TELKOMNIKA, Vol.16, No.2, April 2018, pp. 606~617
ISSN: 1693-6930, accredited A by DIKTI, Decree No: 58/DIKTI/Kep/2013
DOI:10.12928/TELKOMNIKA.v16i2.8444

A Specific Routing Protocol for Flying Adhoc Network

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Abstract

This paper presents a novel data and timed control routing protocol which is Flying Adhoc Network (FANET) specific. The developed FANET specific routing protocol laid emphasis on the route connectivity in the network by considering the captured data size, minimum allowable distance between randomly moving nodes and connection time. The performance of the proposed FANET specific routing protocol was simulated using NS3. The obtained throughput value for the routing protocol fluctuated between 742.064kbps and 755.083kbps as data are exchanged between nodes. This showed that when all the UAVs are on the network and communicating with one another, the throughput is flatline and not plummet. This implies consistency as nodes join and leave the network. The packet delivery ratio obtained for the FSRP during simulation was 96.13%. These results implied that data is successfully transmitted between the UAV acting as server and UAV acting as client on the network.

Keywords*: information communication, Ad Hoc Networks, routing protocol and UAVs*

1. Introduction

Unmanned Aerial Vehicles (UAVs) are small autonomous drone flown without a human pilot, targeted at achieving specific tasks. In recent times, there is a vast usage of these UAVs in civilian applications such as animal tracking, environmental and remote sensing, pipeline monitoring, surveillance, media coverage and broadcasting, sports coverage and production processes monitoring amongst others. These applications made the use of UAVs a very attractive technology [1-2]. In the past, most of these applications were realized using a single large UAV system. Nonetheless, the single large UAV system used then required high-end hardware to ensure seamless communication with the ground terminals or a satellite for information dissemination. They were also affected by limited coverage. In order to solve these problems, researchers suggested the use of small multiple UAVs in an ad hoc manner.

The coordination and cooperation of these multiple UAVs (nodes) in an ad hoc manner is termed as Flying Ad hoc Network (FANET) [4-11]. It is true that the coming of FANET eliminated the problem posed by the single UAV system. But communication between these UAVs became an important and fundamental task to tackle. As such, it became necessary to create an efficient unguided medium for these Multiple UAVs to communicate with one another. However, the efficiency of the unguided medium is highly dependent on the nature of the routing protocol used. Prior to the emergence of FANETs in 2013, wireless ad-hoc networks were the traditional ones such as MANETs and VANETs [12-14]. In MANET, nodes are considered as an animal, mobile equipment or moving person while a VANET node is considered as a moving car [11]. But in FANET, nodes are UAVs which makes the characteristics differ to that of MANET and VANET [15-17] in terms of speed, topological change and security. The characteristics of FANET made the existing routing protocol of MANET and VANET unsuitable when applied by some researchers such as the work of [7, 17]. The unsuitability of the existing MANET and VANET routing protocol when applied to FANET was largely due to its inherent characteristics such as fast movement of nodes, dynamic topological, security amongst others. This made it necessary to develop a FANET specific routing protocol. Therefore, a routing protocol which is FANET specific is proposed in this paper.

The rest of the paper is organized as follows. Section 2 presents the overview of FANET. Section 3 explains the related works. Section 4 proposes FANET specific routing

Received December 28, 2017; Revised January 18, 2018; Accepted February 2, 2018

protocol. Section 4 discusses simulation setup, and results. Finally, Section 5 presents the paper’s conclusions.

2. Overview of FANET

FANET is a special case of the traditional peer-to-peer ad-hoc network where the nodes are UAVs [12]. The word FANET is only valid for multi-UAV systems that form an ad-hoc network with each other. All FANETs are multi-UAV systems but not all multi-UAV systems are FANETs. UAVs are flying vehicles that can move independently without human intervention. These vehicles can also be operated at a distance over wireless channels. The usage of UAVs is on the increase due to their flexibility, versatility, ease of installation and relatively low operating expenses. These features made them applicable for civilian and military purposes [14]. In FANETs, only a subset of UAVs can interconnect with the ground terminal or the satellite using the established wireless links and all UAVs constitute an ad-hoc network. This makes the UAVs communicate with one another and also with the ground terminal. Figure 1 shows the diagram of the typical FANET scenario.

