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# Drone's node placement algorithm with routing protocols to enhance surveillance

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**ABSTRACT**

Flying ad-hoc network (FANET) is characterized by key component features such as communication scheme, energy awareness, and task distribution. In this research, a surveillance space considering standard petroleum pipe was created with three drones viz: drone 1 (D1), master drone (DM), and drone 2 (D2) to survey as FANET. DM aggregate packets from D1, D2 and communicate with the static ground control station (SGCS). The starting point of the three drones and their trajectories during deployment were calculated and simulated. Selection of DM, D1, and D2 was done using battery level before take-off. Simulation results show take-off time difference which depends on the distance of each drone to the SGCS during deployment. D1 take-off first, while DM and D2 followed after 0.0704 and 0.1314 ms respectively. The position-oriented routing protocols results indicated variation of information flow within time notch due to variation in the density of the transmitted packets. Packets delivery periods are $0.00136\times10^3$ sec, $0.00110\times10^3$ sec, and $0.00246\times10^3$ sec for time notch 1, 2, and aggregating time notch respectively. From the results obtained, two algorithms were used successfully in deploying the drones



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## 1. INTRODUCTION

Pipelines play significant roles in oil and gas production process. It is used by petroleum industry to convey crude oil and refined products. Despite its benefits, petroleum pipelines sometimes break down due to wear and tear, and external force acting from the outside amongst others. Due to unmanned aerial vehicles (UAVs) several applications in surveillance, communications, and agriculture [1]–[6], they have been adopted universally by researchers. When a swarm of UAVs is surveying, the task becomes easier to complete due to their ability to share tasks, speediness in acquiring/disseminating information, and cost-effectiveness compared to human patrol teams [7], [8].

As technology advanced, UAVs are substituting hand-held devices in surveying pipelines due to their versatile applications [3], [9]. They are employed in such a manner that they communicate with each other as well as the SGCS to perform their tasks efficiently, thereby forming a flying ad-hoc network (FANET) [10]. A FANET is made up of multi-UAVs communicating with each other in an ad hoc manner with a view to sharing information and resources. Since multi-UAVs must communicate with each other, then multi-UAVs that do not communicate with each other cannot be called FANET [4], [7], [11], [12].

When these UAVs form FANET, it becomes pertinent to consider the inherent characteristics of its application scenario. Inherent characteristics of FANET include security, bandwidth efficiency, and cooperation of UAVs in rapidly changing environments [13], [14]. Although UAVs have several benefits in surveillance, some of their challenges include:

Node placement: precise UAVs placement can efficiently prolong the lifetime of a FANET [11], [15]–[17]. Super-nodes need to be properly placed in a FANET to achieve optimal throughput and lengthier operational life. Many researchers researched node placement and trajectory optimization to improve network performance matrices such as maximum throughput, packets delay, packet delivering ratio, and energy saving. proper node placement also reduces coverage hole in UAV surveillance and enhance the relay of data when used as a relay node [11], [13], [18]–[21].

Routing protocol: protocols are formal policies that govern how two nodes communicate with each other over a network [22]–[24]. Due to the fast movement of UAVs and the unsteadiness of air links, routing in FANET has become a vital task. A node in FANET can serve as a transmitter, receiver, or forwarding node, while protocol can change pending on the application requirement [8], [15], [24]–[26]. Hence, developing appropriate routing protocols for most mission scenarios and FANET features remains a challenge for investigators.

In this research, we are going to develop two algorithms. The first will optimally place the UAV nodes in a surveillance space for better coverage. The second will govern communication between the UAVs and the SGCS terminal with a good packet delivery to enhance surveillance.

## 2. METHOD

### 2.1. Conceptual framework

The research FANET is made up of three (3) drones that are optimally placed over the surveillance space. The space consists of a standard petroleum pipe of 12.2 meter length and 1.22 meter diameter [27]. The conceptual diagram for the overall research work is presented in Figure 1.

