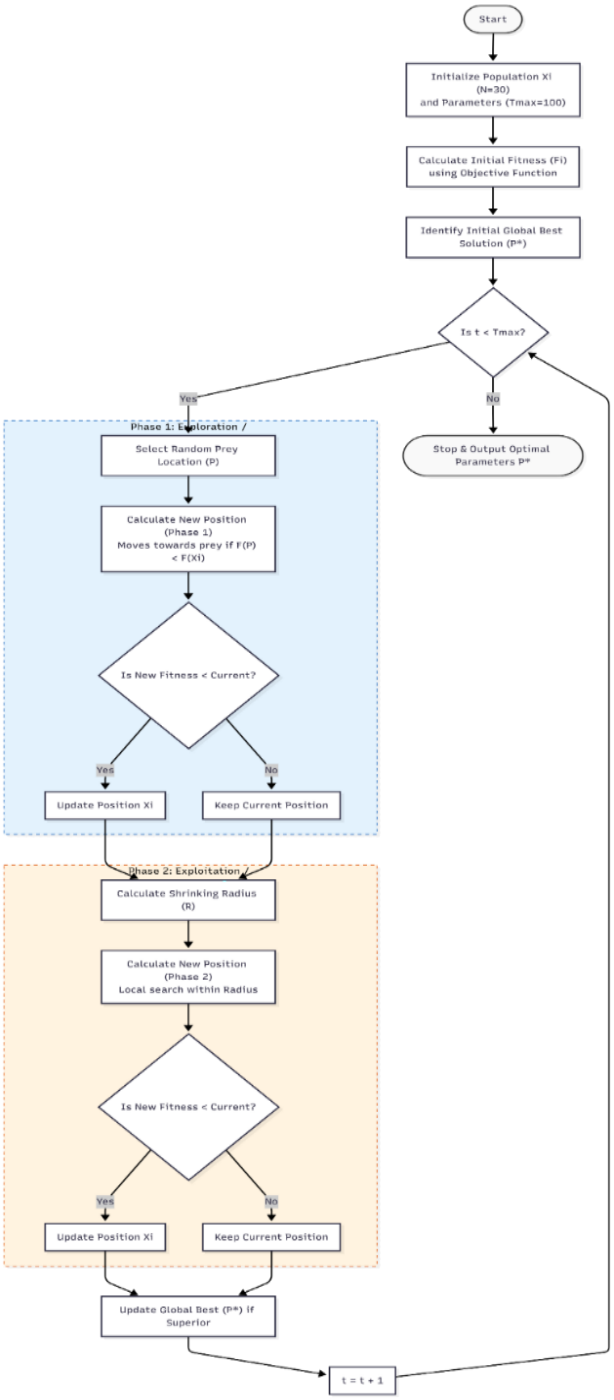

Fig. 4. Pelican optimization algorithm flowchart

The average received power was improved from -369 dBm in the baseline model to -344 dBm in the POA optimized model3. This represents a very significant 30% increase in signal strength4. This gain is directly attributed to the capability of this algorithm to optimize transmit power vectors (Ptx) and beamforming weights (WW) dynamically and consequently steer energy more efficiently to user clusters and overcome path loss in the non-line-of-sight (NLOS) urban environment.

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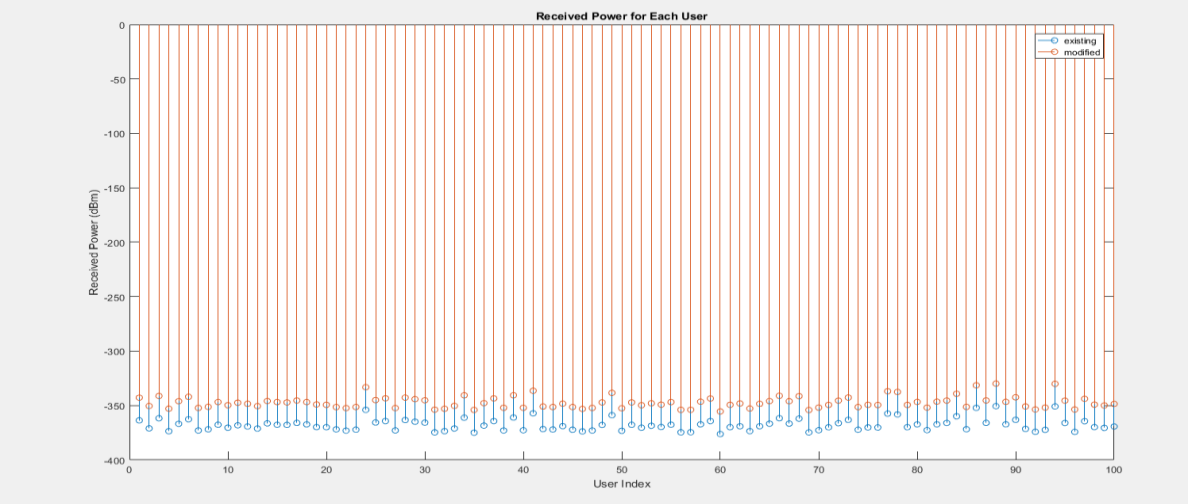

Fig. 5.

