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Articles

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Position and Trajectory Tracking Control for the Ball and Plate System using Mixed Sensitivity Problem

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Abstract: This paper presents the position and trajectory tracking control scheme for the ball and plate system (BPS) using the double feedback loop structure (a loop within a loop) for effective control of the system. The inner loop was designed using linear algebraic method by solving a set of Diophantine equations. The outer inner loop was designed using sensitivity approach. Simulation results showed that the plate was stabilized at 0.3546 seconds, and the ball was able to settle at 1.7087 seconds, when given a circular trajectory of radius 0.4 m with an angular frequency of 1.57 rad/sec, with a trajectory tracking error of 0.0095 m, which shows that the controllers have adaptability, strong robustness and control performance for the ball and plate system.

Keywords: Ball and plate system (BPS), linear algebraic method, Diophantine equation, controller, mixed sensitivity problem.

1. Introduction

The ball and plate system (BPS) problem is a benchmark for testing of control algorithms. The BPS is one of the most enduringly popular and important laboratory models for teaching of the control systems engineering (Oravec et al., 2015; Zeeshan et al., 2012). It is amongst the most well-known and challenging test platform for the control engineers. Example of such systems include the ball and beam system (BBS), traditional cart-pole system (inverted pendulum), double and multiple inverted pendulums (Cheng & Tsai, 2016; Mohajerin et al., 2010). The BBS is a well-known problem for nonlinear control where the system is under-actuated and has two degree of freedom (DOF), while the BPS can be considered as an extension of the BBS, consisting of a ball that can roll freely on a plate. Therefore, the BPS has four DOF, and it is more complicated due to the coupling between the variables (Kassem et al., 2015). This under-actuated system has only two actuators, which is stabilized by just two control inputs (Borah et al., 2017; Ghiasi & Jafari, 2012). The system consist of a plate pivoted at its center such that the slope of the plate can be manipulated in two perpendicular directions (Dong et al., 2011). However, since the movements of the ball can reach high speeds, the design of a suitable controller for the BPS is a major challenge (Galvan-Colmenares et al., 2014). The BPS is made of a small ball and plate with two mutually perpendicular axis of rotation (Fei et al., 2011).

A servo system consist of motor controller card and two servo motors to tilt the plate. Intelligent vision system is used for measurement of a ball position from a CCD camera. The problem of the motion control of this system is to control the position of a ball on a plate for both static positions and desired paths. The slope of the plate can be manipulated in two perpendicular directions, so that the tilting of the plate will make the ball move on the plate (Dong et al., 2009; Dong et al., 2011).

The system has demonstrated various controller design methods for positioning and trajectory tracking of the ball; proportional integral derivative (PID) control, fuzzy control, neural network control and model predictive control (Mochizuki & Ichihara, 2013).

The system finds application in areas like humanoid robot, satellite control and unmanned aerial vehicle (UAV) (Mukherjee et al., 2002) in the field of path planning, trajectory tracking and friction compensation (Oriolo & Vendittelli, 2005).

However, various control methods have been introduced in the recent years for the BPS. A controller design for two dimensional electro-mechanical ball and plate system that was based on the classical and modern control theory was proposed by (Knuplež et al., 2003). In the work of (Hongrui et al., 2008), the position of the ball was regulated with a double feedback loop system, in which recursive back-stepping design was employed for the external loop, while switching control scheme was employed for the inner loop. (Farooq et al., 2013) designed a simple interval type-2 fuzzy gain scheduling controller for the stabilization and reference tracking of the BPS. The developed controller was compared with pole placement and type-1 fuzzy logic controller, in which it outperformed the two other controllers with respect to settling time, percentage overshoot and disturbance rejection capability.

In the work of (Lin et al., 2014) , a controller was designed which ensured the BPS stability by employing a loop shaping method based on Normalized Right Coprime Factor (NRCF) perturbation model, in which the well-known lead-lag series compensation design methods were innovatively adopted to obtain appropriate pre and post compensators as the weighting functions to guarantee the BPS time domain performance requirements. A unique motion controller, based on the evolved lookup tables have been developed by (Beckerleg & Hogg, 2016) in order to move a ball on a set-point on a typical BPS. Also, in order to overcome the problem of under-actuation, instability and nonlinearity, which is attributed to the BPS.

However, (Roy et al., 2016a) presents a comparative study between a cascaded fractional order sliding mode controller (FOSMC) and sliding mode controller (SMC) for trajectory control of a ball in a BPS, the FOSMC was designed by choosing a fractional order sliding surface. The proposed control strategies was experimentally validated on a ball and plate laboratory setup (Feedback Instrument Model No. 033-240), simulation and experimental studies showed that the FOSMC outperformed the SMC in terms of tracking accuracy, speed of response, chattering effect and energy efficiency. Also, a cascaded SMC was proposed by (Roy et al., 2016b) for position control of a ball in a BPS. The effectiveness of the proposed controller was tested through simulation studies by making the ball follow a circular and a square shaped trajectories, and the effect of undesirable phenomenon of chattering associated with SMC was found within satisfactory limit. And (Das & Roy, 2017) dealt with a comparative analysis of the performance of SMC and FOSMC when applied to the problem of trajectory control of ball in a BPS. The two control algorithm were simulated on MATLAB-Simulink environment, and experimental validation was later carried out on a BP laboratory setup (Feedback Instrument Model No. 033-240). Simulation and experimental results conveyed that FOSMC performs better than SMC in terms of speed of response and tracking accuracy without increasing the level of chattering and control effort. Also, (Cheng & Tsai, 2016) presented a skillful robotic wrist system using a visual control technique to demonstrate dexterity of the mechanical wrist from the viewpoint of the table tennis. Intelligent control algorithm using Linear Quadratic Regulator (LQR) approach was developed to adjust the plate's altitude to guide the ball to a specific position to achieve given balancing tasks.

(Debono & Bugeja, 2015) proposed and examined the application of sliding mode control (SMC) to the control problem of the ball and plate. The linear full-state feedback controller was compared with the SMC, and the performance between the SMC and linear full-state feedback controller was tested experimentally on a designed and constructed physical test bed that was meant for the purpose of the research.

One of the most effective control scheme of the BPS is the double feedback loop structure, i.e. a loop within a loop. The inner loop serves as a dc motor servo position controller, while the outer loop controls the position of the ball (Liu & Liang, 2010).

In this paper, the ball and plate system is considered as a double feedback loop structure for position and trajectory tracking control. The outer feedback loop is used regulate the ball's position on the plate, and this is based on controller. The inner feedback loop, which is being controlled by a servo controller, drives the plate's slope to follow the reference position, which will be designed based on linear algebraic method by solving a set of Diophantine equations. The rest of the paper is organized as follows. Section 2 introduces the modelling of the BPS, also the design of the inner and outer loop controller is discussed in section 3. However, section 4 shows the simulation results and the trajectory tracking control of the ball on the plate. And finally, section 5 presents the conclusion.

2.Mathematical Modelling

Figure 1 shows a typical laboratory model of the BPS by HUMUSOFT

Figure 1. The ball and plate system (bps) by humusoft (humusoft ltd., 2012a)

Figure 2 shows the schematic model diagram of the BPS.

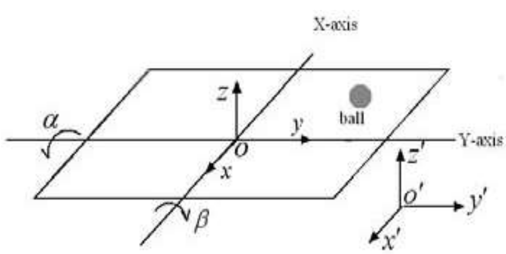

Figure 2. The schematic model for the ball and plate system

The plate rotates around the x and y-axis in two perpendicular directions. The kinematic differential equations of the BPS are obtained using the Euler-Lagrange equation given as (Morales *et al.*, 2017; Yıldız & Gören-Sümer, 2017):

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{q}_i} - \frac{\partial T}{\partial q_i} + \frac{\partial V}{\partial q_i} = Q_i \qquad (1)$$

Where q_i stands for the i^{th}-direction coordinate, T is the kinetic energy of the system, V is the potential energy of the system, and Q is the composite force.

The BPS can be simplified into a system made up of two rigid bodies; the geometry of the plate has limits in translation along x, y and z-axis. It also has a geometry limit in rotation about its z-axis. The plate has two degree of freedom (DOF) in rotation about the x and y-axis. The ball's geometry has a limit in translation along the z-axis. It also has two DOF along the x and y-axis respectively. The BPS system model has four DOF, in which the generalized coordinates are (Hongrui *et al.*, 2008):

$q_1 = x$, $q_2 = y$, $q_3 = \alpha$, $q_4 = \beta$.

The total kinetic energy of the BPS is given as:

$$T = T_{ball} + T_{plate} \quad (2)$$

$$T_{ball} = \frac{1}{2}\left[\begin{array}{l}\left(m_b + \frac{J_b}{R_b^2}\right)\left(\dot{x}^2 + \dot{y}^2\right) + J_b\left(\dot{\alpha}^2 + \dot{\beta}^2\right) \\ \qquad + m_b\left(x\dot{\alpha} + y\dot{\beta}\right)^2\end{array}\right] \quad (3)$$

$$T_{plate} = \frac{1}{2}\left[\begin{array}{l}\left(J_{Px}\dot{\alpha}^2 + J_{py}\dot{\beta}^2\right) + \left(m_b + \frac{J_b}{R_b^2}\right)\left(\dot{x}^2 + \dot{y}^2\right) \\ \qquad + J_b\left(\dot{\alpha}^2 + \dot{\beta}^2\right) + m_b\left(x\dot{\alpha} + y\dot{\beta}\right)^2\end{array}\right] \quad (4)$$

The potential energies of the BPS along the x and y-axis is given as:

$$V_x = m_b g x \sin\alpha \quad (5)$$

$$V_y = m_b g y \sin\beta \quad (6)$$

And the mathematical equation of the BPS is given as:

$$\left(m_b + \frac{J_b}{R_b^2}\right)\ddot{x} - m_b x\left(\dot{\alpha}\right)^2 - m_b y\dot{\alpha}\dot{\beta} + m_b g\sin\alpha = 0 \quad (7)$$

$$\left(m_b + \frac{J_b}{R_b^2}\right)\ddot{y} - m_b y\left(\dot{\beta}\right)^2 - m_b x\dot{\alpha}\dot{\beta} + m_b g\sin\alpha = 0 \quad (8)$$

$$\left(m_b x^2 + J_b + J_{Px}\right)\ddot{\alpha} + 2m_b x\dot{x}\dot{\alpha} + m_b xy\ddot{\beta} + m_b\left(\dot{x}y + x\dot{y}\right)\dot{\beta} + m_b g x\cos\alpha = \tau_x \quad (9)$$

$$\left(m_b y^2 + J_b + J_{Py}\right)\ddot{\beta} + 2m_b y\dot{y}\dot{\beta} + m_b xy\ddot{\alpha} + m_b\left(\dot{x}y + x\dot{y}\right)\dot{\alpha} + m_b g y\cos\beta = \tau_y \quad (10)$$

$m_b\left(kg\right)$ represents the mass of the ball, $J_b\left(kgm^2\right)$ is the rotational moment of inertia of the ball, $J_{P_x}\left(kgm^2\right)$ and $R_b\left(m\right)$ are the rotational moment of inertia of the plate and the radius of the ball; $x\left(m\right)$ and $y\left(m\right)$ gives the position of the ball along the x and y-axis; $\dot{x}\left(m/s\right)$ and $\ddot{x}\left(m/s^2\right)$ are the velocity and acceleration along the x-axis; $\dot{y}\left(m/s\right)$ and $\ddot{y}\left(m/s^2\right)$ gives the velocity and acceleration along the y-axis; $\alpha\left(rad\right)$ and $\dot{\alpha}\left(rad/\sec\right)$ gives the plate deflection angle, and angular velocity along x-axis; $\beta\left(rad\right)$ and $\dot{\beta}\left(rad/\sec\right)$ gives the plate deflection angle and angular velocity along y-axis; and $\tau_x\left(Nm\right)$ and $\tau_y\left(Nm\right)$ gives the torques on the plate in the x and y-axis.

Equation (7) and (8) describes the ball's movement on the plate; it also shows how the effect of the ball's acceleration relies on the plate's angular deflection and its angular velocity. However, equation (9) and (10) describes how the dynamics of the plate's deflection rely on the external forces driving it, and the ball's position (Duan *et al.*, 2009).

Considering the state variable assignment of the BPS (Fan *et al.*, 2004):

$$X = \left(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8\right)^T = \left(x, \dot{x}, \alpha, \dot{\alpha}, y, \dot{y}, \beta, \dot{\beta}\right)^T \quad (11)$$

And the state space equation of the BPS is as follows (Fan *et al.*, 2004):

$$\begin{bmatrix}\dot{x}_1\\\dot{x}_2\\\dot{x}_3\\\dot{x}_4\\\dot{x}_5\\\dot{x}_6\\\dot{x}_7\\\dot{x}_8\end{bmatrix}=\begin{bmatrix}x_2\\B\left(x_1x_4^{\ 2}+x_4x_5x_8-g\sin x_3\right)\\x_4\\0\\x_6\\B\left(x_5x_8^{\ 2}+x_1x_4x_8-g\sin x_7\right)\\x_8\\0\end{bmatrix}+\begin{bmatrix}0&0\\0&0\\0&0\\1&0\\0&0\\0&0\\0&0\\0&1\end{bmatrix}\begin{bmatrix}u_x\\u_y\end{bmatrix} \quad (12)$$

$$y=\begin{bmatrix}1&0&0&0&0&0&0&0\\0&0&0&0&1&0&0&0\end{bmatrix}\left[X\right] \quad (13)$$

$$B=\frac{m_b}{\left(m_b+\frac{J_b}{R_b^{\ 2}}\right)} \quad (14)$$

In the steady state, the plate should be at a position that is horizontal, where both the inclination angles of the x and y-axis are equal to zero, if the inclination angle of the plate does not have much change, i.e. $\pm 5^0$, then, the sine function can be substituted by its argument (Fabregas *et al.*, 2017). The mathematical model of the BPS can be simplified and decomposed into x and y-axis as:

$$\begin{bmatrix}\dot{x}_1\\\dot{x}_2\\\dot{x}_3\\\dot{x}_4\end{bmatrix}=\begin{bmatrix}x_2\\B\left(x_1x_4^{\ 2}-g\sin x_3\right)\\x_4\\0\end{bmatrix}\begin{bmatrix}x_1\\x_2\\x_3\\x_4\end{bmatrix}+\begin{bmatrix}0\\0\\0\\1\end{bmatrix}\left[u_x\right] \quad (15)$$

$$\begin{bmatrix}\dot{x}_5\\\dot{x}_6\\\dot{x}_7\\\dot{x}_8\end{bmatrix}=\begin{bmatrix}x_6\\B\left(x_5x_8^{\ 2}-g\sin x_7\right)\\x_8\\0\end{bmatrix}\begin{bmatrix}x_5\\x_6\\x_7\\x_8\end{bmatrix}+\begin{bmatrix}0\\0\\0\\1\end{bmatrix}\left[u_y\right] \quad (16)$$

3.Controller Design

Determination of the Actuator Parameters

The actuator with a permanent DC motor is considered in the inner loop design. Also, the relationship between θ_L and e_a is given as (Golnaraghi & Kuo, 2010):

$$\frac{\theta_L}{e_a}=\frac{K_t\frac{N_1}{N_2}}{\left[J_{eq}L_as^3+\left(J_{eq}R_a+D_{eq}L_a\right)s^2+\left(D_{eq}R_a+K_tK_e\right)s\right]}=T_L \quad (17)$$

The parameters of the DC motors are derived based on the requirements of the load torque, the speed of the motor, and the moment of inertia. This is given in Table I.