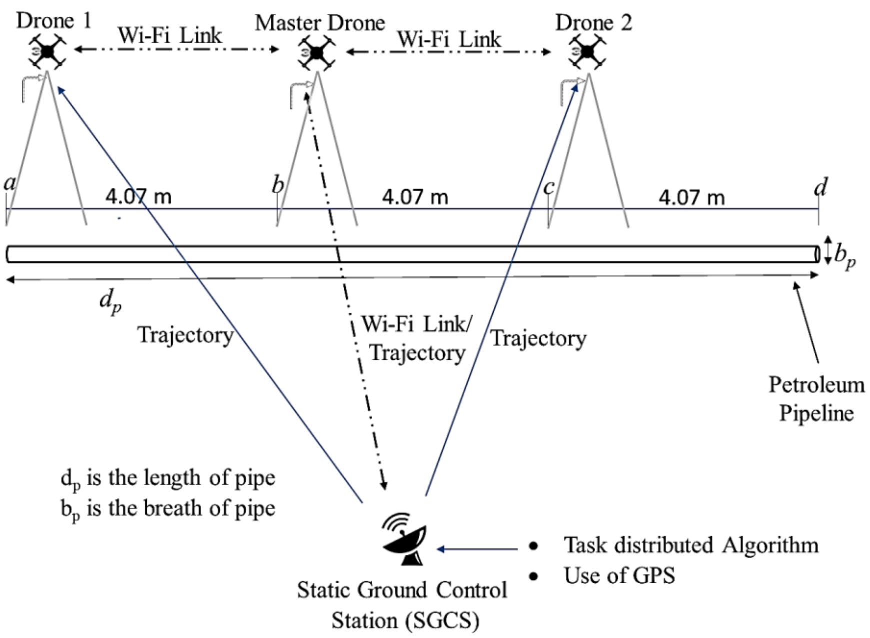



Figure 1. Research conceptual model

### 2.2. Initialization of UAV node deployment

Before deployment, the drones $\{D_1, D_M, D_2\}$ are said to be at initial positions $\{(x_i^1,\ h_i^1),\ (x_i^M,\ h_i^M)\ and\ (x_i^2,\ h_i^2)\}$ along the x-y axis, where$x_i^j = \frac{d_p}{2} m$ and $h_i^j = 0m$. The final positions of drones after deployment are given as $\{(x_f^1, h_f^1), (x_f^M, h_f^M)\ and\ (x_f^2, h_f^2)\}$ where $h_f$ is the flight height of the drone and is given by (1):

$$h_j^f = \sum_{j=1}^{N} \{ \begin{matrix} h_m & if\ h_j^f \geq 10 \\ h_j^f & if\ otherwise \end{matrix} \quad (1)$$

$h_f^j$ denotes the height of the $j$ drone, $h_m$ is the maximum flying height specified for the drones, $j$ represents the actual drone i.e., 1, M, and 2, N is the total number of drones. The initial position $(x_i, h_i)$ of the drone is generated using (2) as:

$$x_i, h_i = r \times cos(\pi) + x_i \quad (2)$$

$\pi$ is generated between 0 and $2\pi$, $r$ denotes the radius of the drone while $x_i$ represents the starting position of the drone along the x-axis i.e., $\frac{d_p}{2}$. The batteries' energies of the drones $E_{d_j}$ were randomly generated for simulation purposes using (3):

$$E_{d_j}(E_{min}, E_{max}, N_d) = E_{min} + \Phi(N_d, 1) \text{x} (\text{E}_{max} - \text{E}_{min}) \quad (3)$$

where $\text{E}_{max}$ and $\text{E}_{min}$ are the maximum and minimum charging capacity of the drones respectively, $N_d$ denoted the total number of the drones and Φ is a number generated using normal distribution and ensures the stochasticity of $E_d$.