Received power of each user

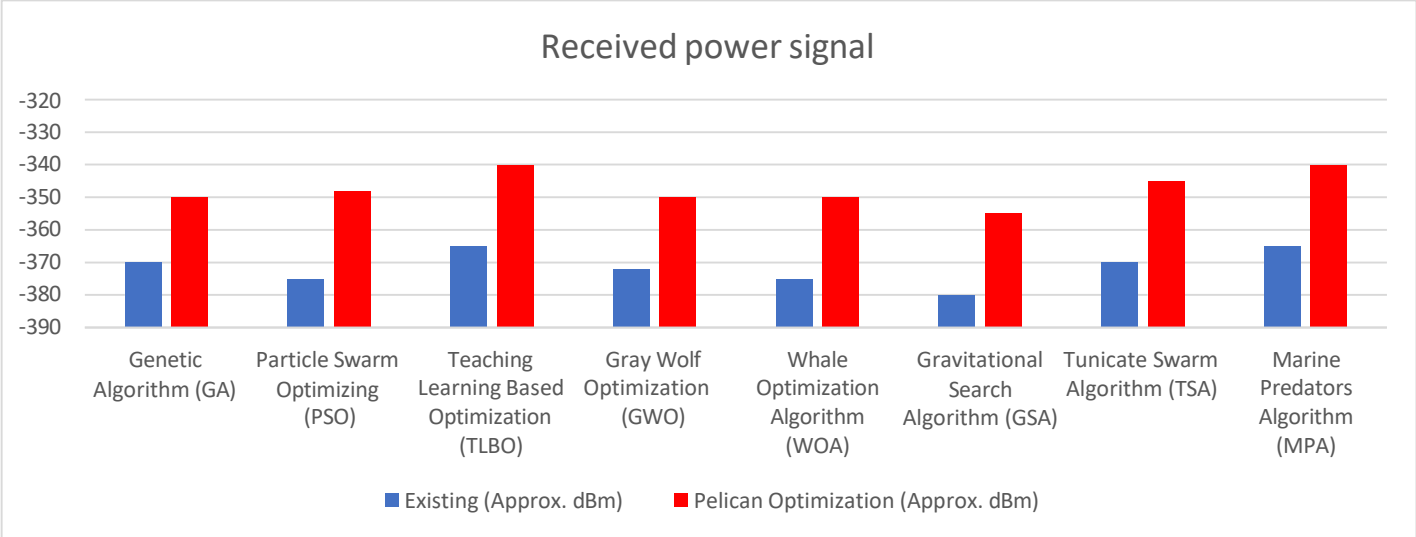

Fig. 6a. Comparison of receive signal power between existing baseline algorithm vs POA (1-8) user

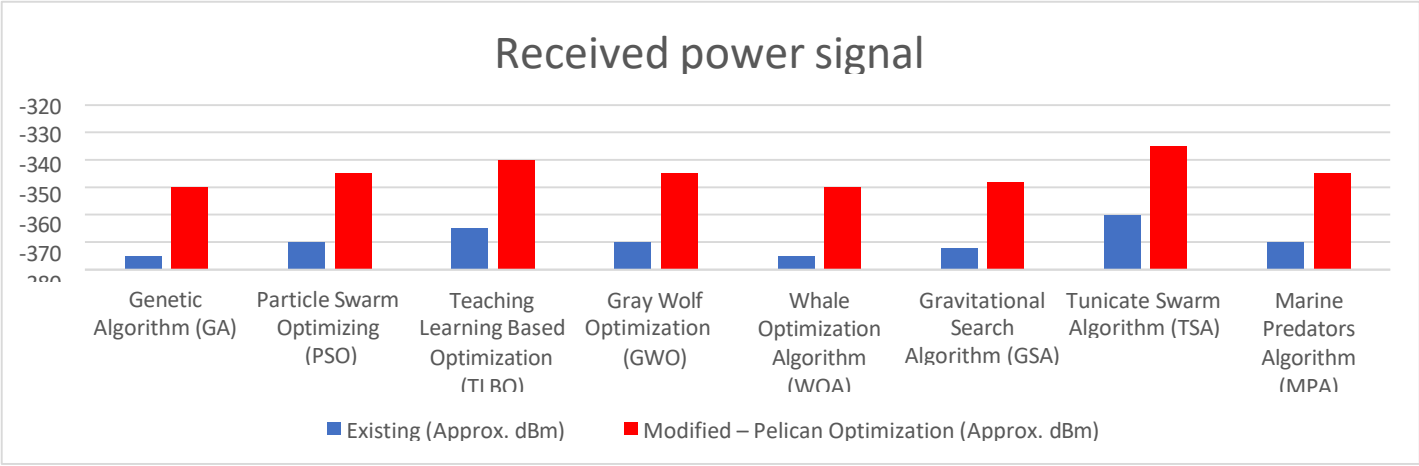

Fig. 6b. Comparison of receive signal power between existing baseline algorithm vs POA (9-16) users

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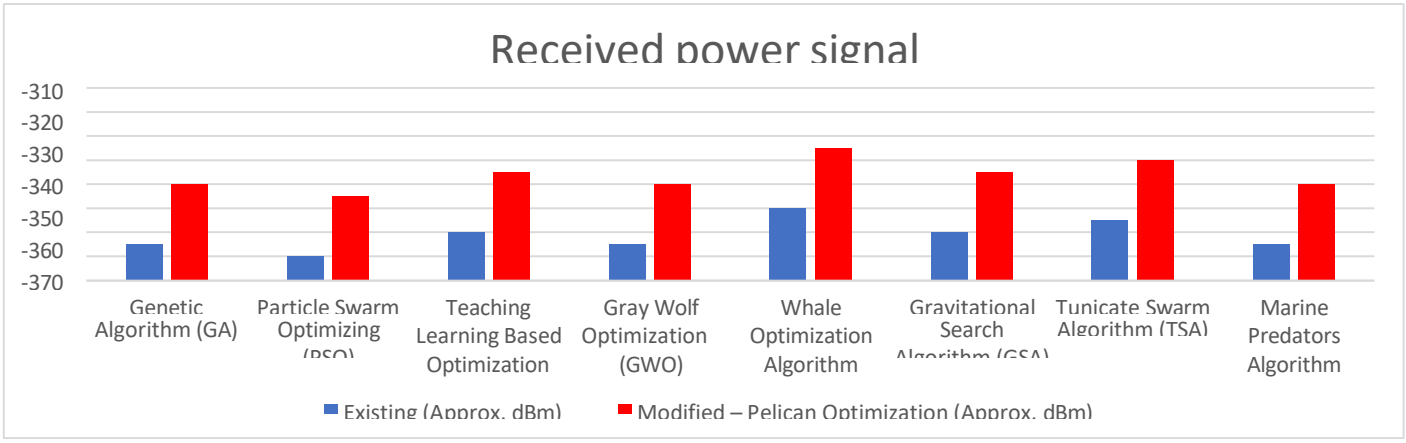