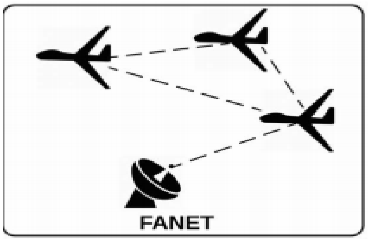

Figure 1. Flying Ad-Hoc Networks (FANET) [18, 19]

3. Related Works

Due to the nature of nodes, FANET and MANET are the most closely related ad-hoc networks. As such, a number of researchers have applied MANET routing protocols to FANET [7,17,20]. However, there was hardly any success in achieving reliable and seamless communication due to the flooding characteristic of the protocol and the frequent transmission of control packets such as the "Hello" message. These features often lead to a large overhead of maintaining routes that are mostly never used [21-23]. Therefore, when used in dynamic networks, the demand for storage is prohibitive. These limitations of the MANET routing protocols when applied to FANET makes it unsuitable. In an attempt to further improve the MANET routing protocol for possible suitability in FANET, the authors in the work of [24] presented a metaheuristic approach using the Ant Colony Optimization technique. Nonetheless, it achieved a short end-to-end delay but still pose very high amount overhead. [11] was the first major author to take into cognizance the inherent characteristics of FANET in developing a routing protocol. In their approach, they used a minimum connection time between two nodes to set up an alternate path. However, so many alternate paths might be setup without been used. Thus, leading to wastage of memory space. Based on this, for a routing protocol to be suitable for FANET, it must address its requirements like adaptive nature to dynamic link conditions, needs few control packets and little memory overhead to find unicast paths to destinations nodes in the ad hoc network. Due to these facts, this paper proposed a data and timed control routing protocol for FANET in a three-dimensional space which are data and time triggered. Hence, the major contributions of this paper are highlighted as follows:

a. We developed the routing protocol to use an optical directional antenna which in this case is the light fidelity (Li-Fi) in order to improve security and reduce the routing overhead to bearest minimum.
b. We allow each node to communicate with it memory directly to trigger connection establishment.
c. We allow communication between nodes timed in order to minimize information loss.

d. We introduce an initial separation distance to avoid jamming of nodes in the flying space. The initial separation distance will function with an intervehicle communication system.

e. We developed a Finite state machine model so as to prevent the protocol specification from dead lock

4. The Proposed Routing Protocol

As mentioned earlier in section 2, we propose a novel FANET specific routing protocol that reduces loss of information and routing overheads to the bearest minimum by considering: (i) captured data size (ii) minimum allowable distance between randomly moving nodes (iii) connection time. The details are described in the following subsections.

4.1. Network Model

The developed routing protocol is designed using the principle of the standard AODV with target on FANET inherent characteristics. The protocol contains three phases: the network discovery phase, the optical link setup for communication stage and UAV-to-UAV and UAV-ground terminal communication stage. Therefore, considering two UAVs within a confined area (A) denoted as $x, y \in N$ are at an initial separation distance d_{min} and distance apart *D(x, y)* such that Equation (1) is satisfied.

$$D(x,y) = \sqrt{(A_y - A_x)^2 + (B_y - B_x)^2 + (C_y - C_x)^2} \tag{1}$$

The nodes (UAVs) are connected via the established wireless link as a peer-to-peer. This means that all nodes are equal and contribute some of their resources with a view to making each node a data requestor and a data provider. The basic networking assumptions made about the computer networks is that All UAVs are equipped with a global positioning system (GPS), a camera for capturing data and an on-board velocity estimator. It is important to note that the foundation of any routing protocol is the algorithm. The algorithms are applied to find the best route for data transmission from source node to the destination node. In the development of the FSRP, the UAVs are considered to be in any of the following positions: Idle position, Static position or Motion position. Due to this fact, an initial separation distance d_{min} is introduced. Therefore, the Equation (1) can be re-written as:

$$D(x,y) = \sqrt{(A_y - A_x)^2 + (B_y - B_x)^2 + (C_y - C_x)^2} + d_{min} \tag{2}$$