Table 1. BPS System Parameters (Humusoft Ltd., 2012b)

S/N	Description	Symbol	Unit	Value
1	Mass of the ball	m	kg	0.11
2	Radius of the ball	R	m	0.02
3	Dimension of the plate (square)	lxb	m^2	0.16
4	Mass moment of inertia of the plate	$J_{Px,y}$	kgm^2	0.5
5	Mass moment of inertia of the ball	J_b	kgm^2	1.76e-5

6	Maximum velocity of the ball	V	m/s	0.04

Equation (17) is given as (Umar, 2017):

$$\frac{\theta_L}{e_a} = \frac{0.105}{\left[0.47005s^2 + 421.113s\right]}$$

(18)

$$= \frac{0.2234}{s(s+895.89)} \approx \frac{2.49x10^{-4}}{s}$$

(19)

3.2 *Two-Port Parameter Configuration*

The two-port parameter configuration was used in the design of the inner loop. To find the value of ω_o, a step response is required, which could settle in 0.4 seconds. From the Humusoft ball and plate system manual, through simulation, $\omega_o = 20\,rad/\text{secs}$ was found to give the steady state response. The ITAE optimal overall transfer function with zero position error of the system, which is $G_0(s)$ is (Chen, 1995):

$$G_0(s) = \frac{\omega_0{}^2}{s^2 + 1.4\omega_0 s + \omega_0{}^2} \qquad (20)$$

An additional gain of 494 was provided to limit the step response using a preamplifier. $G_0(s)$ is implemented as shown in Figure 3 using the two-port configuration

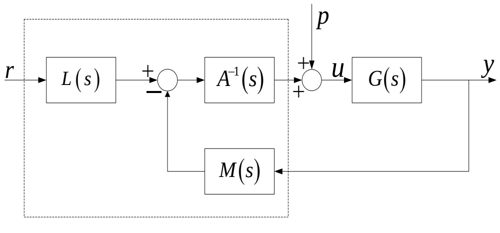

Figure 3. Two-port parameter configuration

Where $L(s)$, $M(s)$ and $A(s)$ are the polynomials that defines the compensator, p which is the input disturbance. Solving the Diophantine equation, the compensator and the DC motor actuator has the following values (Umar, 2017):

$$A(s) = 28 + s$$

(21)

$$M(s) = 3252 + s$$

(22)

$$L(s) = 3252$$

(23)

3.3 H_∞ Controller

The augmented plant model for H_∞ controller can be constructed as (Dingyu *et al.*, 2007):

$$P(s) = \begin{bmatrix} A & B_1 & B_2 \\ C_1 & D_{11} & D_{12} \\ C_2 & D_{21} & D_{22} \end{bmatrix}$$

(24)

With the augmented state space description as follows:

$$\dot{x} = Ax + \begin{bmatrix} B_1 & B_2 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \qquad (25)$$

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} C_1 \\ C_2 \end{bmatrix} x + \begin{bmatrix} D_{11} & D_{12} \\ D_{21} & D_{22} \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \qquad (26)$$

Straightforward manipulations gives the following closed loop transfer function:

$$Ty_1u_1(s) = P_{11}(s) + P_{12}(s)\left[I - F(s)P_{22}(s)\right]^{-1} F(s)P_{21}(s) \qquad (27)$$

The above expression is also known as the linear fractional transformation (LFT) of the interconnected system. The objective of robust control is to find a stabilizing controller.

$$u_2(s) = F(s)\,y_2(s) \qquad (28)$$

Such that

$$\|Ty_1u_1\|_\infty < 1 \qquad (29)$$

The design objective is to find a robust controller $F_c(s)$ guaranteeing the closed-loop system with an H_∞-norm bounded by a given positive number γ, i.e. (Dingyu *et al.*, 2007):

$$\| Ty_1u_1 \|_\infty < \gamma \qquad (30)$$

Then the controller can be represented by (Dingyu *et al.*, 2007)

$$F_c(s) = \left[\begin{array}{c|c} A_f & -ZL \\ \hline F & 0 \end{array}\right] \qquad (31)$$

Where:

$$A_f = A + \gamma^{-2} B_1 B_1^T X + B_2 F + ZLC_2$$

$$F = -B_2^T X \qquad (33)$$

$$L = -YC_2^T \qquad (34)$$

$$Z = \left(I - \gamma^{-2} YX\right)^{-1} \qquad (35)$$

X and Y are, respectively the solutions of the following two Algebraic Riccati Equations (AREs) (Dingyu *et al.*, 2007):

$$A^T X + XA + X\left(\gamma^{-2} B_1 B_1^T - B_2 B_2^T\right) X + C_1 C_1^T = 0 \qquad (36)$$

$$AY + YA^T + Y\left(\gamma^{-2} C_1^T C_1 - C_2^T C_2\right) Y + B_1^T B_1 = 0 \qquad (37)$$

The conditions for the existence of an H_∞ controller are as follows (Dingyu *et al.*, 2007):

1) D_{11} is small enough such that $D_{11} < \gamma$
2) The solution X of the controller ARE is positive-definite;
3) The solution Y of the observer ARE is positive-definite;
4) $\lambda_{\max}(XY) < \gamma^2$, which indicate that the eigenvalues of the product of the two Riccati equation solution matrices are all less than γ^2.

In the design of the optimal H_∞ controller, the optimal criterion is defined as (Dingyu *et al.*, 2007):

$$\max_{\gamma} \| Ty_1u_1 \|_\infty < \frac{1}{\gamma} \qquad (38)$$

3.4 H_∞ Mixed Sensitivity Problem

In the design of the H_∞ optimal control, using the mixed sensitivity problem, the weighting functions which are $\mathrm{W}_1(\mathrm{s})$, $\mathrm{W}_2(\mathrm{s})$ and $\mathrm{W}_3(\mathrm{s})$ are used for shaping the plant model $G(s)$. The weighting function $\mathrm{W}_1(\mathrm{s})$, penalizes the error signal, $\mathrm{W}_2(\mathrm{s})$ penalizes the input signal and $\mathrm{W}_3(\mathrm{s})$ penalizes the output signal (Hossain, 2007). This is shown in Figure 4.

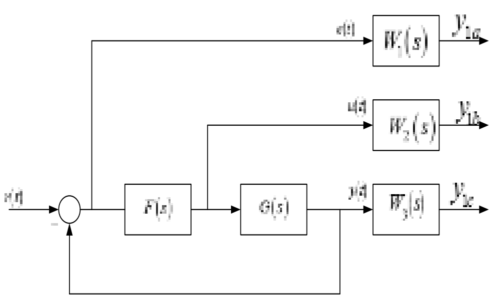

Figure 4. Mixed sensitivity problem

The augmented plant model $P(s)$ is written as:

$$P(s) = \left[\begin{array}{c|c} W_1 & -W_1 G \\ 0 & W_2 \\ 0 & W_3 G \\ \hline I & -G \end{array}\right] \qquad (39)$$

The linear fractional transformation (LFT) of the mixed sensitivity problem Ty_1u_1, the sensitivity transfer function

$S(s)$ and the complementary sensitivity transfer function $T(s)$ are given as:

$$Ty_1u_1 = \begin{bmatrix} W_1S \\ W_2FS \\ W_3T \end{bmatrix} \quad (40)$$

$$S(s) = \left[1 + F(s)G(s)\right]^{-1} \quad (41)$$

$$T(s) = 1 - S(s) = F(s)G(s)\left[1 + F(s)G(s)\right]^{-1} \quad (42)$$

$F(s)$ is the controller, $S(s)$ is the sensitivity transfer function and $T(s)$ is the complementary transfer function.

3.5 Determination of the H_∞ Controller

The weighting functions $W_1(s)$, $W_2(s)$ and $W_3(s)$ for the control of the system were selected after extensive simulation and fine tuning as:

$$W_1(s) = \frac{100\left(1.5s^2 + 12.64s + 18.49\right)}{100\left(1.5s^2 + 103.2s + 18.49\right)} \quad (43)$$

$$W_2(s) = 1 \quad (44)$$

$$W_3(s) = \frac{s^2}{100} \quad (45)$$

4. Simulation Results

The following simulations results were obtained from MATLAB 2017a software.

4.1 Inner Loop Design

The step response of the actuator is shown in Figure 5.

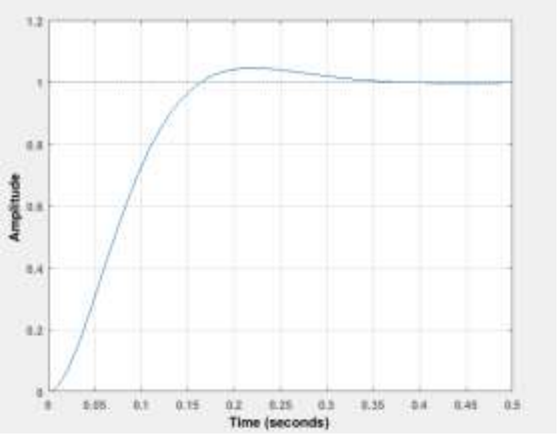

Figure 5. Step response of the actuator

Table II: shows the Properties of the Actuator.

System Response	Value
Settling Time (sec)	0.2989
Overshoot (%)	4.5989

From Table II, the settling time of the actuator is 0.2989 seconds, which shows that the plate will settle before 0.4 seconds that was set for it. However, the actuator $U(s)$ due to a step input should not exceed the rated DC motor voltage of the actuator, which is 75V. Figure 6 shows the step response of the actuator with open parameters (rated power and voltage) of the DC motor.

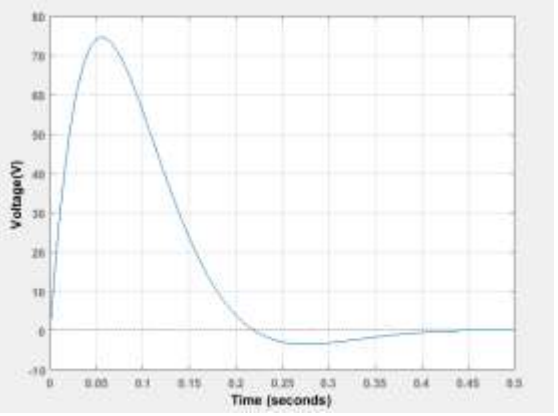

Figure 6. Step response of the Actautor with open Parameters

From Figure 6, the plate stabilized at 0.3546 seconds. Also, the peak voltage is 74.56V, which is closer to the rated voltage of 75V. From this, it shows that a proper inner loop design of the DC motor actuator has the following properties, which is given in Table III.

Table III: Properties of the Actuator with open Parameters

Actuator System Response	**Value**
Settling Time (sec)	0.3546
Peak Voltage (V)	74.5631

4.2 Outer Loop Design

The designed H_∞ controller is:

$$K = \frac{23622(s+1.631)(s+0.2213)(s+0.1794)}{(s+1109)(s+25.82)(s+0.9012)(s+0.3308)} \quad (46)$$

The step response of the H_∞ controller is given in Figure 7

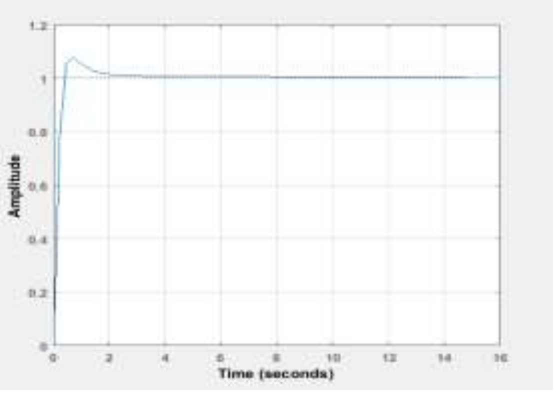

Figure 7. Step response of the H_∞ controller

From Figure 7, the properties of the H_∞ controller is given in Table IV.

Table IV. Properties of the H-Infinity Controller

H-infinity Controller System Response	Value
Settling Time (sec)	1.7087
Overshoot (%)	7.7246

From Table IV, it shows that the H_∞ controller stabilized the ball at 1.7087 seconds, with an overshoot of 7.7246 %. This shows a good indication of tracking the ball on the desired path on the plate.

A circular trajectory of radius 0.4 m, and a sinusoidal reference signal with a reference input of $x = 0.4(1-\cos\omega t)$ and $y = 0.4(\sin\omega t)$ was taken into consideration, and was used to demonstrate the trajectory tracking performance of the ball. The angular frequency of the sinusoidal reference signal used was 1.57 rad/sec. This is shown in Figure 8.

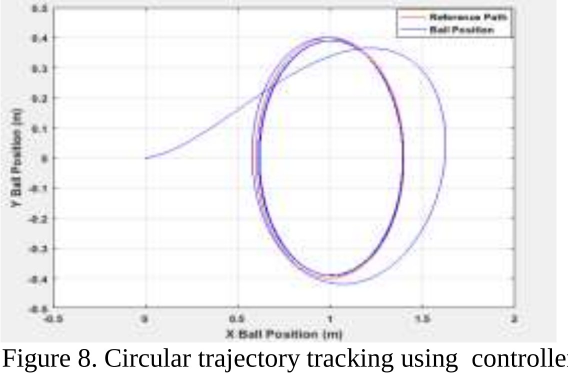

Figure 8. Circular trajectory tracking using controller

The ball was allowed to track a circular trajectory at a frequency of 0.52 rad/sec at a complete revolution of 12 seconds. When the speed was increased to 0.9 rad/sec, at a complete revolution of 7 seconds, the trajectory tracking error increased.

However, it was observed that using the controller, the steady state tracking error of the ball is 0.0095 m. Which shows that the ball was able to track the reference signal with a trajectory tracking error of 0.0095 m.

5. Conclusion

This paper presents the position and trajectory tracking control of the ball and plate system using the double feedback loop structure. For the effective control of the ball and plate system, the double feedback loop structure is considered. The inner loop was designed using linear algebraic method, while the outer loop was designed using function. Simulation results shows that the controllers has adaptability, strong robustness and control performance for the ball and plate system. The ball was able to settle with a good settling time and overshoot. However future research work will be to consider other controller techniques for the design of the outer and inner loop, and incorporating artificial intelligent techniques like grasshopper optimization algorithm (GOA) and weighted artificial fish swarm algorithm (wAFSA) with the controllers for the ball tracking a desired trajectory optimally.

Acknowledgement

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Comparative Analysis of Encryption Algorithms

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Abstract— the vulnerable nature of some sensitive and classified information such as health and bank related data has undoubtedly caused serious havoc to individuals who should enjoy the privacy and confidentiality of their information. In an attempt to guarantee absolute security of information from one source to another and also to prevent confidential information from being revealed to unauthorized people, encryption algorithms are being used to achieve this. Encryption algorithms are basically useful for securing and protecting data being transmitted from one end to another from any form of vulnerability. Over the years, researchers have adopted some of these algorithms to ensure privacy of information in banking, health and military. Some of these algorithms are varied in terms of efficiency, accuracy, reliability and response time whenever they are used for data protection. In an attempt to carry out a comparative assessment, we considered Rivest-Shamir-Adleman (RSA), Advanced Encryption Standard (AES) and Data Encryption Standard (DES) algorithms. Since there is skepticism on which of the algorithms is more reliable, dependable and functional when considering features that characterized their variation, this work therefore, attempts to do a comparative assessment of each of the encryption algorithms to ascertain the best using the stated metrics. The implementation was carried out with C#. The results obtained from the experimentation revealed that AES uses the lowest time for encryption while RSA consumes longest encryption time. Also, AES algorithm is considered the most efficient of all the three algorithms based on the metrics used for the evaluation. Few of the results obtained are presented in this paper.

Keywords/Index Terms— encryption, decryption, analysis, algorithm, audio and video.

1. Introduction

Various Internet applications have emerged in the recent years. Some of these transactions such as internet banking, e-commerce and stock trading are carried out over wireless or cable network that requires efficient and reliable end-to-end connection. What is more? The connection from one end to another end must strictly be protected and confidential to guarantee availability, integrity and confidentiality of information sharing across the network (Tingyuan, Chuanwang & Xulong, 2010.).

With the advent of advance technology in telecommunication and military, the need for more compact, highly secured data, files inclusive, military Intelligence for national security and global unity is important. Encryption comes to play with the sole aim of developing a technique for security mechanism to prevent, protect illegal access to data and files. The need for more complex ways to encrypt and decrypt with algorithms sprung up with various ways of encrypting files, data, password contents which spans across audio, video, pictures and messages (MAbdul, 2009).

Security in computing can simply be defined as a mechanism put in place to ensure that information and services within an organization, a domain, network is well protected, safeguarded from unauthorized individual, illegal access, manipulation, destruction or other vulnerabilities (Azeez and Venter, 2013). Cryptography is considered one of the main approaches being used in networking for achieving security.

Also, encryption is another major technique for ensuring security and privacy of sensitive and classified information. Over the years, encryption algorithms such as AES, RES and DES have been used successfully to protect sensitive and confidential information in military and health institutions. Encryption algorithms allow protection of information from one end to anther (AmanKumar & SudeshJakharet, 2012).