### 2.3. Lunch path to initial surveillance region

To position SGCS, the trajectories of the drones, the final deployment position $(x_f, h_f)$ of the drones, flight velocity, and duration were calculated. The drones were to travel in a straight path from an initial position $(x_i, h_i)$ to $(x_f, h_f)$. To select broadcasting points of the drones at regular vertical intervals, the position of the drone at any instance along the x-axis is calculated by a modified straight-path as (4):

$$d_x D_j = \left( \frac{(d_y D_j - C_{x=0} D_j)}{h_f} \right) (x_f - x_i) \quad (4)$$

where $d_x$ is the instantaneous position of the drone alone $x$-axis, $D_j$ denotes drone during deployment ($j$=1, M and 2), $d_y$ represents the instantaneous position of drone along the y-axis, $h_f$ is the final flight height, $h_i$ is the initial flight height, $x_f$ represents the final position of the drone along the x-axis, $x_i$ represents the initial position, $c_{x=0}$ is the collision-free coefficient of the drone within the surveillance space. In this report, Euclidean distance $E_{D_j}$ is used to determine the absolute distance between SGCS and the drones during deployment. Euclidean distance is given as (5) [28]:

$$E_{D_j} = \sqrt{\left| h_{fD_j}^2 \right| + \left| x_{fD_j}^2 - x_{iD_j}^2 \right|}\, m \quad (5)$$

where $\left| h_{fD_j}^2 \right|$ is the absolute vertical height of drone $D_j$ above SGCS and the absolute horizontal distance is represented as (6).

$$\left| x_{fD_j}^2 - x_{iD_j}^2 \right| \quad (6)$$

Therefore, the travel time of a drone is presented in (7). From the considered flight scenario, all drones take off from the same initial point that is (7).

$$x_{iD_j}^2 = x_{iD_1}^2 = x_{iD_M}^2 = x_{iD_2}^2 = x_{i,0}^2,\ T_{D_j}(h_f) = \frac{E_{D_j}}{v_{D_j}} = \frac{\sqrt{h_{fD_j}^2 + \left| x_{fD_j}^2 - x_{iD_j}^2 \right|}}{v_{D_j}} s \quad (7)$$

During deployment, all drones are to arrive $h_f$ at the same time therefore, take-off times $\Gamma_{D_j}$ for the three drones are given as (8)-(9):

$$\Gamma_{D_1} = \Gamma_{D=0} \quad (8)$$

$$\Gamma_{D_M} = T_{D_1}(h_f) - T_{D_M}(h_f) \tag{9}$$

$$\Gamma_{D_2} = T_{D_1}(h_f) - T_{D_2}(h_f) \tag{10}$$

where $\Gamma_{D=0}$ is the initial take-off time of the drone, assumed to be 0 s.

### 2.4. Communication scheme for node formation and SGCS

A transmission set is defined for the transmission schedule using time notch as depicted in Figure 2. In this research, time notch is used over time slot because it is dynamic and changes for every round of information. A time notch defines communication between the Master drone with drones 1, 2, and SGCS. The transmission time notch is the sum of the transmitting/receiving signals given as $\{T_n(D_1, D_M) + T_n(D_M, D_1)\}$, $\{T_n(D_2, D_M) + T_n(D_M, D_2)\}$ and $\{T_n(D_M, SGCS)\}$ for time notch 1, 2, and 3 respectively. The algorithm that describes the UAV node placement is presented in Algorithm 1.