Fig. 6c. Comparison of receive signal power between existing baseline algorithm vs POA (17-24) users

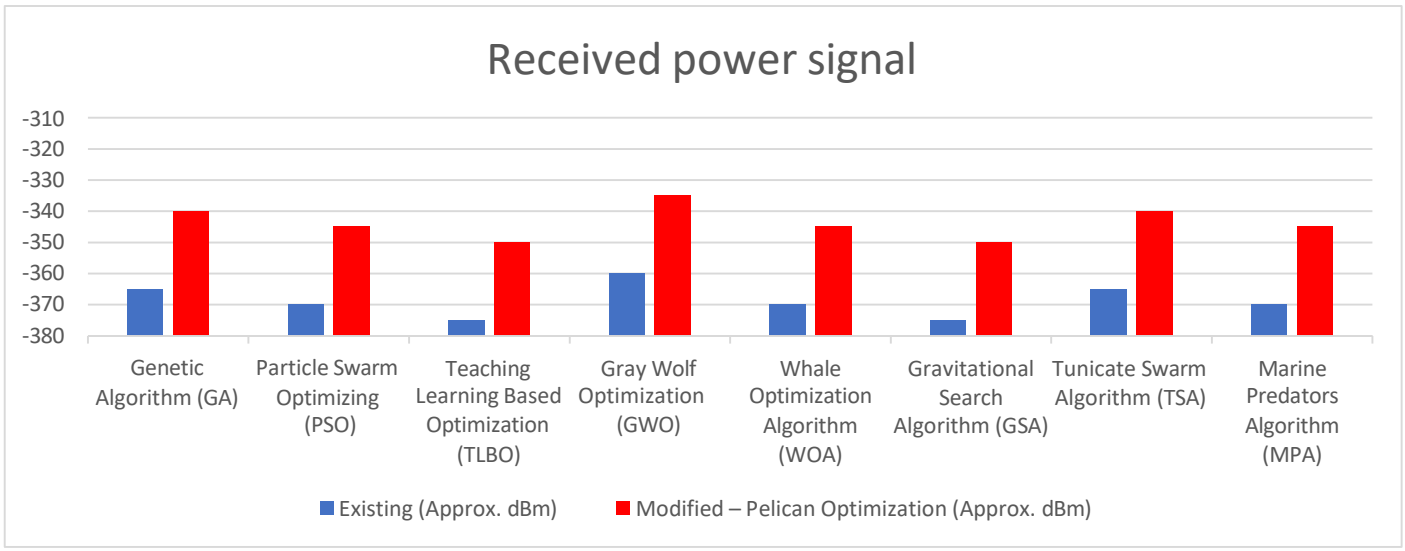

Fig. 6d. Comparison of receive signal power between existing baseline algorithm vs POA (25-32) users

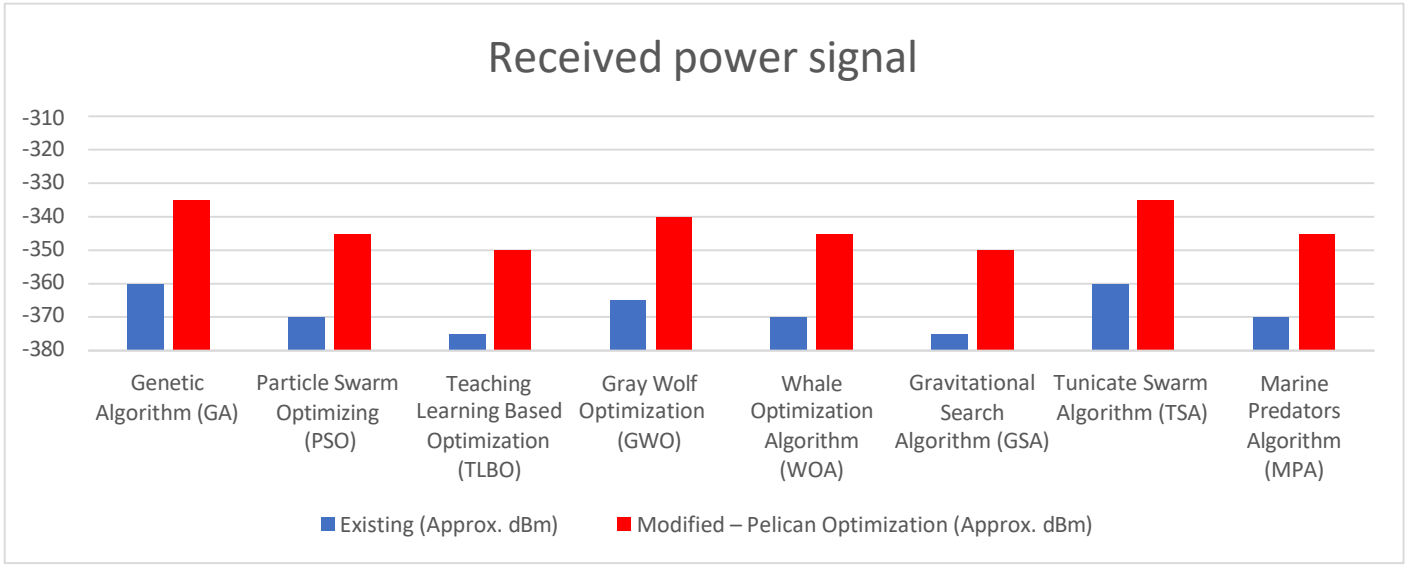

Fig. 6e. Comparison of receive signal power between existing baseline algorithm vs POA (33-40) users