Where, d_{min} is the initial separation distance between any two UAVs. Let d_{min} be the allowable separation distance between two UAVs and is arbitrary chosen as 3m in this work, x(t) be the position at time t and V(t) be the velocity of the UAVs at time t. At static position, the UAVs is at position $x_1(0)$, $y_1(0)$, $z_1(0)$ and $x_2(0)$, $y_2(0)$ and $z_2(0)$ as depicted in Figure 2

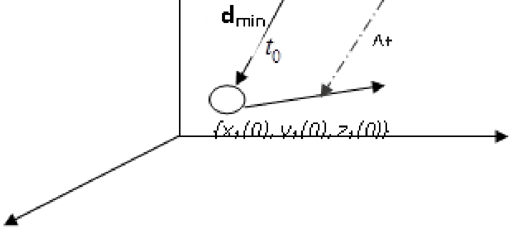

Figure 2. The UAV coordinate system

Let Δt be the time interval between successive steps as position of the UAV changes. v_n and x_{n+1} be the values of the velocity and position at time $t_{n+1} = t_0 + \Delta t$ where, t_0=0 at static position. At time t_{n+1}, it simply implies that the nodes have created a further separation distance between two respective nodes such that the new position of the nodes can be estimated as

$$x_{n+1} + d_{\min} = x_n + v_n \Delta t \tag{3}$$

$$x_{n+1} + d_{\min} = x_n + v_n (t_{n+1} - t_0) \tag{4}$$

$$t_{n+1} - t_0 = \frac{(x_{n+1} - x_n) + d_{\min}}{v_n} \tag{5}$$

Where: t_{n+1} - t_0 is the change in time of a node from one position to another

$(x_{n+1} - x_n) + d_{\min}$ is the equivalent distance between two nodes

V_n is the velocity of the nodes along an axis

But, transmission time (T_t) is:

$$\text{Transmission time } (T_t) = \frac{Packet\_size}{Bit\_rate} \tag{6}$$

However, since the routing protocol is reactive, it will make use of the captured data size.

Therefore, let the size of the routing table be RT (bytes), the size of route entries in the routing table be RE (bytes), the total number of previously established link be LK (bytes) and the number of previously captured/transmitted packet from a particular node be TM (bytes). So, the total stored data at each node is:

$$\text{Total stored data} = RT \times RE \times LK \times TM \tag{7}$$

If the size of the new captured data is NTM (bytes) then, the required data to be sent is:

$$\text{Required data to be sent (RQ)=Total stored data–NTM} \tag{8}$$

For the purpose of analysis, the size of data to be sent at interval is limited to 5MB. Once Equation (8) is satisfied i.e. RQ=5MB, the link is set to establish connection between the server and the client. The FANET routing protocol will make use of the transmission connection estimation (T_{ce}). T_{ce} is a time of establishing connection once the captured data attain 5MB.

So, assuming a transfer speed of 150Mbits/s and a captured packet size of 5MB, the transmission time which is also the required time to keep a link active for transmission between a server and a client can be computed as:

$$\text{Transmission time } (T_t) = \frac{5 \times 10^6 * 8}{150 \times 10^6} = 0.267 seconds$$

Therefore, in order to prevent link interruptions caused by the fast movement of every node, which leads to packet loss, link active time must equal to transmission time. Figure 3 shows a complete time cycle of the UAVs in operation.