Since the implementation of cryptography has become difficult and complex with the emergence of human intelligence, encryption has become a better and reliable alternative being used by information security experts across the globe. Consequently, in this paper, a comparative assessment of encryption algorithms of DES, AES and RSA was carried out and tested with Audio and Video files. The results obtained are shown in this paper.

Decision was reached on the three algorithms used for evaluation because of their popularity along with observable contradictory results obtained on them from previous researches. What is more, they can provide relatively good performance on the comparative assessment task in this work.

2.Literature Review

Sharma and Sharma, 2016 presented a cryptographic algorithm that is FPGA based. It was used for hiding data. They implemented an algorithm that is multi-keyed in nature with key updated functionality that is real time. In the experiment, both sender and receiver update keys with adequate synchronization. The algorithm was designed using Verilog HDL while Spartan 3E Starter Kit was used for realization. The algorithm has a great benefit of changing keys per cycle. This provides the benefit of making it extremely tough to break.

Singh and Supriya, 2013 did a comparative assessment of four encryption algorithms RSA, DES, 3DES and AES. They justified their work on the fact that some of the existing work on the encryption algorithms are real-time and that each of the techniques is special and unique in its own way which are definitely applicable to different applications. The research carried out revealed that AES algorithm is most efficient when considering speed, throughput, time as well as avalanche effect.

Seth et al. 2011 did a comparative assessment of RSA, DES and AES while considering metrics such as memory usage, output byte and computation time which are regarded as the major issues of worry in nearly all Encryption Algorithm. In this work, the experimental results reveal that that DES encryption algorithm consumes lowest time for encryption while AES encryption algorithm consumes the lowest memory usage. Finally, it was established that RSA takes longest encryption time as well as memory usage while RSA has the least output byte.

Elminaam et al., 2008 analyzed the performance of encryption algorithms with entirely different metrics. They evaluated most common algorithms: DES, 3DES, RC2, Blowfish, and RC6. Metrics considered for evaluation include encryption/decryption speed, different sizes of data blocks, different sizes of data blocks, different data types and different key size. The experimental results reveal that there is no much difference when the results are shown in base 64 encoding or hexadecimal base encoding. Also, RC6 requires less time when compared to all encryption algorithms except Blowfish. When changing data type was considered, it was discovered that Blowfish, RC6 and RC2 have merit over other algorithms with respect to time consumption.

Pavithra et al., 2012 did a performance evaluation of different encryption algorithms. They considered time as their main metric. Different video files were considered for the experimentation to affirm their processing speed by each of the algorithms. Also, different video file formats such as .DAT and .vob were considered with various sizes. The experimental results reveal that AES encryption algorithms is the best in terms of throughput level and processing time when compared to Blowfish and DES.

Mandal et al., 2012 compared advanced encryption standard (AES) and data encryption standard (DES) using avalanche effect, memory requirement as well as simulation time for both algorithms. The experimental results show that AES has a very high avalanche effect when compared to DES. However, the time required for simulation for DES is higher when compared to AES. This implies that AES is basically useful for message encryption.

The need for this similar research is as a result of different results obtained by researchers when evaluating the encryption algorithms. Also, some of the algorithms were empirically evaluated with different files. Some researchers used audio, images, videos and text files hence there is no uniformity in the results obtained. Aside from these issues, metrics used for evaluation are different. Some used timing required to encrypt, size of the files, speed and memory requirements for encryption.

3. Evaluation Parameters

3.1. Encryption time

This can simply be defined as the time required to convert a given plaintext to ciphertext. This is dependent on plaintext block size, key size and mode. In this work, we succeeded in measuring the encryption time milliseconds.

3.2. The Decryption time

This is the time required to get back plaintext from ciphertext. In the implementation of this work, we have successfully measured the time for decryption in milliseconds.

3.3. Memory used

Each of the encryption techniques requires a unique and different memory size for its implementation. The number of required memory depends on the size of the file, type of operations, initialization vectors as well as key size adopted. For an algorithm to be termed as being effective, the memory requirement must be very small.

4. Implementation, Findings and Results

Implementation

AES, RSA and DES encryption algorithms have successfully been implemented. They were implemented with Java by using Eclipse IDE. We made use of both java crypto and java security packages which enable several security features such as authorization, authentication, decryption and encryption.

Also, audio and video files of difference sizes were considered (Ten (10) different types of multi-media file formats ranging from 500kb, 1024kb to 900mb) for the empirical evaluation of the algorithms as input files for encryption process. Each of the encrypted files is saved and later decrypted. To have a consistent and reliable comparison, the same input files were used for all the three algorithms.

A single system was used throughout for the implementation and analysis. This was done to ensure and ascertain that memory maintains the same for AES, RSA and DES encryption algorithms.

The two classes previously mentioned can be divided into two subsections. The first class carries out cryptography which implements operations to be transferred while the second class is the access control and authorization classes that perform digital signatures. With the libraries of the package, AES, RSA and DES encryption algorithms were conveniently and successfully implemented with little changes to the calling functions.

s/n	AUDIO	VIDEO
1	MP3	MP4
2	Flaac	FLV
3	.rm	3gp
4	Wma	mkv
5	M3u	webm
6	Amr	
7	M4a	

Table 1 shows the file format used for the implementation and testing of the three algorithms.

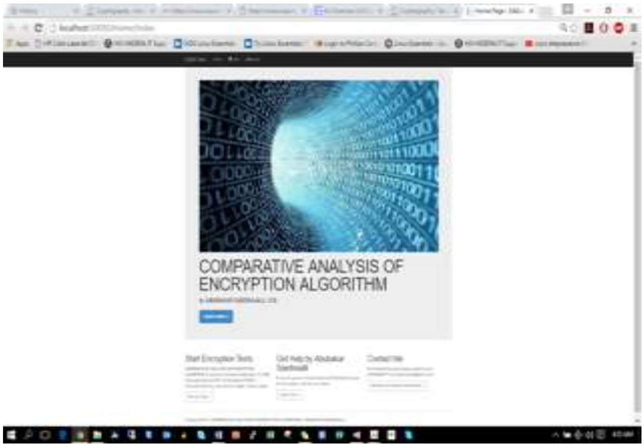

Figure 1. Design interface

5. Data Analysis

After the entire encryption process, the output is displayed in web format form which is then extracted into Excel sheet for further analysis to be discussed in the next chapter. A sample is given in Figure II:

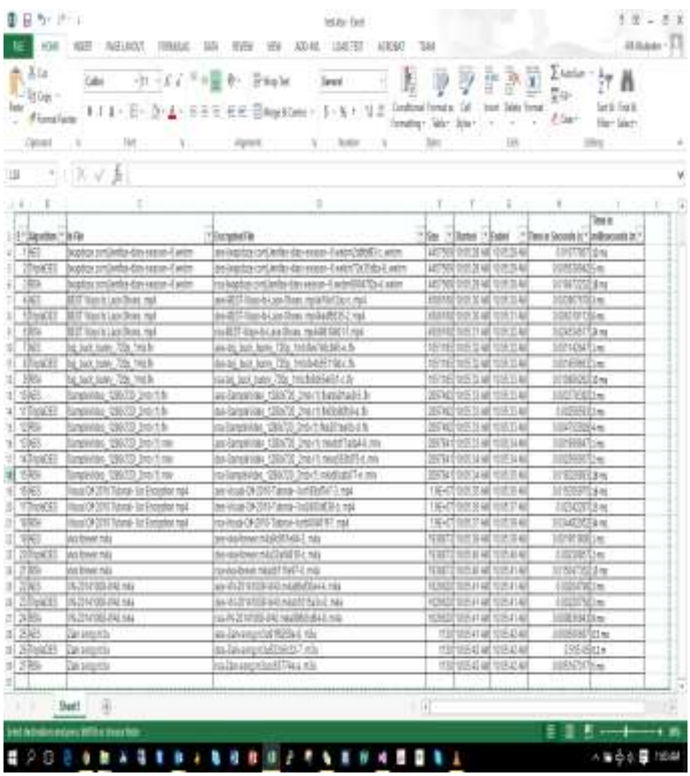

Figure 2: Result Exported to Excel for Analysis

Table 2: AES Audio and Video Results with size and Time

S/N	Algorithm	Size	Time in milliseconds (ms)
1	AES	4457569	10 ms
4	AES	4506168	3 ms
7	AES	1051185	1 ms
10	AES	2097492	2 ms
13	AES	2097841	1 ms
16	AES	19483441	16 ms
19	AES	1938873	1 ms
22	AES	1626620	2 ms
25	AES	1130	0.5 ms

From table Two (2), it was observed that the file format .mp4 and .webm took the longest time for encryption due to the file size of about 4.4mb and 19.4mb. With other format faster to encrypt with about the same file size with different format.

Table 3: DES Audio and Video Results with Size and Time

S/N0	Algorithm	Size	Time in milliseconds (ms)
2	DES	4457569	5 ms
5	DES	4506168	6 ms
8	DES	1051185	1 ms
11	DES	2097492	2 ms
14	DES	2097841	2 ms
17	DES	19483441	23 ms
20	DES	1938873	2 ms
23	DES	1626620	2 ms
26	DES	1130	0.2 m

From table three (3), it was observed that the file format .mp4 took the longest time for encryption, the rest file format moderately of the same time for encryption there about.

Table 4: RSA Audio and Video Results with size and Time

S/N	Algorithm	Size	Time in milliseconds (ms)
3	RSA	4457569	18 ms
6	RSA	4506168	24 ms
9	RSA	1051185	10 ms
12	RSA	2097492	4 ms
15	RSA	2097841	18 ms
18	RSA	19483441	34 ms
21	RSA	1938873	15 ms
24	RSA	1626620	9 ms
27	RSA	1130	5 ms

From Table Four (4), it took almost four times the time of encryption of AES, whilst the same for DES. This shows it's not a faster means and it is slow when used for encryption.

Table 5: Result Exported to Pivot Data for Analysis Combined

S/N	Algorithm	Size	Time in milliseconds (ms)
1	AES	4457569	10 ms
4	AES	4506168	3 ms
7	AES	1051185	1 ms
10	AES	2097492	2 ms
13	AES	2097841	1 ms
16	AES	19483441	16 ms
19	AES	1938873	1 ms
22	AES	1626620	2 ms
25	AES	1130	0.5 ms
2	DES	4457569	5 ms
5	DES	4506168	6 ms
8	DES	1051185	1 ms
11	DES	2097492	2 ms
14	DES	2097841	2 ms
17	DES	19483441	23 ms
20	DES	1938873	2 ms
23	DES	1626620	2 ms
26	DES	1130	0.2 m

3	RSA	4457569	18 ms
6	RSA	4506168	24 ms
9	RSA	1051185	10 ms
12	RSA	2097492	4 ms
15	RSA	2097841	18 ms
18	RSA	19483441	34 ms
21	RSA	1938873	15 ms
24	RSA	1626620	9 ms
27	RSA	1130	5 ms

Table five (5) shows the extraction of all the encryption methods used with the file size (Mb) and Time (mS) to be used for Analysis (Graph and Bar chats) while Table 5, Pivot table broken down and finalized from Table Six (6) with the help of excel.

Table 6: Audio Video Encryption Algorithm Finalized

Sum of Size	**Algorithms**			**Grand Total**
	AES	**RSA**	**DES**	
0.2 m			1130	1130
0.5 ms	1130			1130
1 ms	5087899		1051185	6139084
10 ms	4457569	1051185		5508754
15 ms		1938873		1938873
16 ms	19483441			19483441
18 ms		6555410		6555410
2 ms	3724112		7760826	11484938
23 ms			19483441	19483441
24 ms		4506168		4506168
3 ms	4506168			4506168
34 ms		19483441		19483441
4 ms		2097492		2097492
5 ms		1130	4457569	4458699
6 ms			4506168	4506168
9 ms		1626620		1626620
Grand Total	**37260319**	**37260319**	**37260319**	**111780957**

Figure Four (4) provides the combined Histogram output for all Algorithm used; File Size (Mb) plotted against Time (mS). The tallest Histogram Bar indicates the file format in each Figure from Figure 6, 8, and 10. With the longest time for encryption extracted from (Figure 3); (.webm for AES, .mp4 for DES, and .mp4 for RSA) likewise other histogram.

In Figures 6, 8 and 10, the yellow line indicates the encryption moving average time difference between different file format and sizes. While the red line gives the sudden fall and rise due to file format, sizes simultaneously, for each encryption algorithm technique used. The black line indicates the steady states of time between file format and size simultaneously due to the upload into the application/design used based on each algorithm implemented.

6. Conclusion

Each of the encryption algorithms has unique characteristics that is known for across the globe. Before using any of these algorithm therefore, it is very important the features of such algorithm are well known and familiar with since they are characterized with strengths and weaknesses. Having considered few metrics, as explained in the previous section, the results of the empirical evaluation has shown that Advanced Encryption Standard (AES) is the best when compared with the performances of RSA and DES under the same condition.

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Figure 3: Combined Histogram Output for all Algorithms