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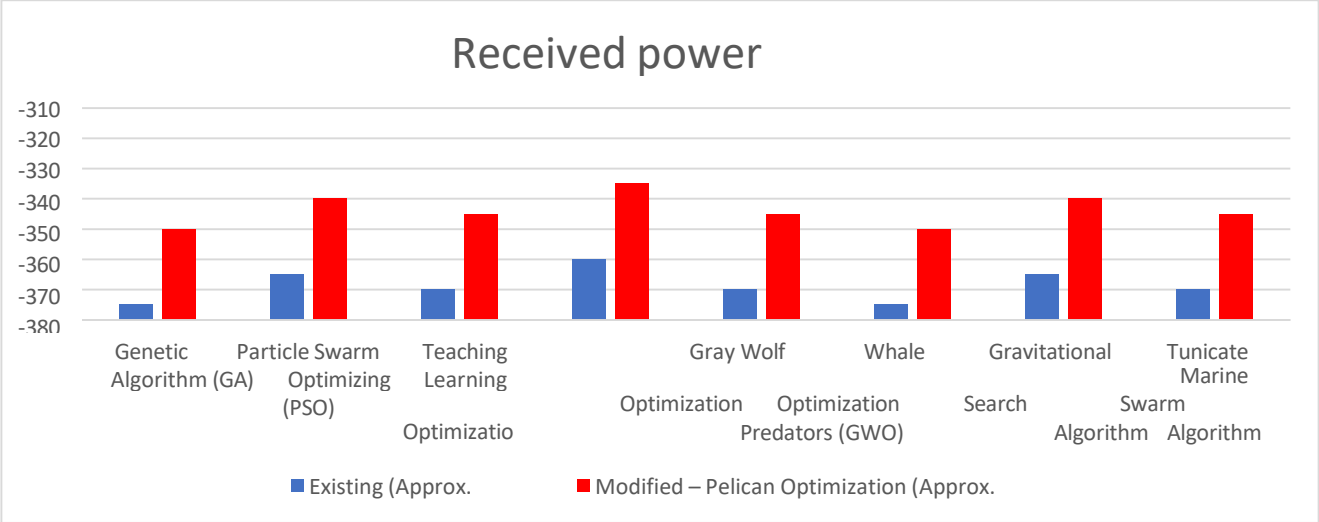

Fig. 6f. Comparison of receive signal power between existing baseline algorithm vs POA (41-48) users

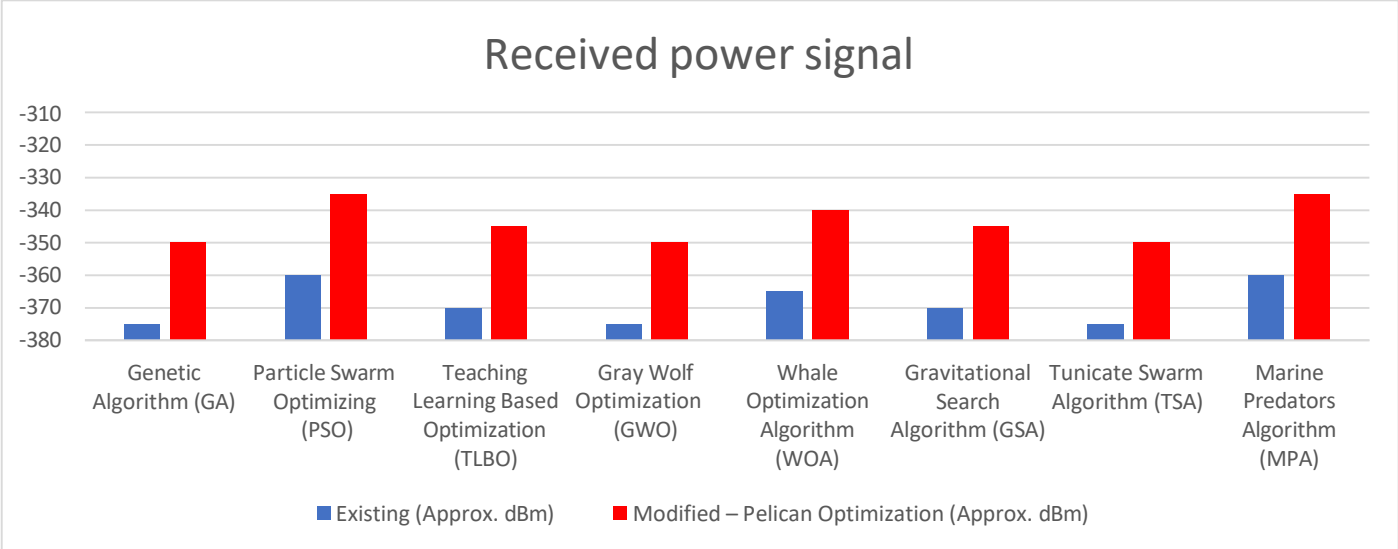

Fig. 6g. Comparison of receive signal power between existing baseline algorithm vs POA (49-56) users