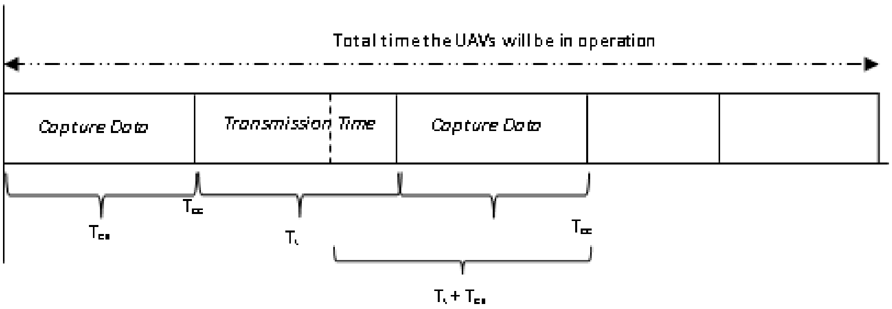

Figure 3. Complete time cycle of UAVs in operation

So, when UAVs are first deployed on the network (idle position), T_{ce} will only be satisfied after a given time. The conventional routine process of the FSRP after sensing and acquisition of data, is that the nodes send queued data packets if a route to the destination has be established using the Li-Fi transmitter and the receiver or initiates a new route discovery process if the communication link has not been established and the captured data size attained the required amount. The messages format tables which are the request (RREQ), reply (RREP) and route error (RRER) are presented in Tables 1. These tables are the extension of the standard AODV

Table 1. Message Format FSRP

RREQ	RREP	RRER
RREQ ID	RREP sender ID	d_{min} not satisfied
Sender's position	Transmission Connection Estimation (T_{ce})	Unreachable Destination IP Address
Sender's velocity	Destination Position	Speed Reduction
Destination IP Address	Destination Velocity	
Originator IP Address	Hop Count	
Hop Count	Originator IP Address	
Captured Data size (bytes)		

4.2. Data Exchange Algorithm

The sequential steps in the algorithm are presented as follows

4.2.1. Network Peer to Peer Discovery Stage (NPD)

The UAVs are assumed to be provided with network connectivity as client and server using the light bulbs fixed on the ceiling (Li-Fi access points) as an optical communication link [19,20]. The location of the UAVs and velocities are determined using a GPS and an on-board velocity estimator respectively. Provided the position and velocities of the UAVs are known, each of the UAV starts it network peer-to-peer discovery by listening to RREQ messages. Each RREQ message is augmented with an IP address, sender's velocity, sender's position and captured date size.

Process 1: Network peer-to-peer discovery stage

a. A node (UAV) conducts a broadcast ping and discovers known addresses of nodes on the network. If the UAV A wants to send messages to other UAVs on the network, UAV A will then act as a server. UAV A will conduct a broadcast ping to discover UAV B and UAV C. UAV A will store neighbor information in it table.
b. A HELLO RREQ message is sent by the UAV acting as the Server.
c. For each of the HELLO RREQ message received, record the destination IP, position and velocity.
d. The server node determines who are immediate peers based on range. The range is specified by the network administrator at initial network configuration stage in order to determine immediate neighbor.
e. Connect immediate as peers by transmitting discovery message with all neighbor UAV information.

4.2.2. Optical Link Setup for Communication Stage

The Li-Fi setup for communication stage continues from the network discovery stage. When broadcast ping messages are sent, the position and velocity are recorded at regular intervals. Changes in the position and velocity are sent alongside the discovery packet in order to set up the Li-Fi access points. The Li-Fi transmitter and receiver waits for the Li-Fi update packets.

Process 2: LiFi setup for communication

a. Each time a HELLO message is being sent, calculate the location using the GPS and the velocity using the onboard velocity estimator sensor.
b. Record the information in (1) in the table and check the captured data packet size values.
c. Calculate the transmission time (T_t) using equation (6) and the node position using equation (2)
d. Send this information along with the DISCOVER packet
e. Wait for LI-FI_UPDATE packet
f. According to the information sent with the LI-FI_UPDATE packet, set the signal strength and set up the Li-Fi network.
g. If Equation (9) is satisfied, display successful data exchange message.