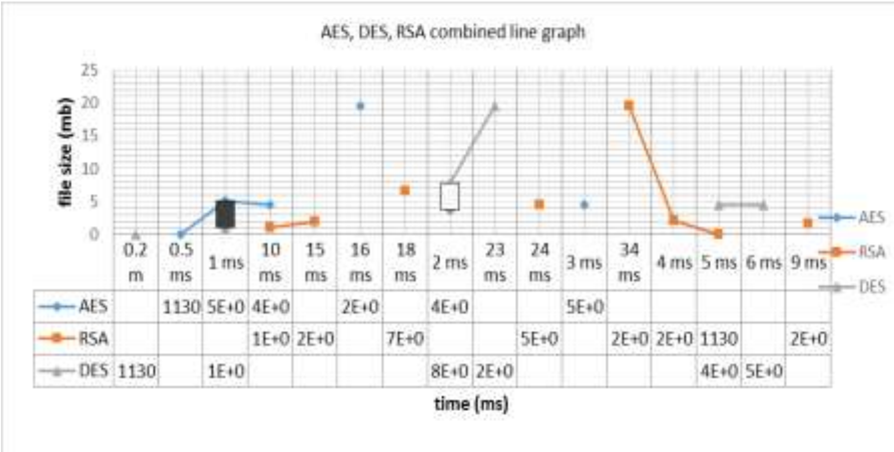

Figure 4: AES, DES, RSA combined line graph

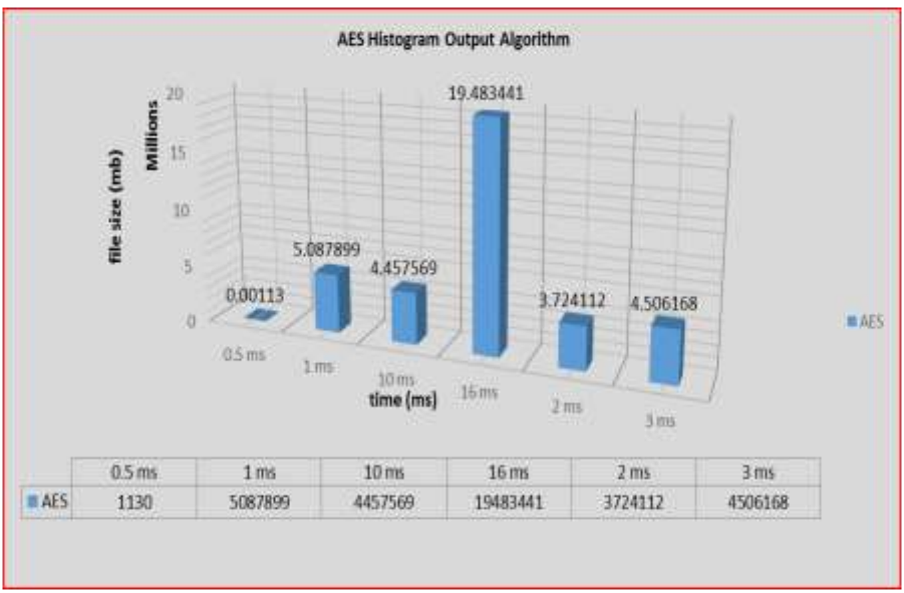

Figure 5: AES Histogram Output Algorithm

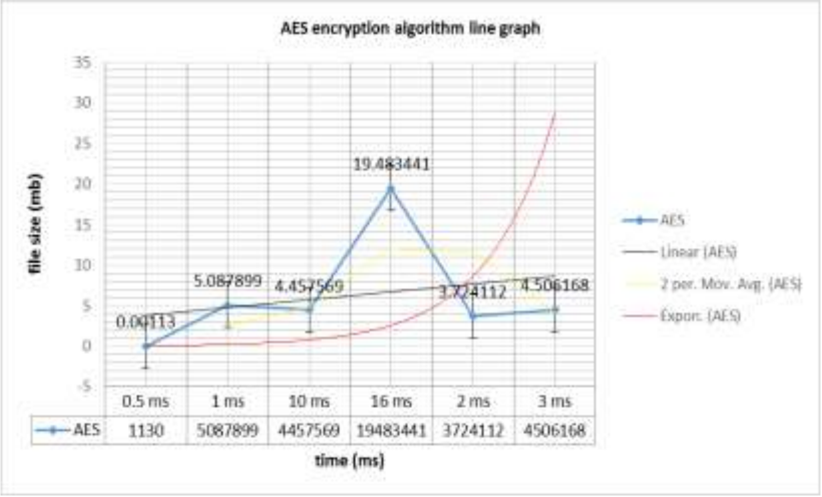

Figure 6: AES Encryption Algorithm Line Graph

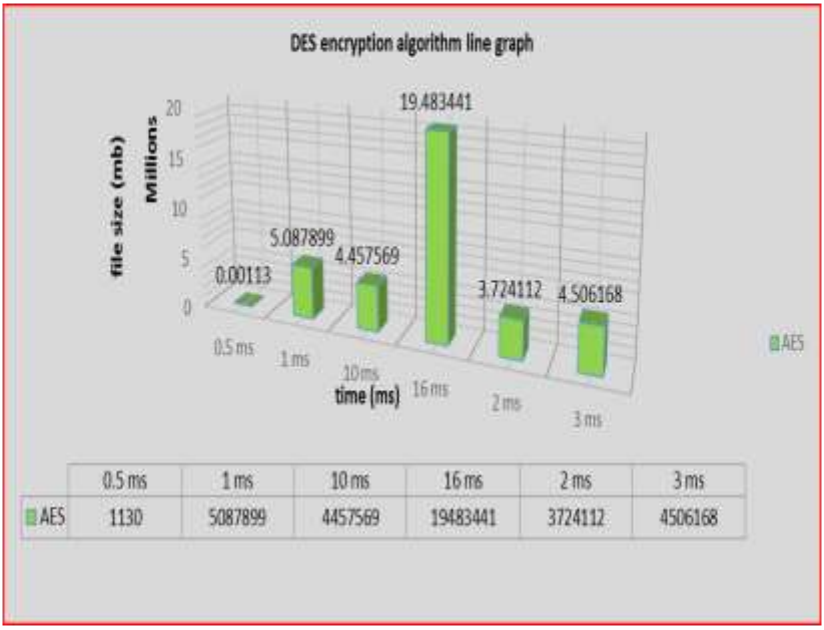

Figure 7: DES Encryption Algorithm Line Graph

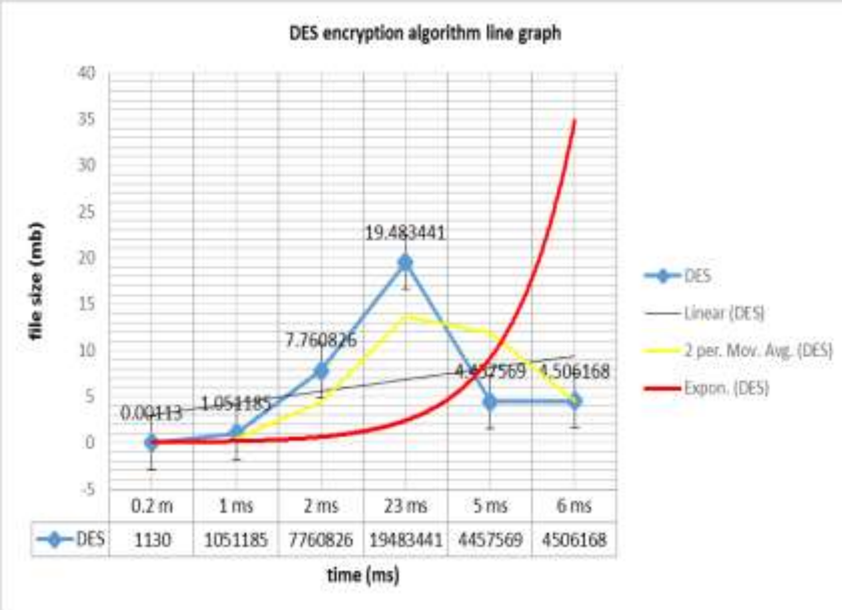

Figure 8: Des Encryption Algorithm Line Graph

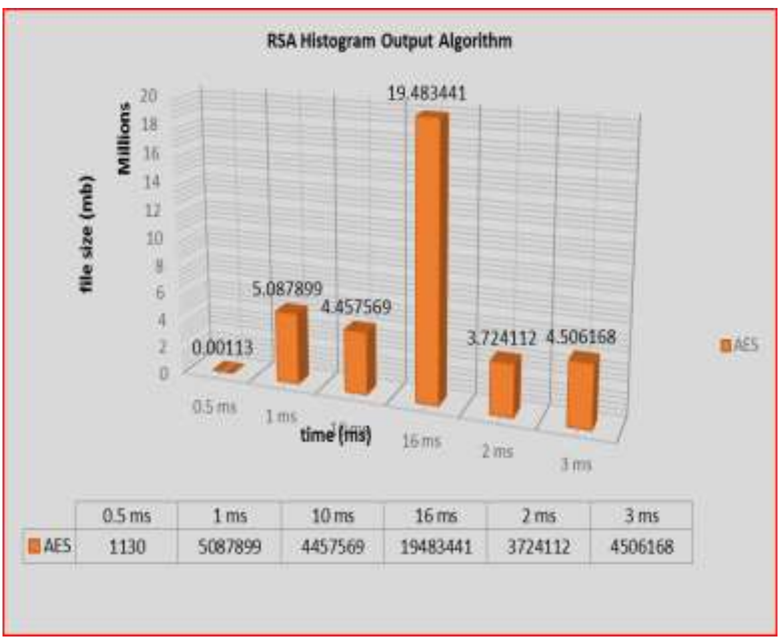

Figure 9: Rsa Histogram Output Algorithm

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Throughput Efficient AODV for Improving QoS Routing in Energy Aware Mobile Adhoc Network

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Abstract:- Mobile Ad hoc Networks (MANETs) is a type of wireless network that is made up of mobile nodes which coordinate themselves without the help of a central coordinator. The network topology changes as nodes are mobile. One of the major challenges of MANET is limited bandwidth which tends to mitigate the Quality of Service (QoS) of the network as users are not satisfied. A variety of routing protocols has been employed aiming at improving the throughput of the network in order to meet user demands. This paper proposes the development of a throughput efficient Ad-hoc On demand Distance Vector (TE-AODV) routing protocol targeted towards improving the QoS of MANET by mitigating network overhead. In this work, all nodes are assumed to be transmitting while calculating their Instant Processing State (IPS) using the concept of knapsack problem. A threshold value for node IPS is set and any node below the set threshold value is not considered during data transmission. An improved Location Aided Routing (iLAR) is used for route search process which helped in reducing network overhead. Results from simulation showed that TE-AODV has improved the throughput of energy aware Ad-hoc On demand Distance Vector (E-AODV) routing protocol. TE-AODV improved the network throughput by 2.9% as a function of simulation time and 3.7% as a function of mobility of node over the E-AODV routing protocol.

Keywords: IPS, MANET, TE-AODV, Energy Aware, iLAR

1 .Introduction

A wireless network or non-wired network is defined as a network that makes use of wireless data connections between network devices (Radhika et al, 2007).

Wireless network is majorly classified into two categories; one with a central coordinator or base station (infrastructure) and the other is without a base station (mohammed *et al* 2016; Koutsonikolas *et al* 2006). Mobile Ad-Hoc Networks (MANET) is a type of wireless network that is without a central coordinator.

Figure 1 shows the form of an ad-hoc network (Juan & Pietro, 2008). Here, nodes move randomly based on a particular mobility model which accounts for the complex and dynamic topology of MANET. (Karadge, & Sankpal, 2013; Patel & Joshi, 2009). Due to the absence of a central coordinator, routing in ad hoc wireless network is now complex (Ket & Hippargi, 2016; Karadge, & Sankpal, 2013). In MANET, routing is done in a distributed pattern in order to establish communication between network devices (Egbugha et al, 2017; Patil and Gaikwad, 2015). A lot of energy aware routing protocols such as EE-AODV and IE-AODV have been developed with the aim of maximizing the lifetime and throughput of MANET networks(Miral & Jignesh, 2015; Qabajeh et al, 2009). During route search, source nodes transmit control packets which include the Route Request (RREQ) and Route Reply (RREP) packets (Miral & Jignesh, 2015; Reena & Shilpa, 2013).

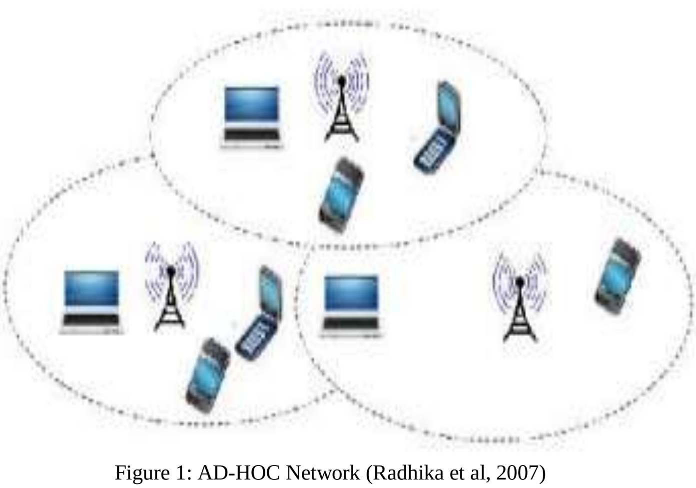

Figure 1: AD-HOC Network (Radhika et al, 2007)

RREQ and the RREP packets contain a Time-to-Live (TTL) header which defines the number of hops a packet is allowed to transit during transmission (Bindra & Singh, 2013; Sujane et al, 2015). Figure 2 shows the route search process in AODV. To improve the QoS of MANET in terms of throughput, traffic should be routed in such a way that the bandwidth of links is significantly maximized as network users need efficient service (Karadge, & Sankpal, 2013; Majdkhyavi & Hassanpour, 2015).This paper proposes a throughput efficient AODV (TE-AODV) for Improving the QoS of energy aware MANET routing protocol. TE-AODV introduces a modified LAR protocol by setting a threshold value for the TTL of packets in order to mitigate packet overhead (Sharma& Kush, 2011; Reena & Shilpa, 2013).

In order to ensure efficient transmission of data and good QoS, ad-hoc networks make use of location aware routing protocols and they are position based (Anand & Sasikala, 2018). Examples of such protocols include; Location Aided Routing (LAR), Distance Routing Effect Algorithm for Mobility (DREAM), Greedy Perimeter Stateless Routing (GPSR) etc. DREAM is a protocol that maintains each node's location information in a routing table which is now used in data packet transmission process. Here, each node periodically broadcasts a control packet containing its own co-ordinates (Reena & Shilpa, 2013). LAR is a scheme that is used to restrict the search zone for routing packet to a particular destination. It employs the knowledge of physical informations of node position via a GPS system which enables it to narrow the area of the network over which the RREQ packet must be propagated. The LAR schemes helps in given specific coordinate in which RREQ may be sent. LAR algorithm makes use of two assumed regions which are the expected

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and the request region (Miral & Jignesh, 2015). A lot of routing protocols have been existing for ad hoc networks engaging different implementation scenarios. Although, the major focus of their work ia aimed at devising a routing protocol that minimizes control overhead and energy usage while maximizing the throughput (Juan & Pietro, 2008). This is because these types of networks are used in for disaster recovery, battlefields and conferences. The routing protocols in ad hoc networks can hence be divided into five categories based on their underlying architectural framework as follows **(**Mohammad *et al* 2016);

a. Source-initiated (reactive or on-demand)
b. Table-driven (proactive)
c. Hybrid
d. Location-aware (geographical).
e. Multipath

This paper proposes a Throughput Efficient AODV (TE-AODV) for Improving the QoS of energy aware MANET routing protocol. TE-AODV introduces a modified LAR protocol by setting a threshold value for the TTL of packets in order to mitigate packet overhead. The first section of this work contains the introduction and the second section is the review of related works which gives an insight on the state of act of works done on AODV for MANET. The third section shows the methodology carried out for the development of TE-AODV. The fourth section shows the parameters used for the simulation. And the fifth section discusses the validation and comparison of the developed work.

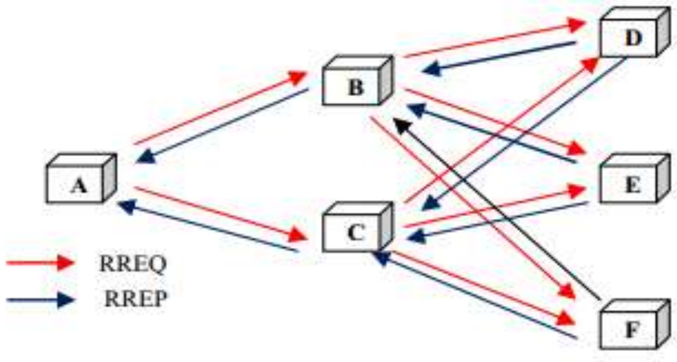


Figure 2: Route Search Process in AODV (Reena & Shilpa, 2013)

2. Review of Related Work

(Anand and Sasikala, 2018) proposed a method to improve the battery power in MANET and provide the better quality in packet transmission. This was carried out by using AODV protocol with improving the routing strategy in packet transmission. The optimization of battery power in MANET is still an ongoing research. Simulation result shows that the proposed work has better performance when compared with the existing power optimization strategy. However, the optimization algorithm used is complex and thus this will lead to an increase in transmission time will mitigate network throughput.

(Bindra & Singh, 2013) Proposed a work that took a look at the effects of TTL alteration in order to see how it can affect the throughput of the network. The work showed that the TTL value of control packets affects the network overhead which in turn affects the throughput of the network. The choice for TTL parameters was made arbitrarily based on the network area or diameter. In order to analyze the effect of altering the TTL value in terms of setting a TTL threshold value on route discovery process, they carried out simulation using OPNET simulator. Simulation result showed that the performance of route discovery and link repair depends on optimal value of TTL increment and threshold. However their work will suffer from overhead as the AODV protocol suggests that packets are flooded in the whole network environment. The flooding of packets consumes the limited bandwidth of the network and as such mitigates the network throughput.

(Radhika et al, 2007) proposed an Energy Aware Routing Protocol (AODVEA) based on AODV which puts into consideration local forwarding decision of nodes and also set up node energy threshold for intermediate nodes. In the work, routing was based on max min energy algorithm aimed at improving the lifetime of the network. Also the work proposed a modified AODV (AODVM) which incorporates same local forwarding decision for intermediate nodes but routing was based on combining max min energy algorithm and shortest distance. Simulation for AODVEA was carried out using NS-2 in terms of network lifetime, average throughput and average delay. Results show that AODV modified gives optimized performance. However the flooding of packets by AODV will introduce packet overhead which reduces the average throughput of their work

(Patil & Gaikwad, 2015) proposed a system which takes some of the properties of Location Aided Routing and AODV routing protocol to form a kind of a hybrid protocol aimed at maximizing node energy and eventually improving network throughput.. The obtained result would have increased if the selection for routing packet was not based on node energy alone. The lone choice of routing path based on energy may lead to packet drop as node may be trying to process packets based on its energy and not minding its buffer size. As a result, packets may be dropped if the buffer size of the intermediate node is full.

(Padmalaya & Pallavishree, 2015) evaluated the performance of the DSR and AODV routing protocol with various mobility model (e.g. RWP). To extend the applicability of the protocol, NetSim Simulator was used to analyze various performance metrics such as Throughput, End to End delay, Packet Delivery Ratio (PDR), Routing Overhead, and Network Lifetime. The work showed that modeling has a great impact on future Internet of Things (IoT) and AODV network. The work still maintained the traditional route search process of AODV which involves the flooding of packets in the whole network. The flooding process of AODV increases network overhead and which further affect the throughput of the network and other measured performance metrics.