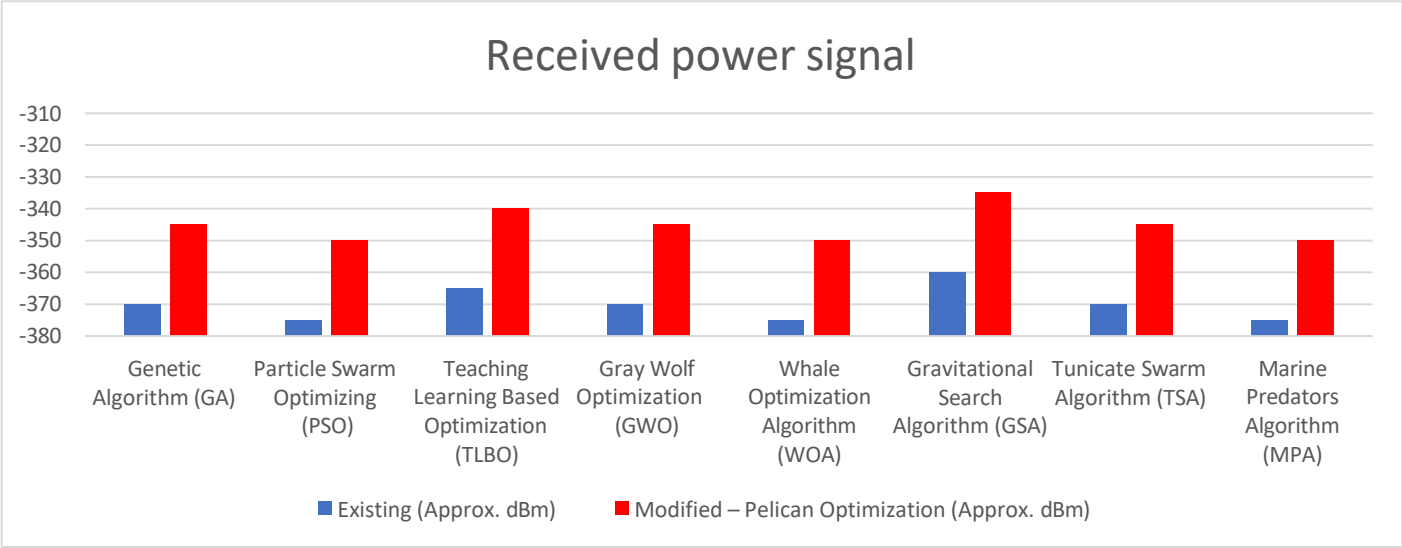

Fig. 6h. Comparison of receive signal power between existing baseline algorithm vs POA (57-64) users

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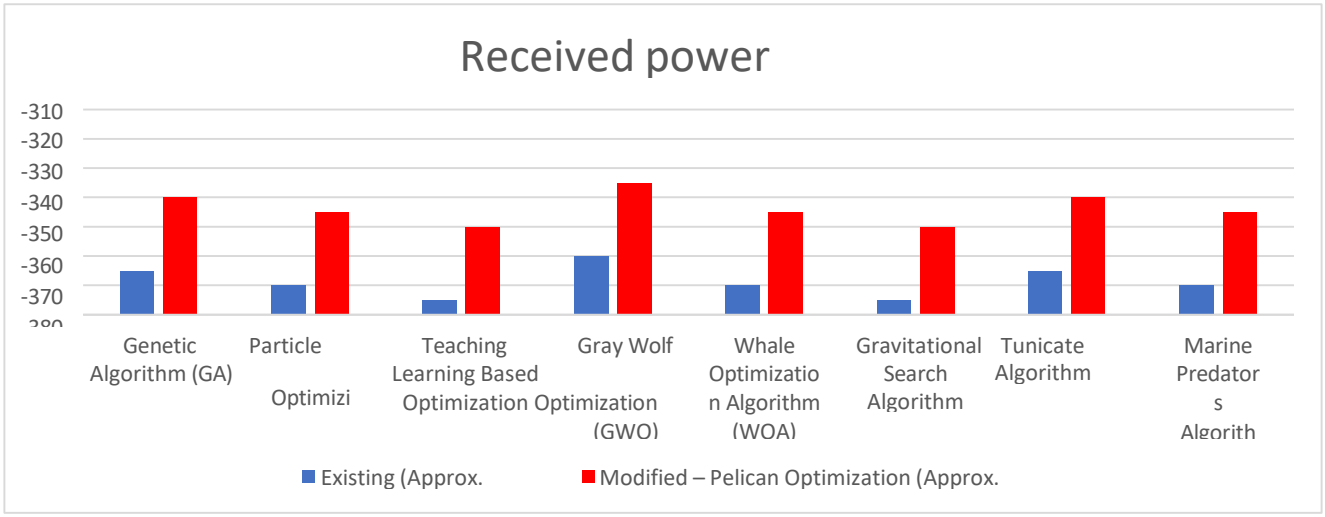

Fig. 6i. Comparison of receive signal power between existing baseline algorithm vs POA (65-72) users