If the total number of UAVs deployed on the network is N, then the total number of possible Links (L) if all the nodes are said to be transmitting and receiving to and from all other UAVs at the same time is $L=N^2 \times 2$.

4.2.3. UAV-to-UAV and UAV-ground Terminal Communication Stage

In order for the UAVs to share information and data with each other and the ground terminal using the Li-Fi transmitter and the receiver, a new route discovery process is initiated if the communication link has not been established or the captured data size attained the required amount. Once the message is read from the queued data of stored information received, the FANET process checks the nature of message received. If the message is a new data to be sent, the process new_information is initiated. If the message is an update message, the RREQ, RREP and RRER are initiated and the routing tables are updated.

Process 3: UAV-to- UAV and UAV-ground terminal communication

a. Conventional Routine Process

```
FANET (ip addresses, velocity, position, data size, rt) // rt denotes the routing table were entries are stored
Information Received (msg) (
Message=new_information (data, destination_ip) // new data to be exchanged (
RREQ (rt, destination_ip, velocity, position, data size, hops)
Request_reply=rrep (destination_ip, velocity, position, data size, hops) // the routing table is updated with this information
)
RREP (rt, destination_ip, data size, hops, velocity, position) (
Reply message=rrer (destination_ip, range, velocity, position) // the routing table is updated with this information
)
RRER (destination_ip, velocity, position)
```

b. RREQ routine process

```
RREQ (rt, destination_ip, range, velocity, position) (
Request_reply=rrep (range, velocity, position) // store the requested information of the range, position and velocity in the routing table
if $D(x,y) \geq d_{\min}$ // establish session for data exchange after required interval of time then, (
Message_exchange=new_information (sip, data exchange, destination_ip) // sip standards for session initiation protocol which is used to manage and terminate sessions in an IP based network.
if $D(x,y) = d_{\min}$ // a warning message should be issued which is displayed as a text message then,
Message_exchange=new_information (sip, data exchange, destination_ip)
```

```
        if $D(x,y) < d_{\min}$
        Request_reply=rrer (reduced acceleration) // the speed of the UAV is reduced
        )
    c.  RREP routine process
        RREP (source_ip, range, velocity, position)
        routing_table=update (range, velocity, position)
    d.  RRER routine process
        RRER (range, velocity, position)
```

5. Simulation Setup and Results

To evaluate the performance of the routing protocol, first the validation of the specification was achieved using a Finite State Machine (FSM) tool which is the UPPAAL software. Simulation was carried out in ubuntu 16.04LTS environment. The importance of using the finite state machine software is to model the behavior of the routing protocol with a view to preventing the protocol specification from deadlock before simulation and implememtation. The simulation parameters are presented in Table 2

Table 2. Simulation Parameters

Simulation Parameter	Values
Number of UAVs	3
Simulation flight area	100x100 m^2
Total Simulation Time	360secs
Speed of UAVs	20m/s
Size of Data Capture to establish connection	5MB
Time in idle position	60secs
Transport Protocol	UDP

5.1 Specification Validation using Finite State Machine

Using the FSM or also known as the finite automata, individual systems can be modelled as:

N=(Q, ε, q_o, f, ϐ)

Where: Q=set of all finite state that N can be in,

ε=set of finite events that can occur in N

q_o=start state or initial state

f=set of final states

ϐ=is the transition function that maps (f: Q X ε ⟶ Q)

From the protocol specification, the individual system can be modelled as:

Q={Idle, Source, Destination} // the idle state is simple a state where the UAV is in rest condition without any transaction but still connected to the network.

ε={Network discovery, Li-Fi setup, UAV-to-UAV communication}

q_o={Idle}

Figure 4 presents the finite State Machine Model for the FSRP.