(Mohammad et al 2016) developed an energy aware reactive routing protocol (E-AODV). Here, in order to avoid a node to experience bottleneck, all nodes in the network area calculates their current processing state. If the choice of a routing path is based on a node satisfying a threshold level, there is high possibility of the network to have heavy traffic on the path of nodes with high energy levels. This is due to the fact that a node may be accepting heavy traffic due to its current energy which eventually leads to rapid energy depletion. This occurrence in a network will lead to decrease in throughput as packet congestion is increased. To solve this problem, E-AODV finds energy efficient route from source to destination based on the concept of knapsacks problem. E-AODV ensures that route is selected based on node energy and input buffer traffic to mitigate the occurrence of congestion in the network. However, constant routing update will lead to network overhead which in turn reduced the throughput level of their result. Also the protocol did not specify TTL threshold value for packet transmission which will result in additional cause of overhead in the network.

(Kaur *et al.*, 2017) evaluated the performance of AODV, DSR and DSDV routing protocols. In the work, each node has limited battery power and low bandwidth during the delivery of messages from one node to another. The nodes are linked together wirelessly and communicate with each other using different protocols. The work implemented the three routing protocols and examined the efficiency of each protocol under a particular scenario in relation to various performance metrics like end-to-end delay and throughput on NS-2. However, the comparative study didn’t suggest a way of improving the existing routing protocols after comparison.

(Reena & Shilpa, 2013) proposed a routing protocol that called Energy

Efficient Ad Hoc Distance Vector (EE-AODV) that was aimed enhancing the existing AODV routing protocol. EE-AODV was able to enhance the route request and route reply handling process in order to save the energy in mobile devices. EE-AODV took into consideration some level of energy as the minimum energy which a node should possess before been selected in the routing path. When the energy of a node reaches to or is below that threshold value, the node should not be considered as an intermediary node for routing packets until alternative path is available. Simulation results show that throughput and network lifetime of the network increased in EE-AODV as compared to traditional AODV. However, the network throughput of the network can be increased if the network routing overhead is mitigated.

From the reviewed literatures, it is evident that the methods adopted for increasing network throughput are broadly divided into two. The first generally adopts an energy threshold value or channel bandwidth, which was used to determine whether a node would participate in a routing process while neglecting the effect of large route search delays that usually leads to traffic overhead. The second generally involves the use of position based routing algorithm which was aimed at reducing route search overhead and energy consumption that may occur due to frequent route update. Additionally, this method did not consider mitigating the possibility of having bottleneck at intermediate node and also an energy efficient route choice algorithm that would have improved network throughput.

3. Improved Protocol: TE--AODV

This work proposes a throughput efficient AODV for improving the QoS of energy aware MANET. To mitigate the effect of overhead, location aided routing was introduced. The following steps were used in the development of TE-AODV.

1. For simulation purpose, a network area of 500x500 was used with node capacity ranging from 10 to 100 in the NS2 network environment where all nodes are assumed to active.
2. Network overhead is usually generated at the route search process. The location aided routing protocol was used to mitigate the occurrence of overhead.
3. To further reduce congestion in route request region, a time-to-live threshold value of seven was set which creates an improved LAR technique called iLAR
4. All nodes in the network evaluate their instant processing state in terms of instant energy and input traffic of the node buffer.
5. A threshold value for IPS was set by which route selection is done. Any node below this threshold value is not considered during the selection process. This process optimizes the performance of the network in avoiding nodes with bottlenecks.
6. The throughput of the network is now calculated using equation 1(Egbugha et al, 201).

7 $$Throughput = \frac{File\ size}{Ttransmission\ time}(bps) \qquad (1)$$

The equation used for the optimization process is given as (mohammed et al 2016):

$$V\left[p, E\left(k_p\right)\right] = \max\left(V\left[p-1, E\left(k_p\right)\right], k_p + V\left[p-1, E\left(k_p\right) - E_p\right]\right) \quad (2)$$

The variables in the equation 1 are defined as follows:

p = Processing packet at an instant of time t

k_p = value of communication packet

$E\left(k_p\right)$ = Node energy to treat k_p value of packets

E_p = Current maximum energy of intermediate node

V= Value of a given parameter.

Table 1 shows the bottom up computing method for evaluating node IPS

Table 1: Bottom-Up Computing by Iteration

$V[p,w]$	$w=0$	1	2	3	......	.....	W
$p=0$	0	0	0	0	.....	.....	0
1	0						
2	0						
...	0						
N	0						

Bottom … up

4. Simulation Environment

Network simulator 2 is an object oriented simulator that creates realistic events that describes different propagation and mobility models. Network Simulator 2 was used to compare the performance of TE-AODV routing protocol and E-AODV routing protocol. The simulation parameters used for this work is shown in table 2. Usually, simulation parameters are user choice.

Parameter	**Value**
Simulator The simulator	NS-2 version 2.35
Simulation time	180s
Propagation model	Two- ray ground
Routing protocols	E-AODV, IE-AODV
MAC	802.11
Traffic source	CBR, FTP
Antenna	Omni Antenna
Packets size	512 bytes/packet
Link layer (LL) type	Logical Link (LL)
Mobility model	Random waypoint model
Pause time type	30s
Area of network	500m x 500m
TTL	7
Velocity of mobile nodes	0-60m/s
Number of nodes	100 nodes
Initial energy of node	15J
Transmission range	250m
Queue type	Drop-tail

Table 2: Simulation Parameter

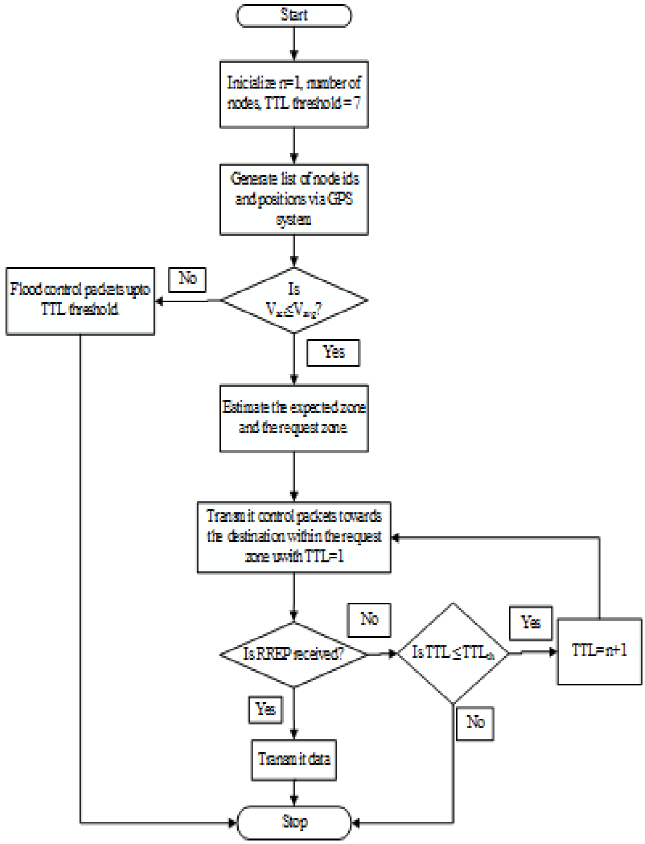


Figure 3: Flowchart Of Ilar Routing Protocol

5. Results and Discussion

Figure 4 shows the result of the performance of E-AODV and TE-AODV. The throughput is calculated using equation 1. The throughput was simulated for node speed ranging from 10 to 50m/s. Random Way Point (RWP) mobility model was used for the network simulation. For both protocols, it was observed that as the speed of the node increases, the throughput also increases. This is because an increase in node speed at a fixed pause time entails that a wider network area would be covered at the same period hence ensuring a fast packet delivery to the destination. Simulation results show that both approaches ensure that all nodes in the whole network calculate their IPS which helps in mitigating packet drop. This figure shows that the TE-AODV protocol outperform the E-AODV routing protocol.

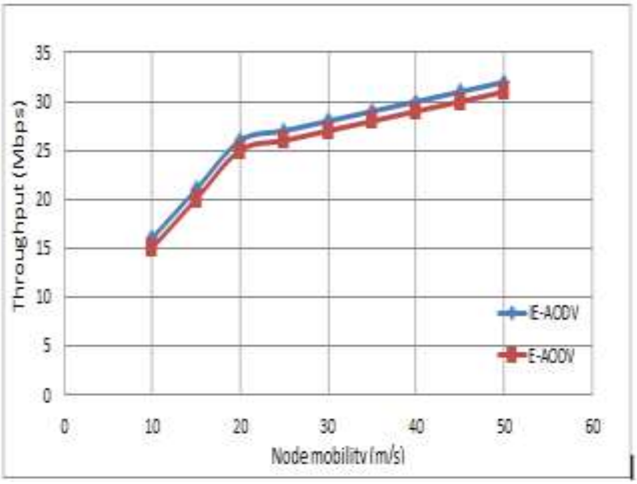
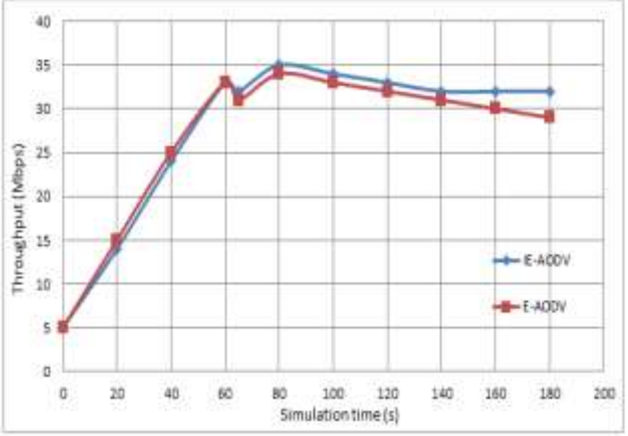


Figure 4: Plot of Throughput for the two Protocols against Node Mobility.

Figure 5 shows the result of the performance of E-AODV and TE-AODV in terms of throughput against simulation time. The throughput of the network was tested at simulation time ranging from 0 to 180 seconds. The network throughput is given in equation 1. It was observed that as the simulation time increase, the throughput of the network improves. This is because each node calculates its IPS in terms of buffer size and energy in order to avoid bottleneck nodes during packet forwarding. It was observed from the plot that the performance of TE-AODV is better than the E-AODV approach. This is as a result of a reduced transmission area which entails lower network overhead that reduces packet drop. Also, due to the TTL threshold value that was set, it limits the number of hops a packet can transit within the route request zone.



Figigure 5: Plot of throughput for the two Protocols against Simulation Tim

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Classified Medium Access Control Algorithm (CL-MAC) for Enhanced Operation of IEEE 802.11ah

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Abstract—We present in this apaper a high level framework of a proposed Medium Access Control Algorithm known as Classified Medium Access Control Algorithm for enhanced operation of IEEE 802.11ah. IEEE 802.11ah is an amendment for the IEEE 802.11 standard known as Wireless Local Area Network (WLAN) or Wi-Fi network standard. This amendment was mainly established to increase the number of Wi-Fi stations managed by the single Access Point. As more and more number of heterogeneous network stations emerge to also utilize this network, some techniques have been employed to ensure better management of the network but this still remains an open issue that needs to be tackled. This paper presents a hybrid TDMA and CSMA/CA scheme for the channel access in lieu of the default Enhanced Distributed Channel Access (EDCA) of the WLAN. When compared with the result of the EDCA, the proposed scheme provided a better throughput performance for the IEEE 802.11ah amendment.

Keywords— CSMA/CA, EDCA, IEEE 802.11ah, TDMA, Traffic Management.

1. Introduction

In the global world today, the presence of the sensor/actuator devices to interact with the environment has fostered the establishment of new applications and services. The development of smart grids and smart cities are made based on the existence of such sensor/actuator networks in order to achieve a more sustainable utilization of the resources in the environment and also to provide a better quality of life to citizens (Bellalta et al, 2016). IEEE 802.11 task group proposed IEEE 802.11ah to support a network communication known as Machine-to-Machine (M2M) communication as an amendment to IEEE 802.11 (Akeela & Elziq, 2017). This M2M has attracted a lot of users in the industries as well as in the academic environment for ubiquitous communication within devices. M2M which is also known as MTC (Machine Type Communication) (Yue, 2015), is a technique that involves automatic communication between two or more devices without the need for human intervention. Applications scenarios for this technology include smart cities, industrial automation, environment and agriculture monitoring as well as emergency services and intelligent utilities. This M2M has so far been one of the fastest growing technologies in wireless communication. It was employed even in mechanical automation such as Internet of Things (Borgia, 2014). In comparison with the human centric communication technologies, features peculiar to M2M communications include scalability of large number of devices and infrequent transmission of small data. Thus, in order to facilitate M2M solution by existing wireless technologies such as cellular network (known as Long Term Evolution (LTE)) and short range radio (known as the Wi-Fi), such technologies face greater challenges due to the above features. One of the challenges faced is the inability to minimize energy consumption as device batteries are drained very fast which is unsuitable for M2M use cases that take cognizance of energy management. IEEE 802.11ah was then proposed as an amendment for such applications.

IEEE 802.11ah contributes to Wi-Fi networks by extending the range and accommodating up to 8191 stations coordinated by a single AP (Leon, 2015). However, with increasing number of heterogeneous beacon-enabled Stations (Traffic Indication Map (TIM) stations) of different traffic profiles and priorities, to effectively manage the network by the AP becomes an issue. This challenge of poor traffic management results in: data loss that results in low throughput, uncontrollable packet delay and more power consumption by such battery powered stations (nodes) which shortens their lifetime. Therefore in this paper, we are designing an algorithm that will classify the numerous beacon enabled groups of stations into traffic profiles based on battery level, positions to the AP and the application priority. This paper covers the classification of stations into four profiles. It also covers the channel access for the stations in their respective transmission queue. It will also evaluate its throughput performance. With the advent of several heterogeneous stations with different traffic profile and application priorities especially in the urban areas, this research will help in ensuring better quality of life to citizens as regards security through immediate attention to real time applications as slots will be reserved for high priority stations. Details of this paper is given in the next section.

The remaining part of this paper is as follows; Section II describes the background of the network and relevant amendments on the MAC Layer of the standard. Section III analysis the proposed traffic management algorithm for the beacon enabled IEEE 802.11ah stations. In section IV, we described the result for implementing the algorithm with the hybrid MAC while section V shows the conclusion of the paper.

2. System Description

In this section, we looked at technical background of the IEEE 802.11ah starting with the IEEE 802.11 Standard (Wi-Fi) and further gave details of amendments of the IEEE 802.11ah standard in the MAC layer as well as the specific requirements considered as given by the task group.

2.1. WI-FI Network

Wi-Fi is also known as Wireless Local Area Network (WLAN). It is an IEEE 802.11 Standard that connects nodes (stations) with an access point (AP) in wireless communication. In 1997, the version of this standard was introduced to support existing wired LAN with the aid of Ethernet technology (Bellalta et al, 2016). Since then, there have been more functionalities, emerging technologies and amendments. It has been very important as internet access technology and also been very available everywhere. Among the several factors that have immensely contributed to Wi-Fi are the flexibility, ease of use and interoperability. Table I. shows the summarized Wi-Fi amendments which include their released dates and goals.

Table I. Summary of IEEE 802.11 Standard Ammendment

Amendments	Released Date	Band	Goal
IEEE 802.11aa	2012	2.4, 5Ghz	Robust streaming of Audio/video
IEEE 802.11ac	2014	5Ghz	Very High Throughput WLAN
IEEE 802.11af	2014	470-790 MHz (EU)	WLAN in TV White Space
IEEE 802.11ah	2016	902-928 MHz (US)	WLAN in Sub 1GHz license exempt band
IEEE 802.11ax	2019	2.4, 5GHz	High Efficiency WLANs

2.2. IEEE 802.11ah

IEEE802.11ah is a WLAN standard that operate at sub 1GHz ISM (Industrial, Scientific and Medical) band in the license exempt bands (Sun et al, 2013). IEEE802.11ah is employed to reduce power consumption and as well support large number of devices (Stations) by a single Access point. Unlike the conventional 2.4GHz and the 2.5GHz bands of the WLANs technology, IEEE802.11ah provides an increased transmission range with a relatively narrow bandwidth as well as a reliable use for outdoor environment for cellular traffic offloading. Its relevance is felt in reducing the saturation of the two spectra above in limiting the irregular deployment of stations and excessive utilization of channels. This made it easy to deploy 11ah sensors across basements, backyards, garages and market areas that are all connected to a single Access Point. Table II. summarizes the respective features of the IEEE 802.11ah.