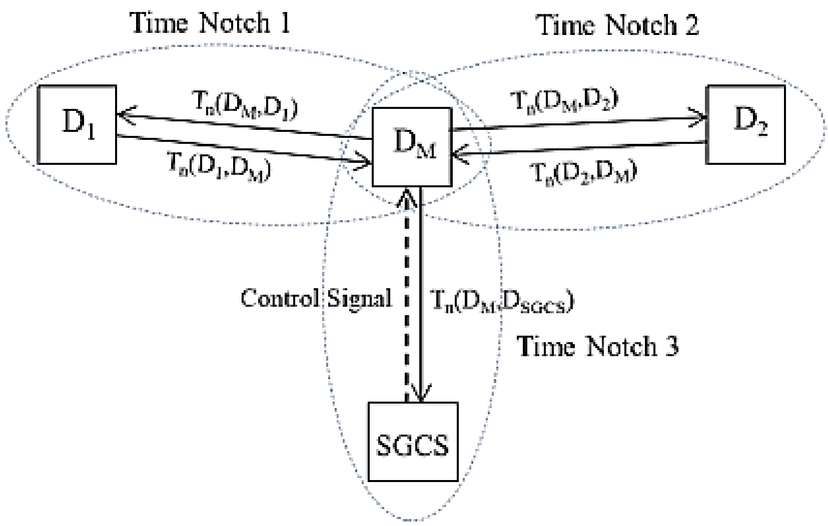



Figure 2. Developed transmission schedule diagram based on time notch

Algorithm 1. UAV node deployment Algorithm

Input: $(x_i^1,\ h_i^1); (x_i^M,\ h_i^M); (x_i^2,\ h_i^2); \theta; d_p; b_p; V; I; K; Emax_{min}$

Output: $(x_f^1, h_f^1); (x_f^M, h_f^M); (x_f^2, h_f^2);$

1. Compute surveillance space
2. Assign $D_1$, $D_M$ and $D_2$
3. Assign initial position of drones using inputs $(x_i^1, h_i^1); (x_i^M, h_i^M)$ and $(x_i^2, h_i^2)$
4. Compute flight trajectories
5. Calculate absolute distance of each drone
6. Determine travel time of each drone
7. Compute take-off time of each drone
8. Determine the diameter of view area of each drone
9. Define communication scheme for node formation and SGCS
10. **If** UAV is optimal position
11. Form UAV node
12. **Else**
13. Return to step 4
14. **Output:** $(x_f^1, h_f^1); (x_f^M, h_f^M); (x_f^2, h_f^2);$
15. **Stop**

### 2.5. Routing protocol

Algorithm 2 presents the proposed position-based routing protocol. The UAVs and the ground station exchange "Hello" messages periodically in the networks. Links are said to be full-duplex and all the UAVs were assumed to have slightly different energy levels.

Algorithm 2. Algorithm for the routing protocol

```
1. Input : FANET Component
2. Output: path for transmission
3.     While (Node position is optimal) do
4.      Initialize Network
5.      Master Drone initiate "Hello Messages" to all nodes in the network for required
        information
6.      Node formation based on Time notch
7.      L=1
8.      While (r ≤ d_p) do
9.                  if GS, {D1, DM, D2} are reachable Then
10.                 add UAVs in a notch to connected route matrix
11.             else
12.                 remove the UAV that does not belong to a connected route matrix
13.             end if
14.             L = L+1
15.             Transmission path ready (connected route matrix [])
16.     End while
17.        Operate all connected routes and recheck conditions
18.     Repeat steps 7 to 16 until all UAVs are in a time notch
19.    End while
20. Stop
```

## 3. RESULTS AND DISCUSSION

In this section, the results obtained through simulation are presented. The simulation was carried out for the UAV dynamic node placement and routing protocol algorithms. The results were analyzed while the significance of the results is also discussed.

### 3.1. Simulation set-up

MATLAB R2020b was used for the simulation of the developed UAV dynamic node placement and position-oriented routing protocol algorithms. The parameter used is presented in Table 1 based on the drone manufacturers' manual [29]. The united metallurgical company sheet [27] is also used.

Table 1. Simulation Parameters

| S/N | Parameter | Definition | Value |
|---|---|---|---|
| 1 | $N_d$ | Number of drones | 3 |
| 2 | I | Battery rating of the drone | 1,100 mAh |
| 3 | V | Battery voltage | 3.8 V |
| 4 | H*L*B | Dimension of the drone | (98×92.5×41) mm |
| 5 | E | Drone's battery Energy (V*I*T*K) | 15.048 kJ |
| 6 | $d_v$ | Instantaneous position of drone alone y-axis | 0 – 10 m |
| 7 | $C_{x=0}$ | Collision free coefficient | |
| 8 | $D_j$ | Drone *j* during deployment | |
| 9 | $E_{Dj}$ | Euclidean distance | |
| 10 | $T_{Dj}$ $(h_f)$ | Drone travel time during deployment | |
| 11 | $d_p$ | Length of the pipeline | 12.2 m |
| 12 | $b_p$ | Diameter of the pipeline | 1.22 m |
| 13 | $h_f$ | Drone flight height | 10 m |
| 14 | $v_{Dj}$ | Speed of the drone | 4 m/s |
| 15 | θ | Observation angle of the drone | $82.2^0$ |
| 16 | $h_m$ | Specify the flying height of the drone | 10 m |