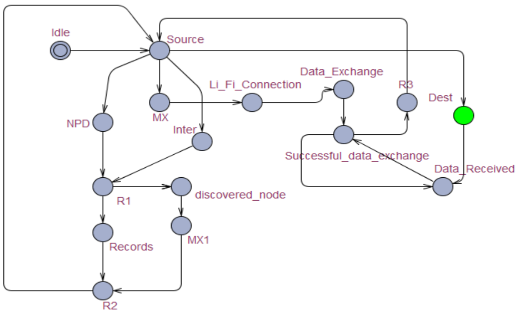

Figure 4. Finite state machine model for the FSRP

The source node will act as the server when the captured data attain a certain amount. In order to establish connection (T_{cp}), the server initiates a network peer-to-peer discovery process by sending HELLO RREQ message and wait to record the destination IP, position and velocity during the time duration of the RREP. The RREP can be from the intermediate node or the destination node. The reply response is stored in the memory. The memory (MX) can be of two types which are: (i) Cache, for routing table (ii) Main memory for storing the captured data content to be exchanged.

Once the client, which is the destination node or intermediate node receives the RREQ message and respond by sending the RREP message. The information received and stored in the memory triggers the Li-Fi communication stage for information exchange. Success or failure of the data exchanged is relayed back to the node acting as server. The individual set of all finite state that the nodes can be in is presented in Figure 5

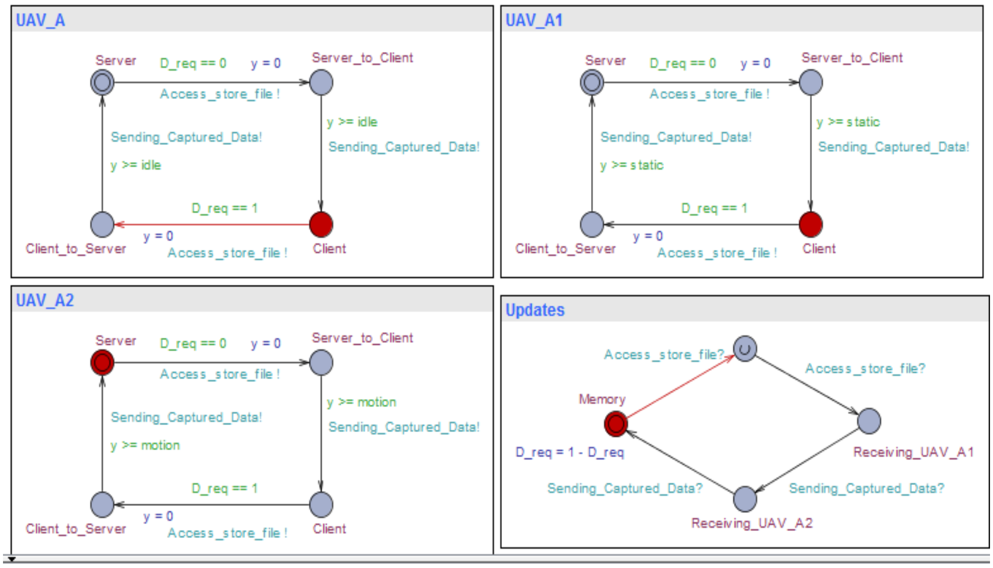

Figure 5. Individual set of all possible finite states of the nodes

In order to model the FANET Specific routing protocol as timed automata, the set of all finite state that each UAV can be in are: the idle state, the static state and the motion state. The idle state is simply a state where the UAV is in rest condition without any transaction but still connected to the network. So, before a UAV can move from an idle state to the static state, the UAV must have captured some amount of data. At the static state, the UAV has data to be transmitted to other UAVs on the network but is not in motion. Therefore, to change from the idle state to another state, the operation has to be timed. Figure 6 shows the FSRP operation in timed automata.