Table II. Basic Features of IEEE 802.11AH

Parameters	**Values**
Number of Stations	8191
Network mode	Single hop
Transmission mode	OFDM
Channel Bandwidth	1, 2, 4,8,16 MHz
Range	1000m outdoor
Packet Length	Up to 100 byte
Data Rate	150-4000 kbps(for 1MHz BW), 65-7800KBPS (for 2MHz BW)

In 2010, a task group known as the Task Group ah (TGah) was set up in the IEEE 802.11 working group that triggered the IEEE 802.11ah to work on the Sub 1GHz standardization to ensure better performance in Internet of things (IoT) and applications that involve extended range. Below are specific requirements the group have set for any novel amendment (Adame et al, 2014):

- A numerous stations with power constraint
- Extended transmission range
- Low data rates
- Small and infrequent data messages
- Non-critical delay

The MAC layer of IEEE 802.11ah is designed to increase the number of stations supported by a single AP in the network provided that the energy consumption is minimized. In IEEE 802.11ah, stations are categorized into three based on their respective procedures and periods of time for channel access as seen in Fig 1: they are TIM (Traffic Indication Map), Non-TIM and unscheduled stations (Adame et al, 2013).

TIM Stations only need to listen to beacons from the AP in other to receive or transmit data frame and they must transmit within a RAW (Restricted Access Window) period. The Non-TIM stations need not listen to beacons in other to transmit data. They only negotiate directly during the association process with the Access Point for allocated transmission time in the PRAW (Periodic RAW). Just like the Non-TIM stations above, unscheduled stations need not listen to beacons, they rather send poll frame to the AP requesting immediate access to the channels within the RAW. There is a response frame which indicates periods (outside both RAWs) for which such stations can gain channel access. This is relevant for stations that intend to sporadically join the network.

Enhancement made by the MAC layer of the IEEE802.11ah for desired system requirements include support of numerous number of stations (about 8191 stations per AP), increased energy saving features, efficient mechanisms of medium access, and higher throughput by greater compactness of several frame formats. Some specific features of the MAC layer include hierarchical TIM (Traffic Indication Map) structure, RAW (Restricted Access Window) technique, Non-TIM operation and TWT (Target Wake Time) mechanism as well as long sleeping and waking interval to reduce energy drained by batteries. Relay operations which involve tree-based multihop network are also mechanisms included in the amendment.

3. Related Works

There are some methods that have been employed in traffic management of IEEE 802.11ah to solve the problem of contention, energy consumption, throughput, delay and other important metrics.

In the channel access for TIM stations in IEEE 802.11ah, allocation system for AP-Centralized period is combined with the DCF (Distributed Coordination Function) medium access technique within such periods. Immediately after each period, a time between successive TIMs that contains RAW (that has one downlink, one uplink, and one multicast segment) is placed. In the downlink, for a packet to be sent by AP to a station, the TIM group for such station must be included on the bitmap of the DTIM beacon. Also, the TIM group includes such station in its bitmap. DCF is used by that station for contention as it listens to beacons of its own TIM group and it then sends a Poll frame to get its corresponding data after its backoff elapses. For the uplink, In other to send an uplink message to the AP, a station must first listen to its corresponding TIM group to be aware of time for channel contention through the DCF Scheme. Request to Send RTS/Clear to Send CTS as mechanisms for both basic access and handshake could be employed (Qutab-ud-din, 2015).

EDCA is a channel access mechanism that amends for the Distributed Coordination Function (DCF) of the IEEE 802.11 standard. It is also the default channel for channel access for group of stations in IEEE 802.11 Standards. EDCA uses the CSMA/CA Mechanism and also employs backoff mechanism together with the AIFS (Jun et al, 2009).

Another scheme carried out is a technique known as Grouped Synchronized Distributed Coordination Function (GC-DCF) that uses the RAW and RAW slots to grant access to the IEEE 802.11ah groups of stations (Zheng et al, 2014). It yielded about seven times the throughput of the pure DCF scheme. In (Tian et al, 2016), the paper carried out a research to also use the RAW to distribute stations into various group but could only grant a particular group of stations medium access simultaneously without priority. In Virtual Grouping and Power Saving Techniques for IEEE 802.11ah enabled M2M networks, a random AIFSN scheme that complies with the CSMA/CA protocols was employed (Ogawa et al, 2013). parameters (randomly selected by the stations) are distributed by the AP to each station through a data frame against traffic congestion. The method provided a good throughput and delay as well as an improved power saving compared to the conventional DCF considering 6000 stations. However, it only employed the AIFS parameters without considering other important parameters in prioritized grouping. In order to reduce association delay of IEEE 802.11ah network in (Pranesh & Jae-Young, 2017), a mechanism is introduced as authentication control for classifying stations into groups and identifying the best group that allowed specific groups to communicate over the channel in a beacon interval. There was a fair medium access considering a large number of stations. The best group size ensured minimum access delay. Although the throughput of other groups were not much considered. Grouping of real-time stations in IEEE 802.11ah dynamic traffic IoT networks Parameters for Optimal RAW grouping was determined using a traffic adaptive RAW algorithm (TAROA) to enhance (Tian et al , 2017). The TAROA then assigns RAW slots to the stations with respect to their transmission frequency. TAROA performed better compared to EDCA/DCF on scalability and throughput.

the impacts of latency and throughput

So far from our researches, we have not seen a developed algorithm based on prioritized classes of stations to enhance the performance of IEEE 802.11ah networks. Thus our scheme will be compared with the EDCA based on the conclusion as shown in Table III.

Table III. Comparing te Features of both EDCA and the Proposed Hybrid MAC

Features	EDCA	Hybrid TDMA and CSMA/CA
Access Categories	AC1, AC2, AC3 and AC4	TP1, TP2, TP3 and TP4
Channel Access parameters by a queue	AIFS, (CW_{min} and CW_{max}), TXOP	SIFS, GTS, RTS, CTS, ACK
Channel Access mechanism	Enhanced CSMA	Both TDMA and CSMA/CA
Prioritized Scheduling	No	Yes
Reserved slots	No	Yes

4. Classified Management Traffic Algorithm

In line with the review of existing techniques adopted for protocol amendments in wireless sensor networks especially the Queue-MAC technique (Zhuo *et al*, 2012), an algorithm is proposed to ensure better management of traffic for prioritized scheduling of stations in order to reduce overheads and congestion and as well reduce energy consumed by the batteries. This can be achieved by employing the algorithm and then modify the Queue-MAC technique in the MAC layer. Fig. 1 shows the positions of stations in the respective class.

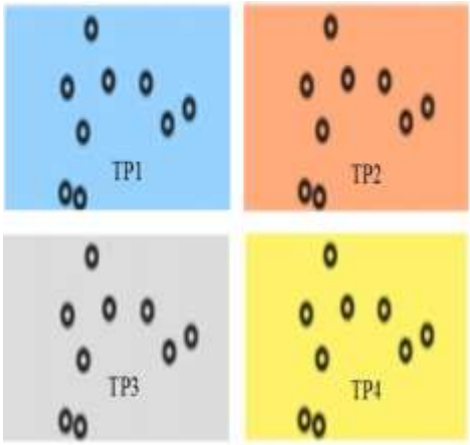

Figure 1. Scattered Positions of Deployed Stations for Respective Traffic Profiles

4.1 Classification of Stations

The classification was made with respect to the traffic profiles for access to channel. The random distribution of the stations into traffic profiles based on location to AP (which is at the centre) is as shown in Fig 2:

The terms TPs (Traffic Profiles) are described with respect to their features and further analyzed well in Table III: As the payloads of stations are available to be sent to the AP, each of the traffic profiles can have either a real time or non-real time packets, their battery levels and distance to AP can also be similar or different. AP observes from the Group Association Packet sent by the stations and then class each into any of the group as regards the information of each station as shown in Table IV.

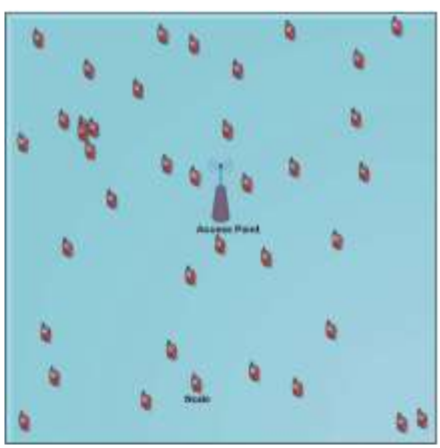

Figure 2. Random Distribution of Stations (Nodes) with ap at the centre of the Playground

Table IV. Classification of Stations

Classes of Grouped Stations (TP1, TP2, TP3 or TP4	REAL TIME PACKETS	NON-REAL TIME PACKETS	≤ 50% BATTERY LEVEL	> 50% BATTERY LEVEL	AT MOST 200m DISTANCE TO AP	ABOVE 200m DISTANCE TO AP
TP1	✓	✓	✓		✓	
TP2	✓	✓	✓			✓
TP3	✓	✓		✓	✓	
TP4	✓	✓		✓		✓
TP1	✓		✓		✓	
TP2	✓		✓			✓
TP1	✓			✓	✓	
TP2	✓			✓		✓
TP3		✓	✓		✓	
TP4		✓	✓			✓
TP3		✓		✓	✓	
TP4		✓		✓		✓

TP1: This is the class with the highest priority. It is nearer to AP (<200m to AP) and with packets that contain mostly real time applications.
TP2: This is the second category which is farther from AP (>200m to AP) and with real time applications.
TP3: This class has stations that are nearer to AP (>200m to AP) and packets contain mostly non-real time applications.
TP4: This is the traffic profile whose stations are farther from AP (>200m to AP) and packets have mostly non-real time applications

4.2 Design of the Traffic Management Algorithm

The algorithm shows the flow chart for the traffic mechanisms that will be implemented on the AP. Four different buffers are considered for scheduling which are as shown in Fig. 3.

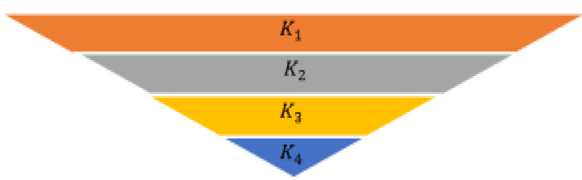

Figure 3. Diagrams showing different hierachy of buffers

From the figure, K_1 represents the buffer for the highest profile priority TP1. This is the first buffer where the packets from the stations are processed before relayed to the receivers. It has the maximum capacity in which packets can no longer be buffered. Followed the K_1 is the K_2 and other buffers in the order of priorities.

4.3 The Modified Queue-Mac Design

The Access Point broadcasts periodically beacon frames in order to split time into repeating superframes with both active and inactive periods. Activities and communications are arranged in the active period while all the stations are on sleep mode (radios are turned off) in the inactive periods for energy conservation. Fig 4 shows the packet structure of the AP MAC. The Group Association Packet (in lieu of the Queue indicator) includes the respective traffic profile (TP1, TP2, TP3 or TP4) that give the information of the load of the stations as in Fig 4.

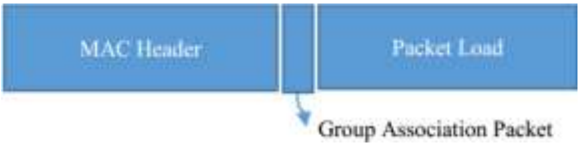

Figure 4. MAC Packet Structure

In the superframe structure of the AP in Fig. 5, there exist the variable TDMA, the CSMA/CA and the inactive period in the IEEE 802.11ah RAW period between the beacon intervals.

Figure 5. Superframe structure

The TDMA slots are assigned based on traffic priority and load of nodes as notified by the Group Association Packets. More TDMA Slots are granted if the capacity of the buffers are not filled. There is also an amount of Guaranteed Time Slots GTS reserved for high priority stations. Assuming request for GTS allocation by the TP1 and TP2 are piggybacked onto the packets without the need to send certain control packets in advance. A fixed CSMA period is then employed to cater for nodes that may not have access to TDMA slots. All nodes will now be in a sleep mode to conserve energy during the inactive period.

As regards the CSMA period, the stations that are yet to be granted channel access contend for the limited channel. GTS will be available for TP1 and TP2 Stations upon request. Then the other two categories contend with the four way handshake of the CSMA/CA mechanism. The four way handshakes are in the order RTS-CTS-Data-ACK.

In this mode of contention, a station first senses for free channel, sends RTS (Request to Send) to the AP and waits SIFS (Short Interframe Space) period for CTS (Clear To Send), the AP then sends CTS to the stations if the channel is idle. Then the station waits further SIFS period and then transmit after the SIFS period. The station also waits further SIFS for ACK upon successful reception of the packets and check for packets available. But if ACK is not received (as a result of collision), the station goes back to backoff counter and transmit available packets or otherwise terminate communication. If the medium is busy, the station goes to back off timer (for time when the channel will be free again) sending a back off counter, transmit immediately and thereafter receives an ACK for successful transmission. All classes of stations go on sleep mode in the inactive period until they receive another beacon from the AP before waking up to listen again.

4.4 Flow Chart For The Traffic Profile Access

From the flow chart in Fig 6, the packets to be sent to the receiving stations are first buffered in their forwarding queue. Each of the buffer has its capacity, (that is maximum number of packets in its queue). Each packet is served based on time of arrival. Thereafter, access for channels are started based on the profile and the information of the queue indicator of each node. TDMA slots are available for all the classes but priority is granted from the first categories to the last. For stations that were unable to transmit in the TDMA period, they can then contend to transmit in the CSMA period. Guaranteed Time Slots are also available for TP1 and TP2 within this period to enable real-time transmission without delay. CSMA/CA protocol is employed to cater for light traffic of nodes without TDMA slots where each node contends for channel access.

5. Simulation Results

A very reliable network simulator for discrete events known as NS3 was employed for IEEE 802.11ah (Tian *et al*, 2016). A TDMA module was added in the NS3 for periodical transmission. We then enabled a hybrid TDMA and CSMA/CA Wi-Fi network. We input the physical data rate of the Wi-Fi mode, the slots value for TDMA users, varied TDMA cycle value and other parameters. We ensured that packets to be transmitted with TDMA are sufficient. The throughput of each class is measured with increasing number of stations from 32 to 1032. Fig. 7 shows the result at the end of the work considering the required parameters. Evaluations were carried out for each class in both EDCA and the CL-MAC (the hybrid MAC proposed). When compared with the EDCA, the performance of the proposed scheme provides better output of the two most prioritize classes showing greater throughput.

Table V. Default and Assumed Parameters for Simulation

Parameters	TP1	TP2	TP3	TP4
Data rate	150kbps	512kbps	1024kbps	1024kbps
DIFS	186μs	212μs	238 μs	264μs
SIFS	160μs	160μs	160μs	160μs
CW_{min}	1	3	7	15
CW_{max}	1023	1023	1023	1023
Number of Stations	32 – 1024			
Payload size (bytes)	256			
Wi-Fi mode	MCS8, 2MHz			
Size of playground	400m by 400m			
MAC Header (bytes)	12			
Length of ACK (bytes)	14			
Length of RTS (bytes)	20			
Length of CTS (bytes)	14			
RAW Duration	500ms			
Beacon Duration	10ms			
TDMA Period	300ms			
TDMA Slots for one Packet	5ms			
TDMA Slots duration	4ms			
CSMA period	90ms			
Inactive period	100ms			
Slot time T_{slot}	52μs			
Channel Bandwidth	2MHz			
Max capacity of forwarding queue of each station	50			
Maximum Capacity of buffers (Packets)	K1- 100 K3- 50		K2- 75 K4-25	

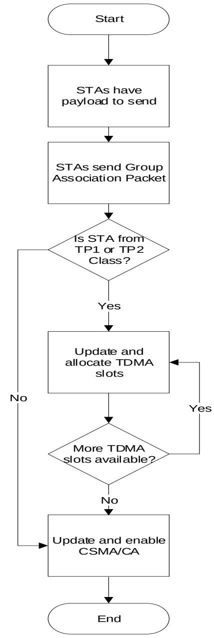

Figure 6. Flow Chart for the CL-MAC Algorithm

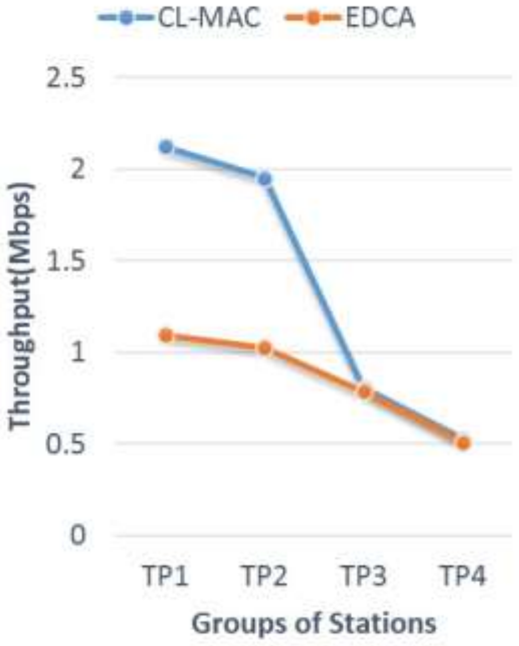

Figure 7. A Compared Result for the Proposed Alggorithm and EDCA.