### 3.2. Results for development and simulation of a UAV dynamic node placement and routing protocol algorithms

This subsection presents the simulation results as well as their explanation. The UAV dynamic node placement results are obtainable in 3.2.1 through 3.2.4. The results for routing protocol are offered in 3.2.5.

#### 3.2.1. Drones' trajectories

The trajectories of the drones are shown in Figure 3. In (1) and (4) were used for the trajectories, where the three lines indicate the trajectories of the three drones. The * indicate spots where the three drones broadcast their positions along the x-y coordinates, their speeds, energy level, and direction. The pipe is at 1.22 m on the y-axis indicating the height of the pipe surface above ground. The drones' take-off point is in the middle of the surveillance space i.e. 6.1 m. A +1 meter is added on the left of the x-axis to improve the clarity of the survey space in the diagram.

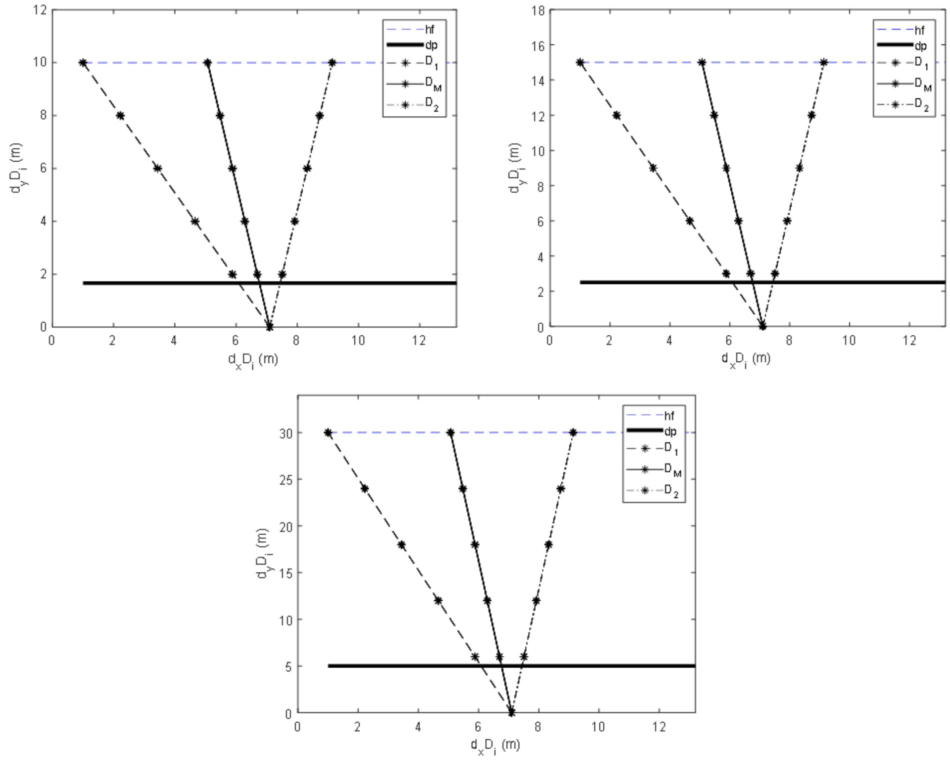
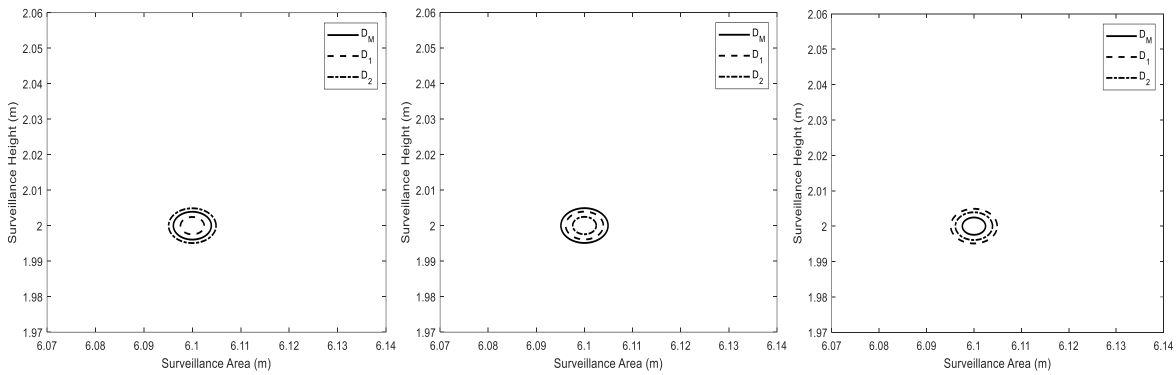