The major concern of the FSRP operation in timed automata depicted in Figure 7 is whether the client is ever able to establish a route to server, so that it can deliver its packet. Whereby, the time to establish communication between the client and the server is determined by the amount of captured data. The state begins with the three UAVs deployed on the network at the same time. The UAVs check their memories for the stored data (Access_store_file). Once this has occurred, the UAV acting as the server begins the route discovery process. All information received are placed in the memory as updates. Looking at the sequence chart of the FSRP operation in timed automata, when the UAV attain the required data limit to establish connection and a route has been established, the server sends the captured data to the client (Sending_Captured_Data). The client can also send data to the server, making it a full duplex transmission. The parameters presented in Table 2 are used to simulate the routing protocol in Network Simulator (NS3). Figures 7 depict the exchange of information as the nodes move within the area.

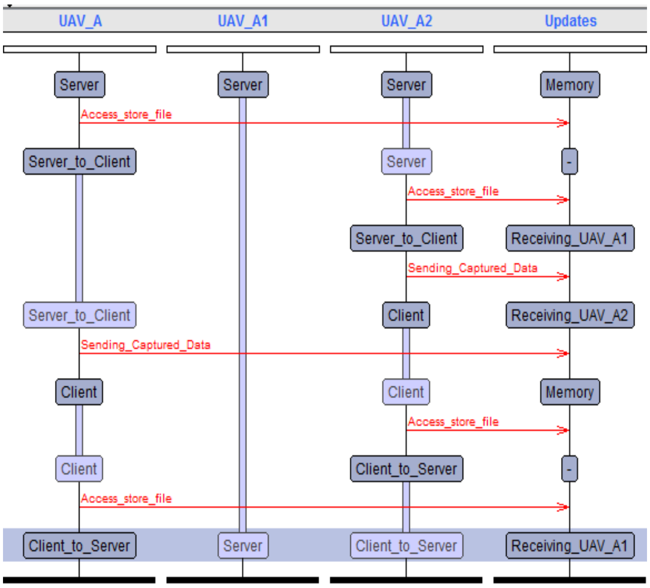

Figure 6. FSRP operation in timed automata

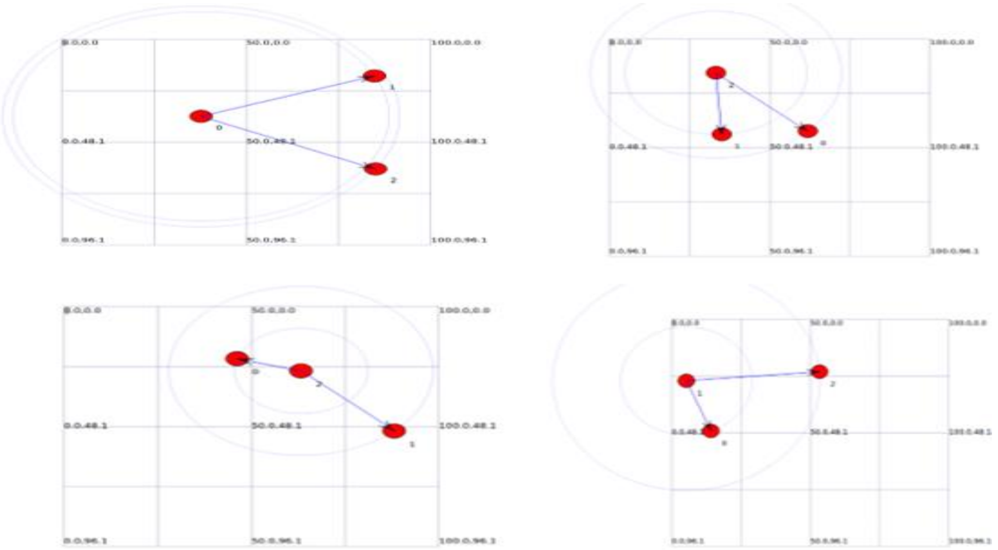

Figure 7. Movement of nodes from one position to another whilst exchanging information

The output result generated in simulating the developed routing protocol in NS3 using the command terminal prompt is depicted in Figure 8 were the plot of the throughput against the time is presented.