6. Conclusion

We discussed in this paper, IEEE 802.11ah and its amendments with respect to traffic management. We first looked at its basis (the Wi-Fi) and then explained its features such as the MAC layer channel access mechanisms for the numerous stations. Finally, we developed a classified traffic management algorithm for beacon-enabled IEEE 802.11ah stations and showed the simulation result of its performance and then compared it with the EDCA scheme. The results show that the CL-MAC is a better scheme for the IEEE 802.11ah amendment than the EDCA in terms of throughput.

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Mobile Robot Path Finding using Nature Inspired Algorithms - A Review

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Abstract — In today's world, Mobile Robot has been widely used for various purposes across several aspects of life. The environments could be static and dynamic. Path planning for mobile robot is a very important problem in robotics. Path Planning for robot could be referred to the determination of a path; a robot takes in to perform a task given a set of key inputs. To find the best and optimal path from the starting point to the goal point, such that time and distance is reduce, in any given environment avoiding collision with obstacles is an interesting area for research. This research presents a review on the application of nature inspired algorithms in solving the problem of mobile robot path planning such that the robot reaches the target station from source station without collision with obstacles. The future of these nature-inspired algorithms on mobile robot is also discussed.

Keywords: Index Terms — Nature-Inspired Algorithms, Optimization, Path Planning

1. Introduction

The field robot path planning started in the middle of the 1960's. Path planning is an important part in the design of mobile robots. The objective is to find the best and collision free path from a start position to a target position in a given environment. Path planning would aid robot to automatically decide and execute a sequence of steps in order to accomplish a task without colliding with obstacles in a given environment (Parvez & Dhar,2013). In an environment, there are many paths for a robot to reach the goal, but the best path is selected according to some criteria. These criteria are the shortest distance, the shortest time, the least energy consumed. The most adopted criteria are the shortest distance. Path planning is an optimization problem since its purpose is to find a path with the shortest distance under certain constraints such as the given environment with collision-free motion (Agarwal & Goel, 2013).

In the past several decades, research on optimization techniques has captured the attention of most researchers. Optimization techniques can be classified in many ways; however, the simplest way is to look at the nature of the algorithm. In this light, they can be grouped into two: deterministic and stochastic techniques (Chen et al ,2011). Deterministic techniques depend on the mathematical nature of the problem, while stochastic methods do not depend on the mathematical nature of the problem. Stochastic techniques use randomization in its techniques to arrive at a solution. They are more appropriate for finding the global optimal solutions for any type of objective function. However, the weakness of the deterministic techniques is its dependence on gradient. Local optima and inefficient in large scale search space and cannot solve discrete functions. Stochastic techniques are more user friendly. The complexity of today's real-world optimization problem has made the use of stochastic techniques inevitable. These algorithms have been discovered to perform better than the classical or gradient based methods, especially in optimizing discrete complex, multimodal and non-differentiable functions (Chen et al ,2011). Nature Inspired algorithms are stochastic techniques that mimic the behaviors of human evolution, certain animals or insects. They have been developed since 1980s. Today, these nature inspired algorithms have already been applied to many areas in engineering fields.

Currently, the existing research in the path finding problem in robotics can be classified in two aspects: classical and heuristic. The most famous classic methods of path planning are potential field methods, grid methods and visibility graph methods. The potential field methods have very simple structures and are used in real time hurdle avoidance. However, there are inbuilt limitations in them; these includes trap conditions due to local minima, no passage between closely spaced objects or obstacles, oscillations in the presence of obstacles and oscillations in narrow paths. In the grid methods where grids are used to form the map of the environment, the size of the grids and the environment representation are directly proportional. The main problem of visibility graph methods is that they have very intricate search paths and very less search efficiency (Nizar & Farah,2014).

To overcome the limitations of classic methods to path planning; researchers have over time move towards heuristics methods. There is an increase in the development on heuristics methods over the past two decades. Heuristics methods has helped to deal with the complexities and computational costs associated with classical methods. However, one is not sure to come across a solution while using the heuristics methods, but if there is a solution it will be found much faster than the classical methods. The following heuristics approaches have been applied to the path planning problem in mobile robot.

They are Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Bee Colony Optimization (BCO) etc.

In this research, the application of nature-inspired heuristics algorithms in solving path finding problem in Robotics is reviewed also the expected future of the path finding problem in Robotics using nature-based heuristics algorithms would be discussed. The work is organized as follows: Section 2 deals with path planning optimization techniques, introduced nature-inspired algorithms, and described how some nature inspired algorithms have been applied to the path planning problem, Section 3 gives a summary of the application discussed in section 2, Section 4 gives the expected future trend and Section 5 provides the conclusion.

2.Mobile Robot Path Planning Optimization

Path finding is a fundamental aspect of many applications in the fields of GPS, games, robotics, logistics and crowd simulation (Zeyad et al ,2015). It can be implemented in static, dynamic and real-time environments. Several developments have carried out to improve the accuracy and efficiency of the path finding solutions over the past two decades. However, the problem still attracts a great deal of research. Today, the most important area of concerns is the provision of high performance, realistic paths for users (Zeyad et al ,2015).

In general, there are various kinds of path finding problem, such as single agent, multi-agent, adversarial. Some problems could be in the dynamic environment, heterogeneous terrain, mobile units and incomplete information. Each of these problems has different applications in different fields. Solving path finding problems consists of two main steps: graph generation and a path finding algorithm (Zeyad et al ,2015). Several techniques have been used to solve the graph generation problem; such as cell decomposition and Skeletonization.

The second step in the path finding process is the search algorithm itself. The objective of the algorithm is to return the optimal path to users in an efficient manner. These algorithms can be broadly classified as discrete path planning algorithms and Nature-inspired algorithms. Discrete path planning algorithms, such as potential fields, splines, grid based and tangent finding have been found to have high processing and large memory for computation. However, the nature inspired algorithms have been seen to provide possible solution to the limitations of these discrete techniques. Heuristics algorithms are able to cover a large search space and use a relatively low amount of memory and CPU resources.

2.1 Nature Inspired Algorithms (NIAs)

Nature-inspired algorithms are also referred to as evolutionary algorithms (EAs) (Emad et al ,2005). The limitations associated with using classical optimization techniques on large scale engineering problems have led to the development of alternative solutions. Nature-inspired algorithms are stochastic search methods that mimic the behaviour of natural biological evolution and/or the social behaviour of species. The behaviour of these species is guided by learning, adaptation and evolution. To imitate the efficient behaviour of these species, several researchers have developed computational systems that seek fast and robust solutions to complex optimization problems.

Some of the Nature inspired heuristics algorithms are:

- Genetic Algorithms (Inspired by evolution)
- Memetic algorithms (Inspired by evolution)
- Particle swarm optimization (Inspired by social foraging behaviour of some animals)
- Ant colony systems (Inspired by the foraging behaviour of ants)
- Bee colony system (Inspired by the foraging behaviour of honey bees)
- Fruit fly algorithm (Inspired by the food finding behaviour of fruit flies)
- Firefly algorithm (Inspired by the flashing behaviour of fireflies)
- Bat algorithm (Inspired by the echolocation behaviour of micro bats)
- Simulated annealing (Inspired by the process of annealing in metallurgy)
- Neural Networks (Inspired by the neurons in the human brain) etc.

However, in this study we will look at the application of four of these nature-based heuristics algorithms to the mobile robot path finding problem. They are Genetic Algorithm, Particle swarm optimization, Ant colony systems and Bee colony system.

Genetic Algorithms are search and optimization techniques first proposed by John Holland in the early 1970s (McCall ,2005). It is based on the principles of natural evolution. GA has been recognized as one the most robust search methods for complex and ill-behaved optimization problems. In Genetic Algorithm, a solution to a given problem is given in the form of chromosome, a chromosome consists of a set of elements, called 'genes' that hold a set of values for the optimization variables.

Particle Swarm optimization is a global optimization method proposed by Kennedy and Eberhart in 1995 (Bai, 2010). PSO is a stochastic optimization technique which is also population based like Genetic Algorithm. PSO is inspired by the social foraging of bird flocking together. PSO uses the information sharing mechanism. The population grows from experience learnt from each other.

Ant colony optimization is a meta-heuristic stochastic optimization technique developed by Marco Dorigo in 1992. ACO is inspired from the ants foraging behaviour. The behaviour in particular is how ants can find the shortest paths between their nest and its food sources. Ants deposit pheromone as they move around in search for food. These pheromone serves as a communication information to other ants. It is used to mark the way taken to a destination. Ants can also find the optimum path quickly when an obstacle suddenly appears in their way as they search for food.

The Artificial Bee Colony (ABC) optimization technique is also a population based meta-heuristics algorithms. It is inspired by the intelligent behaviour of real honey bees (Mohd et al ,2015). The algorithm was first proposed by D. Karaboga in 2005 for real parameter optimization problems (Nizar & Farah,2014). The ABC algorithm employs fewer control parameters in its implementation, these characteristics gives it an advantage over other population based algorithms. ABC algorithm has been applied to solve many practical optimization problems because of its flexible, simple and easy to implement.

2.2 Robotic Path Planning Using Nature Inspired Algorithms

2.2.1 Robotic Path Planning using Genetic Algorithm in Dynamic Environment (Arora et al ,2014)

The researchers apply Genetic Algorithm at a point in the problem space unlike the other existing approaches where GA has been applied to the whole problem space. The simulation system was dynamic and it was carried out in a 2-D space. The approach uses 20 randomly generated rectangular obstacles with variable sizes which positions is not known to the root prior to its movement (dynamic system) as shown in Figure 1. The authors allow the robot to begin its movement towards the destination using a diagonal path. On an encounter with an obstacle the robot takes three steps backward and applies Genetic Algorithm to determine the next path as seen in Figure 2. This approach was simulated using MATLAB. CPU utilization was obtained for four iterations as seen in Table 1. However, there was no explicit comparison of this approach to other known results to ascertain the optimality of the approach. The author, however concluded that the approach led to the shortest minimum path or the robot as seen in Figure 4

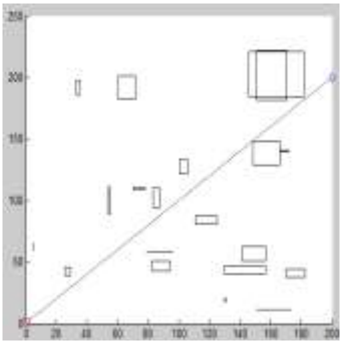


Figure 1: Problem Configuration (Arora et al ,2014)

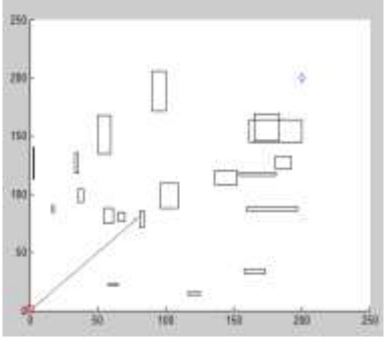


Figure 2: Robot Encounters an Obstacle (Arora et al ,2014)

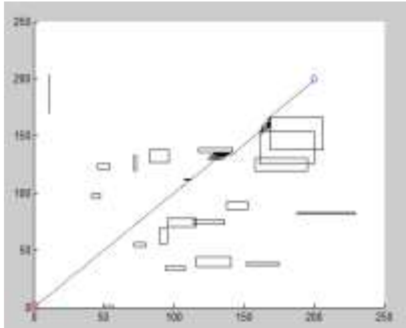


Figure 3: Solution Obtained (Arora et al ,2014)

Table I: Number of Iterations Vs CPU Time in Seconds (Arora et al ,2014).

No. of iterations	CPU Time (sec).
10	26
20	102
30	122
40	139

2.2.2 A Mobile Robot Path Planning Using Genetic Algorithm in Static Environment (AL-Taharwa et al ,2008)

This study shows the implementation of Genetic Algorithm in a static environment, this means the environment has been predefined and the position of obstacles are known to the navigating robot prior to its movement. A simplified fitness function was used; it uses the path length to determine the best individual in a generation. Simulations were done in obstacle free environment and three obstacle full environment. It was discovered that Genetic Algorithm converges irrespective of the population size used. However, increasing the population size increases the computational cost. Table 2, 3, 4 gives a tabular display of the results obtained.

Table II: GA Performance with Population Size 10 (Al-Taharwa et al ,2008).

Environment	Population size	Best fitness value	Generation No.
Obstacle-free environment	10	20	60
Indoor Environment	10	38	100
Moderate environment	10	26	90
Complex environment	10	26	80

Table III: GA Performance with Population Size 20 (AL-Taharwa et al ,2008)

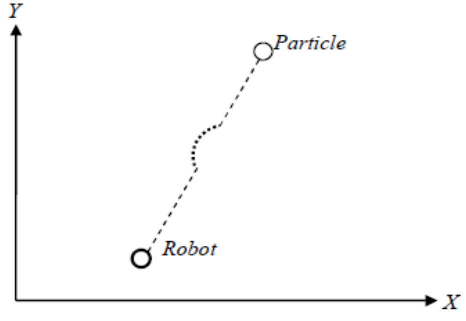
Environment	Population size	Best fitness value	Generation No.
Obstacle-free environment	20	18	60
Indoor Environment	20	32	100
Moderate environment	20	22	90
Complex environment	20	26	30

Table IV: GA Performance with Population size 50 AL Paths by ACO (AL-Taharwa et al ,2008).

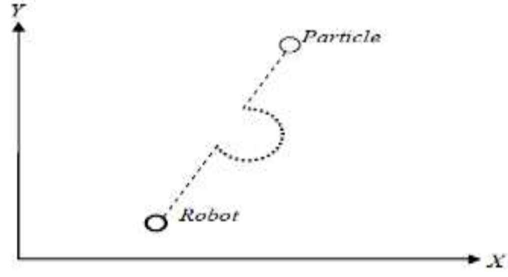
Environment	Population size	Best fitness value	Generation No.
Obstacle-free environment	50	18	60
Indoor Environment	50	28	100
Moderate environment	50	20	90
Complex environment	50	24	80

2.2.3 Using Particle Swarm Optimization for Robot Path Planning in Dynamic Environments with Moving Obstacles and Target. (Yarmohamadi et al ,2011)

The study uses the particle swarm optimization techniques in a dynamic environment where the position of the target moves over time. Moving and static obstacles were also present in the system. In order to simulate the proposed approach; assumptions were made. Some of them are that the robot (Vrobot) and target (Vgoal) have maximum footsteps for which they must not exceed and there is also a relocation probability associated to the moving obstacles (Pobs) and the target (Pgoal). Circular shaped obstacles were used and the root moves in a rotational manner, it also investigates its surroundings using a radius from itself in order to find the next position with minimum collisions. A penalty function was introduced to solve the local optimum problem of PSO. This function uses the size and position of the obstacles to determine the next position. Simulations were carried out using MATLAB and it was successful. Figure 4 shows two possible routes the robot could take if an obstacle is encountered; however using the penalty function; the path with the shorter length will be selected. Figure 5 shows the result of the simulations when the relocation probability of the target and moving obstacles are set to 0. Figure 6 shows when the parameters were varied. Again, the performance of the novel approach was not compared to the existing approaches existing in the field.



(a)



(b)

Figure 4: (a) and (b) are two possible routes the Robot can take. using the Penalty Function the Route (a) Will be Selected (Yarmohamadi et al ,2011).