Figure 3. Drones' Trajectories with surveillance heights of 10, 15, and 30 m

#### 3.2.2. Drone selection

In (2) and (3) were used to initialize drones' positions and to generate their energies respectively. Parameters from Tello Edu drone data sheet were used to calculate the energy of the drone using (12). Figure 4 shows different scenarios where the drones were selected just before take-off.

Figure 4 depicts the selection of drones base on their energy levels. The code is to assign the drone with the highest battery level as $D_M$, the higher battery level as $D_1$, and the least as $D_2$. In Figure 4(a), the first, second, and third drones (from the top view) were selected as $D_1$ with 14.9659 kJ, $D_M$ with 15.0173 kJ, and $D_2$ with 14.8215 kJ respectively. Figure 4(b) shows the first, second, and third drones from the top view as $D_2$, $D_1$ and $D_M$, while Figure 4(c) depicts selection from the top view as $D_M$, $D_2$ and $D_1$ respectively.




(a) (b) (c)

Figure 4. Drone selection (a) first scenario, (b) second scenario, and (c) third scenario

#### 3.2.3. Drone's take-off time

In Figure 3, the distance of each drone from the SGCS varies. Since the drones fly with an equal speed of 4 m/s and are to reach their deployment points at the same time, take-off time must also vary.

In (8)-(10) were used to determine the take-off time of each drone relative to other drones in the FANET. Table 2 depicts the time at which each drone will take off assuming drone $D_1$ takes off at time $\Gamma_{D=0} = 0$.

Table 2. Drone’s take-off time

| S/N | Drone | Take-off Time (ms) | Time Difference (ms) |
|---|---|---|---|
| 1 | $D_1$ | 0.00 | 0.00 |
| 2 | $D_M$ | 0.0704 | 0.0704 |
| 3 | $D_2$ | 0.1314 | 0.0610 |

### 3.2.4. Drone’s flying time

Figure 5 depicts the flying time of the drones. Using (7) to simulate the flying time of the drone with respect to the drone’s position in meters. From the figure, $D_2$ has the shortest deployment flying time as indicated by the straight line in the graph. $D_1$ graph shows the longest deployment flight time as depicted by the curve between 1 m to 3 m on the x-axis.