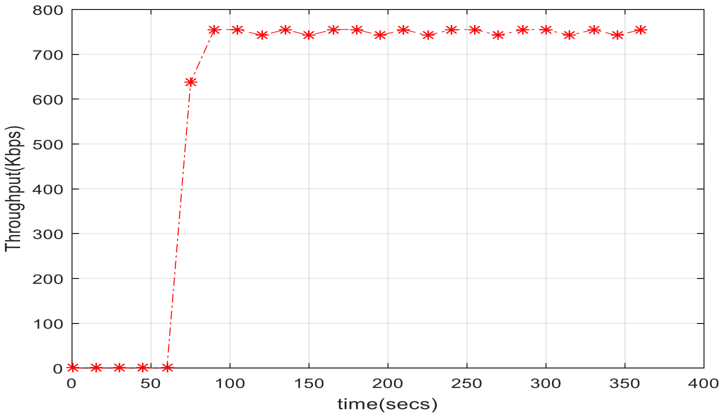

Figure 8. Plot of throughput against time

From the generated statistics in Figure 8, it can be observed that the throughput value is 0kbps until after a certain time of 60secs. This is because in the simulation, 60secs was set as a time required for a UAV to leave the idle mode. It is assumed that after time 6osecs, the UAV must have captured enough data to be exchanged. The throughput value obtained for the FSRP was 637.915kbps initially and then fluctuated between 742.064kbps and 755.083kbps as data are exchanged between nodes. These throughput values were obtained using Equation (9)

Throughput=(Number of data packets Received * Packet size * 8) /Simulation Time (9)

This showed that when all the UAVs are on the network and communicating with one another, the throughput is flatline and not plummet. During the simulation time, a total of 1190 packet was sent and 1144 packet was received, which amounts to 96.13% packet delivery ratio. This implied that data are successfully transmitted between the UAV acting as server and UAV acting as client on the network. The Simulation made use of the User Datagram Protocol (UDP). which is a connectionless oriented protocol that does not guarantee delivery. It alternative is the TCP that guarantees delivery and is a connection oriented protocol. However, TCP consumes memory space, bandwidth due to frequent retransmission of packets.

In comparison with the standard AODV which is the benchmark for FANET protocol obtainable by default in the NS3 simulator [11-12] the packet delivery ration was 40%. This showed that the FSRP is better applied to FANET than the standard AODV. The bar chart for the comparison of the exsisting routing protocol when applied to FANET in terms of throughput and packet delivery ratio is presented in Figure 9.

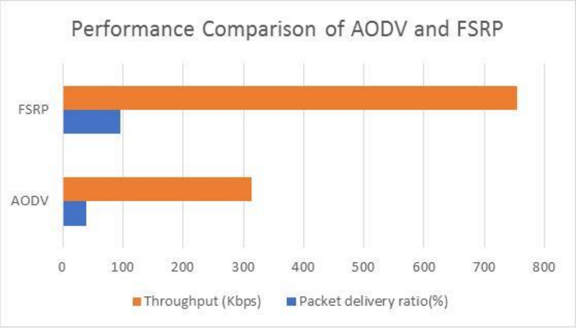

Figure 9. Performance comparison of AODV and FSRP

5. Conclusions

In conclusion, this paper addressed the inherent characteristic in FANET by developing a FANET specific routing protocol due to the fact that MANET routing protocols are unsuitable. The paper has successfully developed a FSRP obtaining a throughput value that fluctuated between 742.064kbps and 755.083kbps as data are exchanged between nodes and a packet delivery ratio of 96.13% as compared to the standard AODV of 40%. The developed FANET specific routing protocol laid emphasis on the route connectivity in the network, by considering the captured data size, minimum allowable distance between randomly moving nodes and connection time to tackle the FANET inherent characteristics. Therefore, the FANET specific routing protocol can be termed as a data and timed control protocol. The further work will focus on developing a Link Velocity Connectivity Algorithm (LVCA) that will be used with the routing protocol as an intervehicle communication system using the Li-Fi as a communication Link.

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