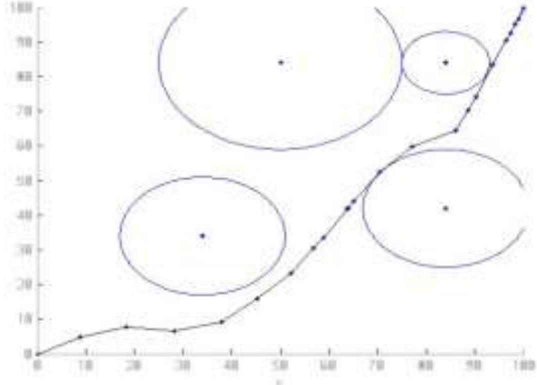


Figure 5. For the Robot, VROBOT =10. For every obstacle, POBS=0. For the goal, PGOAL=0 (Yarmohamadi et al ,2011).

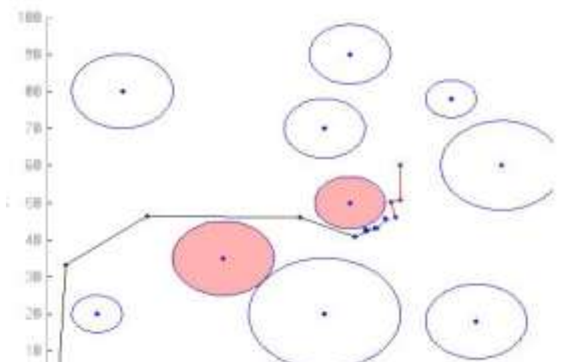


Figure 6. For the robot, VROBOT=30. For the obstacles, VOBS=5; P1obs =0.4 and P2obs=0.7. For the goal, pgoal=0.3 and VGOAL=10 (Yarmohamadi et al ,2011).

2.2.4 Improvement of Robot Path Planning Using Particle warm Optimization in Dynamic Environments with Mobile Obstacles and Target (Nasrollahy & Javadi,2009).

The researchers here improved the penalty function used in (Yarmohamadi et al ,2011). The penalty function was based on the state of the environment. A penalty value is assumed for every obstacle and the influence of the adjacent obstacles are added to the length of the arc for that portion. Simulations were done using MATLAB with four different environmental set up. Table 5 gives the details of the environment. It was concluded that the improved penalty function achieved a better result compared with the results of previous work. Figures 7 and 8 were captured during the simulations with varied parameters.

Table V: Details Of The Four Simulation Environments (Nasrollahy & Javadi,2009).

Figure	No of Obs	No of SObs	No of DObs	Pgoal	Vgoal	Vrobs
7	5	5	0	0	0	10
8	8	8	0	0.3	5	30

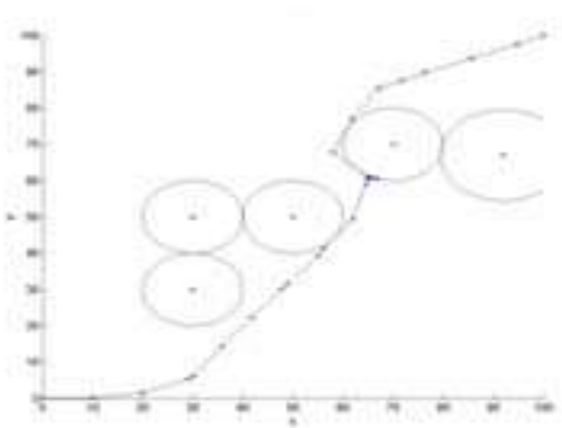


Figure 7 : Path Displayed with Robot Velocity =10 (Nasrollahy & Javadi,2009).

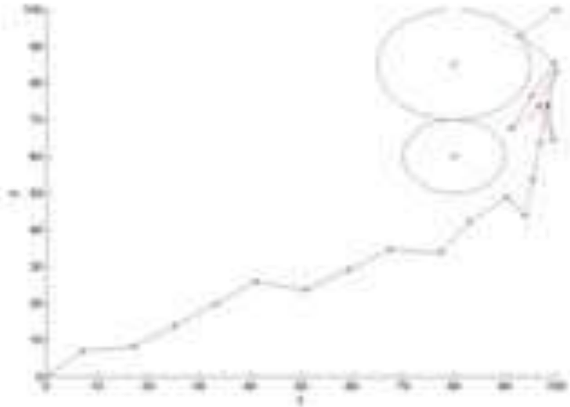


Figure 8: Path Displayed with Robot Velocity = 30 (Nasrollahy & Javadi,2009).

2.2.5 Mobile Robot Path Planning Using Ant Colony Optimization (Mohanraj et al ,2014)

A grid based environment represented in a grid model was used to simulate the path planning of mobile robot. The researcher represents the robot as a point in the grid to reduce computational complexities. A heuristics factor was added to the simple ant colony optimization algorithm. Simulations were done using MATLAB and it was clear that the ACO-MH outperform the SACO. Table 6 shows the parameter specification used for ACO and ACO-MH. Figure 9 and 10 show the map taken by the robot during simulation.

Table VI: Parameter Specification for ACO and ACO-MH Algorithms (Mohanraj et al ,2014).

Parameters	SACO	ACO-MH
No. of Ants (m)	10	10
Weight value (α)	0.25	0.25
Heuristic Factor (β)	0	1
Radius of the obstacles	1	1
pheromone evaporation rate (ρ)	0.1	0.1

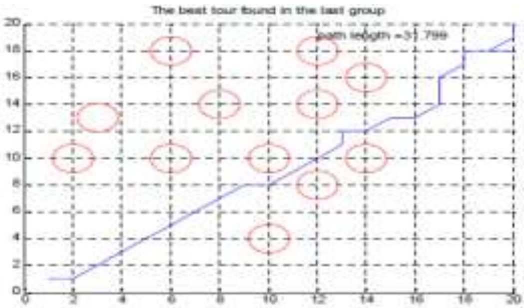


Figure 9: Optimal Path using ACO Algorithm (Mohanraj et al ,2014).

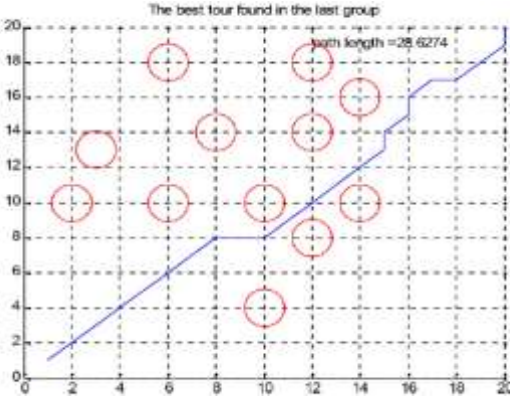


Figure 10: Optimal path found using ACO-MH Algorithm (Mohanraj et al ,2014).

Table VII: Comparison of results for ACO and ACO-MH Algorithms (Mohanraj et al ,2014).

Ex No	SACO (ACS)		ACO -MH	
	Distance (cm)	Time (sec)	Distance (cm)	Time (sec)
1	31.799	3.669818	28.6274	3.26651
2	33.8995	6.5687	32.1421	6.903165
3	32.7279	2.398471	32.1421	2.369687

2.2.6 Path Planning For a Mobile Robot Using Ant Colony Optimization and the Influence of Critical Obstacle (Hyungjune & Seo,2016).

The ant colony optimization was applied to the path finding problem using inference of critical obstacle. The proposed methodology uses the values propagated by the critical obstacles as the initial pheromone and initial transition probabilities. This approach enhances the standard ACO algorithm by directing ants towards the preferable direction rather than allowing them to wander all directions in the same weight. This will enable the ants to reach the target efficiently without considering all regions since the optimal path can be obtained around the critical obstacles. Simulations was carried out in three maps with different configurations. In all the maps, the critical and non-critical obstacles were assigned different values. The performance was compared with the standard ACO algorithm. It was seen that ACOIC out performed ACO.

Table VIII: Result of Path Length (CM) Obtained using Acoic and Aco (Hyungjune & Seo, 2016).

	ACOIC		ACO	
	Length of the best path	Average path length at t=50	Length of the best path	Average path length at t=50
Map 1	5400	6546.7	5600	6706.7
Map 2	4500	5260	4700	5900
Map 3	2700	3446.7	2700	3513.3

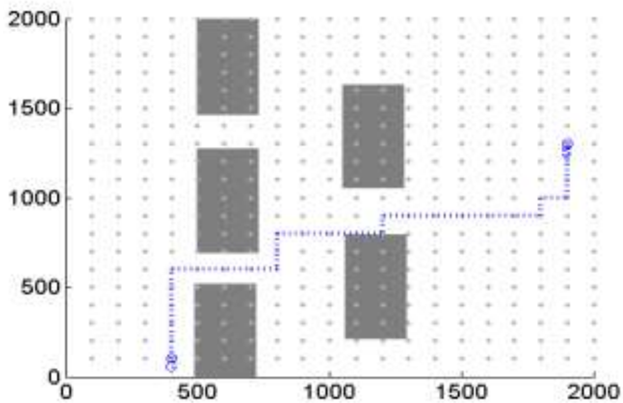


Figure 11: Optimal Paths by Acoic (Hyungjune & Seo, 2016).

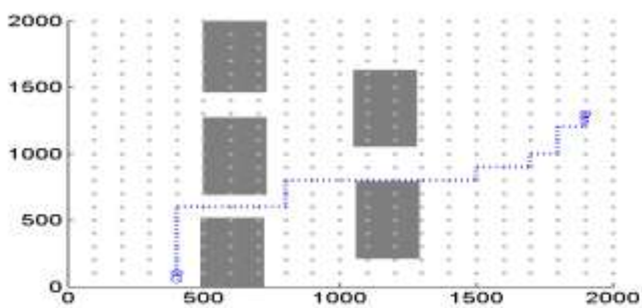


Figure 12: Optimal paths by ACO (Hyungjune & Seo,2016).

2.2.7 Path Planning of Mobile Robots Using Artificial Bee Colony Algorithm (Agarwal & Goel, 2013).

In this work, the researcher applied the artificial bee colony algorithm to find the optimized path for the robot. Two steps were used in the by them; first was to create an initial collision free path from the start point to the goal point and the second was to use the ABC algorithm to find optimal initial path. The proposed algorithm considers that every path consists of straight line segments passing through or from specific points. These points will be selected according to the fitness values to produce a path with shorter lengths. The ABC algorithm5 was used to find this optimal path. The simulation was performed on the grid environment. The population size and number of iterations was kept at 100 and 50 respectively for both environments. The result obtained shows that the ABC algorithm was able to find an optimized path from the start point to the goal point.

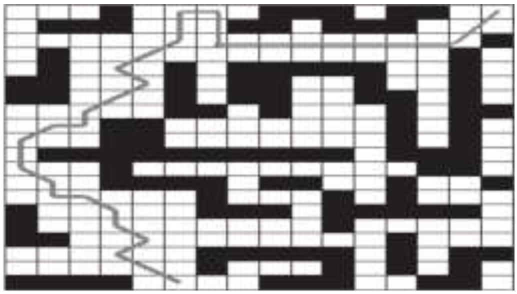


Figure 13: Simulation result in densely occupied environment (Agarwal & Goel, 2013).

3. Application of the Nature Inspired Algorithms to Mobile Robot Path finding Problem.

Nature inspired algorithms have been applied to the mobile robot problem by several researchers. These algorithms have been applied to both the static and dynamic environment. Static environment is when the robot is aware of the obstacles positions in the map and the position of the obstacles do not change with time while in dynamic environment; these obstacles appears unpredictably in course of motion and the position of the obstacles changes with time. In case of robot navigation, a mobile robot reaches the target destination from source station, avoiding collision with obstacles and upon iterations gives an optimal path without any human involvement (Mohanraj et al ,2014).

Genetic Algorithm was applied by (Yarmohamadi et al ,2011) to solve the mobile robot path finding problem in a dynamic environment. They tested the approach using 20 randomly generated obstacles. The location of the obstacles is not known to the robot; hence it is dynamic. Out of the many paths generated; the one with the minimum distance is from start to goal node was selected as the optimal path.

In (AL-Taharwa et al ,2008) Genetic Algorithm was applied in a static environment where the positions of the obstacles were known to the robot prior its movement. A simplified fitness function was used; it uses the path length to determine the best individual in a generation. It was discovered that Genetic Algorithm converges irrespective of the population size used.

Modified Particle Swarm Optimization was applied to the path finding problem of mobile robot by ((Yarmohamadi et al ,2011). A penalty function was proposed as a constraint optimization to enable the robot finds the shortest path to the destination by observing the size and position of the obstacle which has blocked its trajectory. This approach allows the process not to be trap in local optimum and ensures a path is found always if it exist.

The penalty function introduced in (Arora et al ,2014) was improved upon by (Nasrollahy & Javadi,2009). Every obstacle was given an assume penalty value and the influence of the adjacent obstacles were added to the length of the arc. It was concluded that the improved penalty function achieved a better result compared with the results of previous work.

Ant Colony Optimization algorithm was modified using the inference of critical obstacles to guide the robots in order to find the shortest path to the goal. This approach was proposed by (Hyungjune & Seo,2016). The ACOIC methodology was implemented in several maps in order to find a feasible and shortest path. The results were compared to the standard ACO algorithm. It was seen that ACOIC outperformed the ACO; that is utilizing the initial pheromones to lead ants to the critical obstacles is more effective in quickly finding an optimal path than in applying the constant initial pheromones as done in ACO.

Artificial bee colony was applied by (Agarwal & Goel, 2013) to the problem by using two steps: first was to create an initial collision free path from the start point to the goal point and the second was to use the ABC algorithm to find optimal initial path. The proposed algorithm considers that every path consists of straight line segments passing through or from specific points. These points will be selected according to the fitness values to produce a path with shorter lengths. The ABC algorithm was used to find this optimal path.

Table 9 shows some of the characteristics of the nature inspired algorithms x-rayed. Artificial Bee Colony Optimization algorithm can be concluded due to the few number of parameters that can be tweaked, the implementation is easier compared to Genetic Algorithm whose number of parameters is as high as 5.

Table IX: Some Characteristics of the Nature Inspired Algorithms.

Nature Inspired Algorithms	Genetic Algorithm	Particle Swarm Optimization	Ant Colony Optimization	Artificial Bee Colony
No. of Parameters	5	4	4	2
Large Scale Problems	Yes	Yes	Yes	Yes
Computational time	High	Low	Low	Low
Concept Clarity	Complex	Complex	Complex	Easy
Feedback Mechanism	No	Yes	Yes	Yes
Implementation	Complex	Easy	Complex	Easy

4. Future Trend

The review shows that there is still scope for developing more efficient on-line path planning algorithms (Tang et al ,2015) with moving obstacles that will produce better quality routes by addressing real-time recognition of the moving obstacles and producing the shortest and safe path dynamically.

With the prediction of the future of robotics being the drive for innovation to give company the competitive edge.

Robot should be able to move from point to point without human intervention and smoothly by avoiding collision with obstacles and human in its work space. Introduction of sophisticated sensors and camera in the robot space will aid a smooth path generation by the robot to enable it to achieve the goal with the shortest possible time.

As we know, organisms do not have sensors, but they are able to achieve perfect sense function. In the future nature inspired sensors and cognitive model should be developed in order to improve the precision of the sensors and to reduce the high production cost incurred with the development of high precision sensors. The cognitive model of organisms can also be applied to the mechanism of robots. The performance of these nature inspired algorithms in real applications of mobile robot is also a concern to be addressed in the future. This will lead to the development of robot with high intelligence, self-learning, and self-perception in the mobile robot field. . In the future we hope to see where robots can move in a dynamic environment powered by a more efficient hybridize algorithm, nature inspired sensors and mechanisms.

5. Conclusion

In this work, we have reviewed the application of nature inspired algorithms to the problem of path finding in mobile robot. We can see that several approaches have been used to solve this problem both in static and dynamic environment.

It is clear that nature inspired algorithms is an expandable field with innovative ideas and thoughts. It is also one of the hottest research points in the computation world today and will play an important role in mobile robot control, which will be a good solution to improve the intelligence and autonomy of mobile robot.

Currently, ways of solving the path finding problem in mobile robot based on these algorithms have been explored and the results are exciting to demonstrate the potential of NIAs. However, most of the results available are only conducted by simulation; additional efforts are needed to develop some more efficient NIAs and transit these results to real applications in mobile robot control.

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