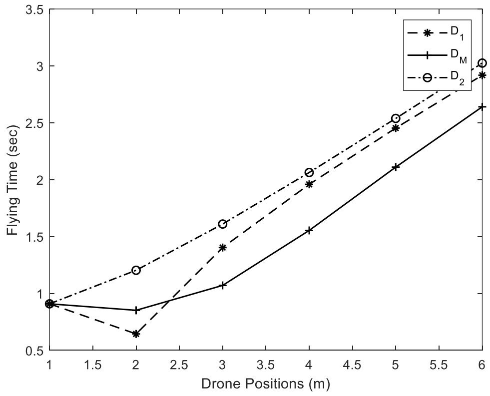



Figure 5. Drone’s flying time with respect to position

### 3.2.5. Routing protocol

Figure 6 illustrates information flow when both drones are communicating pending on which notch is first established. In Figure 6(a), time notch 1 is established first, therefore, making the information flow period minimum while the opposite occurs in Figure 6(b). For the aggregating time notch in both (a) and (b), the information flow period is the sum of the two periods. Packets delivery periods for Figure 6(a) are $0.00136\times10^{-3}$ sec, $0.00110\times10^{-3}$ sec, and $0.00246\times10^{-3}$ sec for time notch 1, 2, and aggregating respectively.

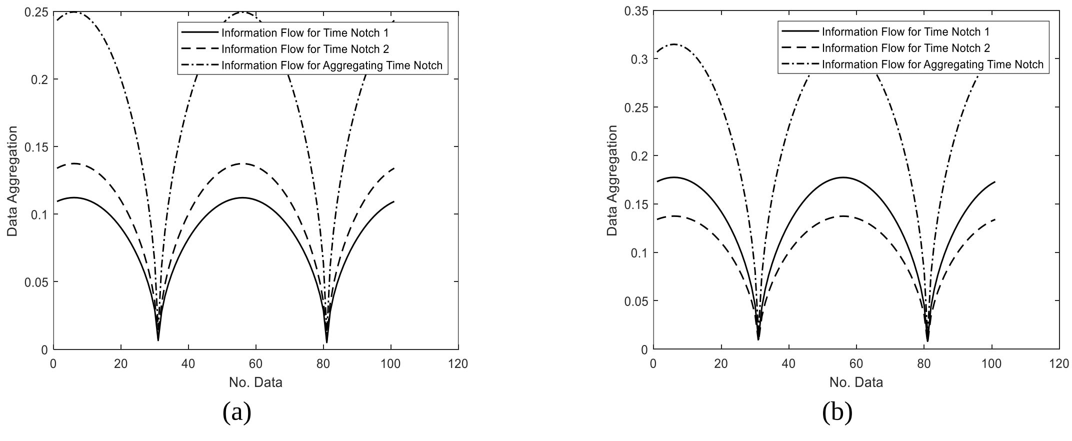



Figure 6. Aggregating time notch information flow when (a) time notch 1 established first and (b) time notch 2 established first

Although the rate of information flow does not change with flight distance, Figure 6 illustrates that the information between time notch 1 and 2 depends on which of the drones $D_1$ or $D_2$ connects with $D_M$ first. Figure 6(a) depicts time notch 1 established first, therefore, making the information flow period minimum while, in Figure 6(b), time notch 2 established first. For the aggregating time notch in both Figures 6(a) and (b), the information flow period is the sum of the two periods.

## 4. CONCLUSION

In this research, a UAV dynamic node placement in a petroleum pipeline surveillance area has been developed. Three drones were surveyed as FANET with the $D_M$ communicating with the SGCS. The starting point of the three drones and their trajectories during deployment were calculated and simulated with the selection of $D_M$, $D_1$, and $D_2$ successfully done using the initial energy level of the drones' batteries which is presumed to be 95% to 100% full prior to take-off. Simulation results depict take-off time difference which depends on the Euclidean distance of each drone to the SGCS during deployment. This also affects the drones' flying time with respect to the x-y coordinates position during deployment as indicated in Figure 5. Simulation results were obtained for the position-oriented routing protocols that governed the communication between the UAVs and the SGCS terminal. Results indicated that information flow within the time notch decreases for the aggregation time notch due to the higher density of packets to be transmitted. From the results obtained, the two algorithms were able to deploy the drones and established routing protocols among the drones and the SGCS.

In subsequent research work, we will look into the energy-aware message distribution algorithm for UAV node exchange to maximize energy usage. Also, an interaction-based task distribution algorithm for cooperative task sharing will be developed. The simulation will be done on the research findings and results will be well discussed.

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