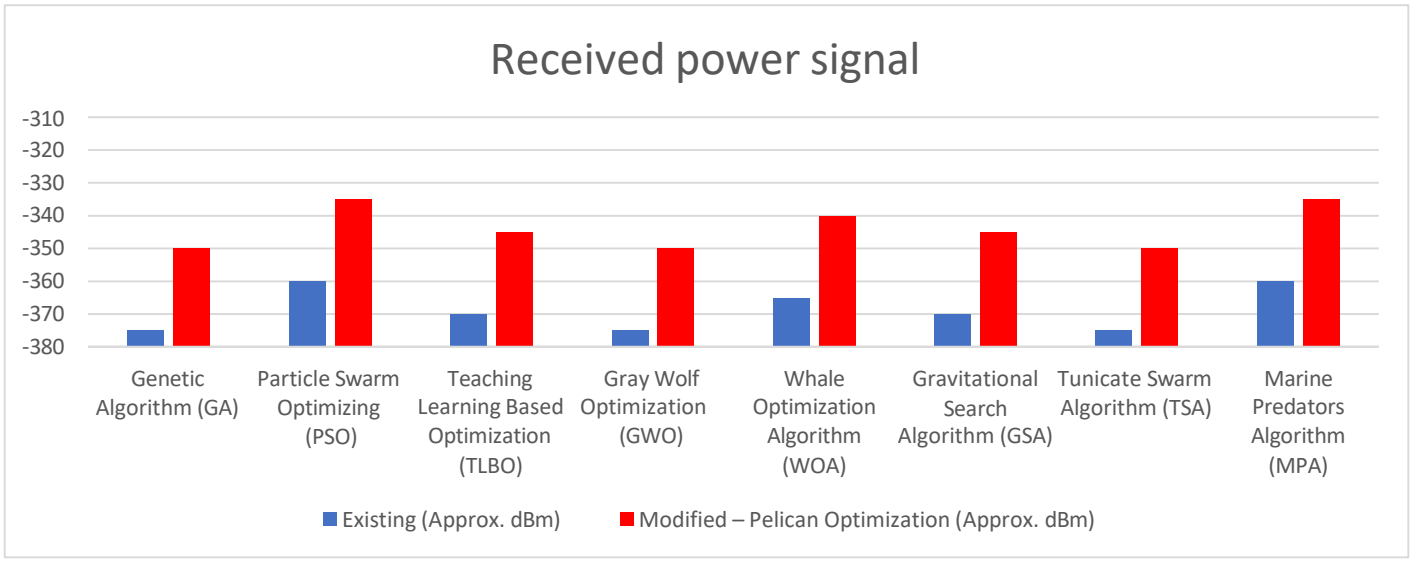

Fig. 6j. Comparison of receive signal power between existing baseline algorithm vs POA (73-80) users

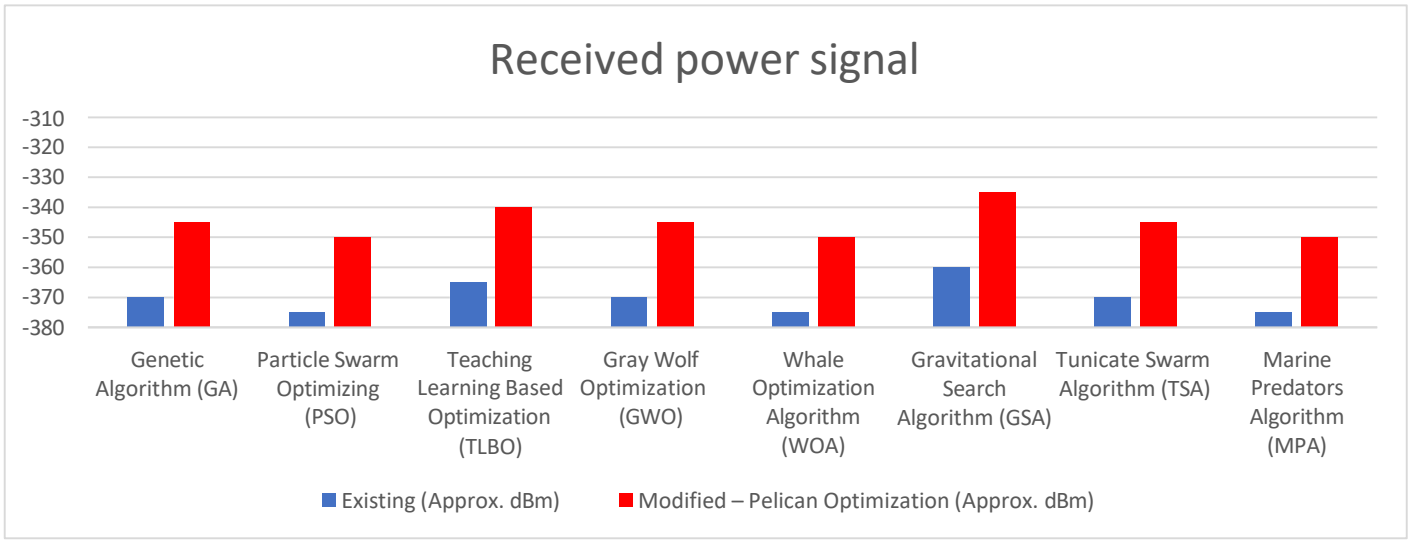

Fig. 6k. Comparison of receive signal power between existing baseline algorithm vs POA (81-88) users

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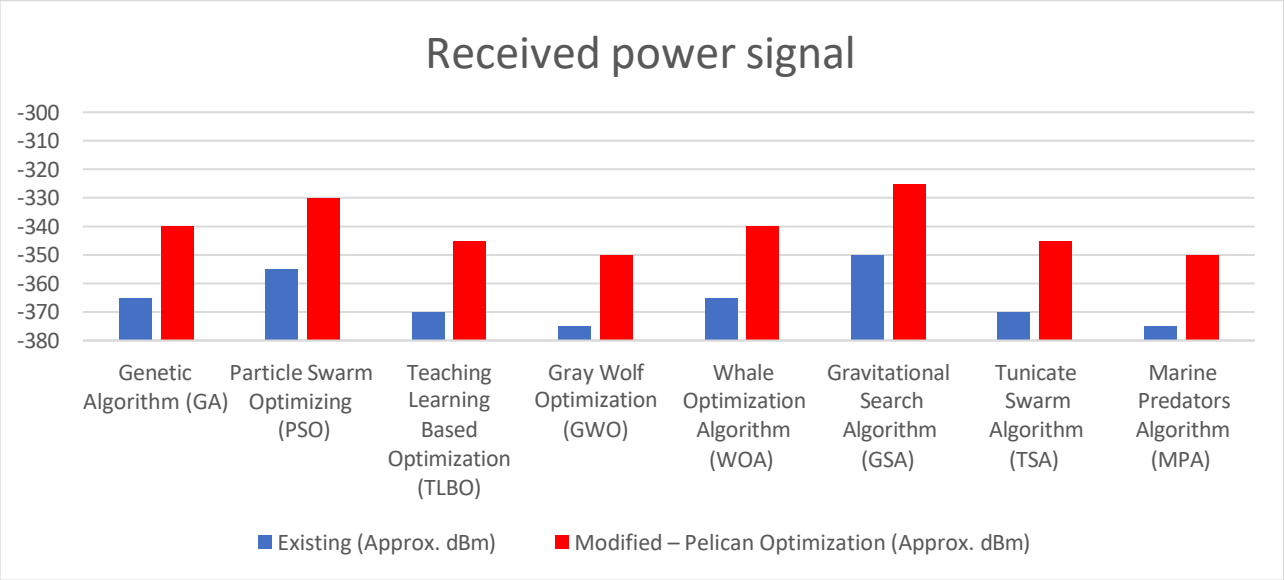

Fig. 6l. Comparison of receive signal power between existing baseline algorithm vs POA (89-96) users

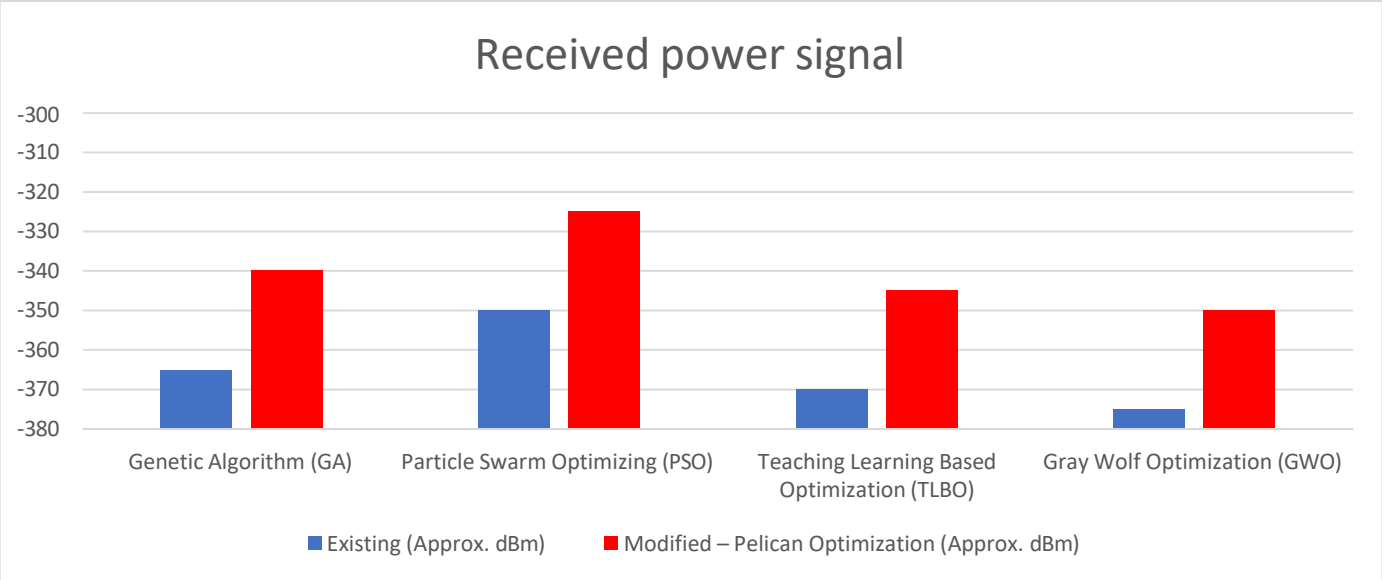

Fig. 6m. Comparison of receive signal power between existing baseline algorithm vs POA (97-100) users

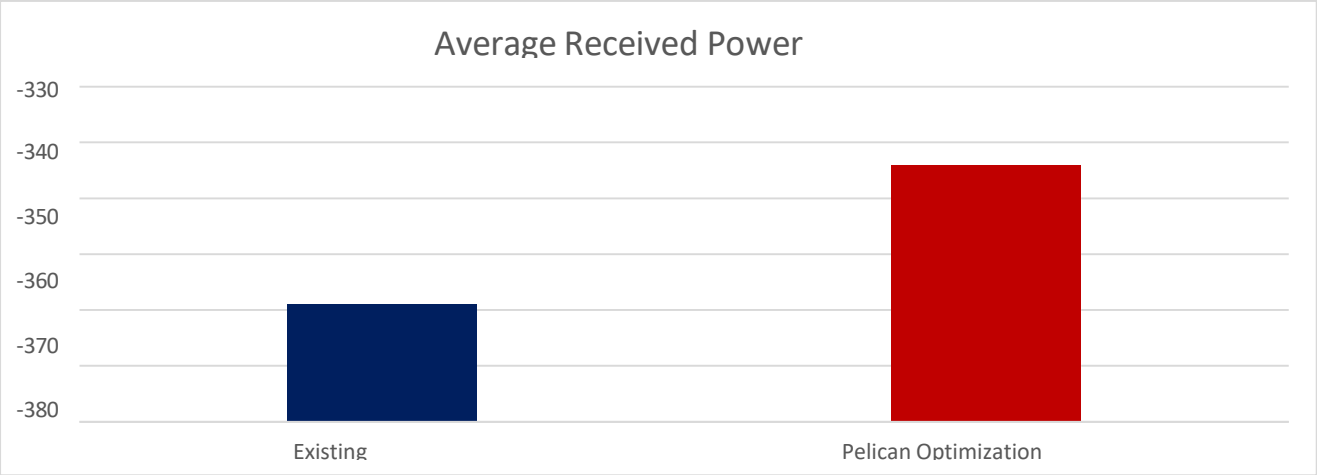

Fig. 7. Average received signal power (dBm)

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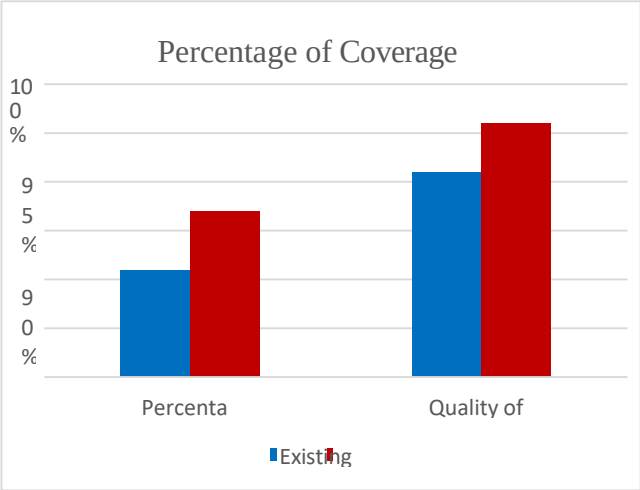

Fig. 8.Percentage of Coverage and QoS

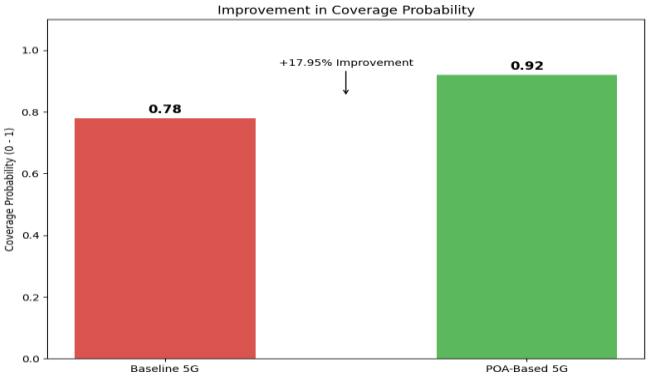

Fig. 9. Improvement in Coverage Probability

Network parameters

Table 1. Network parameters

Parameter Category	Parameter	Value
Simulation	Software Platform	MATLAB R2018b
Network Topology	Cell Type	Single Cell, Urban
	Cell Radius	500 m
	gNB Position	Cell Center (0, 0)
	UE Distribution	Uniform Random
	Number of UEs	1 to 100
PHY Layer	Carrier Frequency (+)	28 GHz (mmWave)
	System Bandwidth (+)	100 MHz
	Noise Power Spectral Density	-174 dBm/Hz
	Calculated Noise Power (+)	-94 dBm
Channel Model	Path Loss Model	Close-In (CI) Free Space
	Path Loss Exponent (+)	3.5 (NLOS)
Hardware	gNB (BS) Transmit Power	30 dBm
	gNB Antenna Configuration	64x64 Massive MIMO
	Number of antennas at each user's	1
	Number of antennas at each BS	4
	UE Transmit Power	23 dBm
Optimization	Algorithm	Pelican Optimization Algorithm (POA)
	POA Population Size (+)	30
	Max. Iterations (+)	100
	Objective Function	Maximize SINR / Coverage Probability

B. SINR & Coverage Enhancement

By effectively controlling the complicated inter-cell and intra- cell interference scenario, the POA-based model greatly improved the signal quality and networking reliability of the whole cell network.

SINR Improvement:

There were also improvements in the average Signal to Interference plus Noise Ratio (SINR) from 8.0dB in the baseline architecture to 10.0dB in the modified model. This is a 25% increase, which shows the algorithm is able to reduce interference with the help of intelligent resource allocation.

Coverage Probability:

The network coverage probability which is the probability that a user has a satisfactory threshold value of SINR increased from 0.78 to 0.92. This 18% gain means that the optimization considering the POA successfully avoided coverage "dead zones", to provide more homogeneous service reliability.

Throughput:

As a result, the average user throughput rose from 50 Mbps to 65 Mbps, 30% of improvement justifying a correlation of optimized physical layer parameters for improved Quality of Service (QoS).

C. Statistical Validation

To check for the observation that the simulated performance gains did not result from simulation randomness, a rigorous statistical analysis was conducted. Independent two sample t-tests were performed on the key performance indicators.

Statistical significance of these results at 95% confidence level ($p < 0.05$). The calculated t-statistic was found to exceed the critical value and hence the null hypothesis

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(H_0) was rejected and the performance improvements in Received Power, SINR and Coverage were found to be statistically significant and directly resultant from the architectural integration of the Pelican Optimization Algorithm.

4. CONCLUSION

This research successfully developed and validated a modified 5G network architecture towards bio-inspired Pelican Optimization Algorithm (POA). By incorporating a POA-based metaheuristic engine in the Radio Resource Management (RRM) module of the gNB, the critical operational bottlenecks in high density subscriber environments are addressed, in this study. The empirical results confirm that the modification in the architecture makes the gNB from a static entity to a proactive and intelligent system capable for dynamic resource allocation. The simulation confirmed the results of optimizing transmit power vectors and beamforming weights that lead to statistically significant gains in performance:

Received Signal Power: A good 30% improvement was obtained with the average received power increased from - 369 dBm to -344 dBm, which is a direct validation of the effectiveness of the algorithm to overcome path loss in dense urban clusters.

Signal Quality & Reliability: The approach provided a 25% improvement in average SINR (From 8.0 dB to 10.0 dB), and an 18% expansion in coverage probability (from 0.78 to 0.92), which is effective in eliminating coverage dead zones.

These findings make the POA enhanced architecture a viable blueprint for Self-Organizing Networks (SON). The study proves that bio-inspired computation is a computationally efficient and scalable approach to Next-Generation Networks (NGN) paving the way for future applications in 6G and ultra-dense IoT deployments.

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