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Interface protocol design: a communication guide for indoor FANET

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Abstract

The present and the future routing protocols in relation to the high throughput requirement, adaptivity to fast-changing link topology and speed makes the choice of routing protocol for unmanned aerial vehicle communication important. Due to this fact, an efficient routing protocol is highly dependent on the nature of the communication link. A flexible solution that presents these features is the use of light fidelity as a communication medium. Therefore, this paper presents the design of an interface protocol for indoor Flying Ad-hoc Network specific routing protocol using light fidelity as a communication link. The interface protocol governs communication when UAV move in a swarm. The architecture, the state machine model is discussed in this paper. Results of the design are validated via simulation using the NS3 in terms of packet delivery ratio and throughput.

Keywords: *FANET, indoor sports coverage, Li-Fi, link velocity connectivity algorithm, UAV swarm*

1. Introduction

The term FANET is valid for a multi-UAV system that forms an ad hoc network with each other [1]. It differs from other types of ad hoc networks due to its inherent characteristics such as the dynamic nature of nodes, topology change, and speed [2-4]. Some of the applications of FANET in recent times are, but not limited to indoor sports coverage and media reporting. These applications are only achievable using an efficient routing protocol. The efficiency of the routing protocol is based on the type of communication medium used [5-9]. The most prominent routing protocol used in the past for FANET is the standard Ad hoc On-Demand Distance Vector (AODV). But, as the use of FANET increases, modification to the standard AODV was presented by various researchers with a view to achieving seamless communication for information dissemination. An example of such a protocol is the FANET Specific Routing Protocol (FSRP) [6]. FSRP is a modification of the standard AODV routing protocol for Flying Ad-hoc Network (FANET) applications only. The nodes in FANET are UAVs and best suited with the FSRP as presented by the authors in [6], while the standard AODV are designed to be used with the Mobile Ad hoc Network (MANET). The nature of the topology of nodes in FANET, bandwidth requirement, fast-changing nature of the link amongst others which are inherent characteristics of FANET accounted for the failure of the AODV when applied to FANET. As such, for FANET communication to be effective, the authors in [6] designed a routing protocol that will address these FANET inherent characteristics with a view to having seamless and efficient communication between nodes. Similar to the standard AODV [7, 10], FSRP also has four types of control packets which are the RREQ, RREP, RRER and HELLO. These control packets are modified in the FSRP to address the requirement for FANET.

Other authors such as [8, 10] have also presented works that developed a FANET routing protocol in order to address the shortcomings of the AODV when applied to FANET. Nonetheless, the peculiarity of the work of [6] as compared to others is that the developed protocol is FANET specific and was designed to use light fidelity (Li-Fi) as the medium of communication. This was because of the qualities the Li-Fi as a communication medium possesses such as directionality that reduces the routing overhead, high bandwidth requirement, security amongst others [11-16] which makes up the characteristics of an efficient

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FANET. This is not to say that the protocol cannot function with another communication medium [17-22].

FANET in an indoor environment for sport and media coverage requires efficient coordination and collaboration due to its specific usage. For indoor sport and media coverage, communication between UAV nodes is expected to be governed for effective information dissemination. The actual scenario of FANET in an indoor environment for media and sports coverage is that one of the nodes only have the permission for information acquisition and all other nodes connect to each other to share the captured information. In view of this, information dissemination, as well as movement, should be coordinated. Since the FANET specific routing protocol uses the Li-Fi as a communication medium and Li-Fi is another form of sophisticated infrared, it can also be employed for UAV coordination and collaboration of nodes. However, in order to achieve this, there is a need for an interface protocol design termed Link Velocity Connectivity Algorithm (LVCA). It is also important to note that the LVCA design in this paper is not designed for FANET applications only. It can be applied to Vehicular Ad-hoc Network (VANET) and Under Water Sensor Networks (UWSN).

Therefore, the main objective of this paper is to design an interface protocol that will govern communication in indoor FANET (when UAV move in a swarm) using light fidelity as a communication medium. In order to achieve this objective, insight into the working principles of the FSRP is required as presented in [6] and [18]. As such, the state transition model and the architecture of the FSRP that will be used to design the interface protocol are depicted in Figures 1 and 2.

The state transition model is a better way to understand a protocol at a low level of abstraction. This is presented in other to aid the future implementation of the design on a Field Programmable Gate Array (FPGA). The remaining aspect of the paper is organized as follows: section 2 presents the description of the existing FSRP. The description of the interface protocol for the FANET and light fidelity as a communication medium is presented in section 3. Section 4 presents the LVCA Algorithm. Section 5 presents a discussion of the result obtained. The conclusion drawn from the results is presented in section 6.

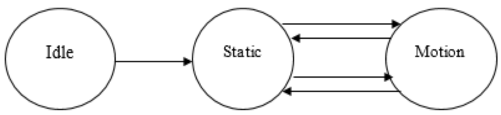


Figure 1. State transition model of the FSRP

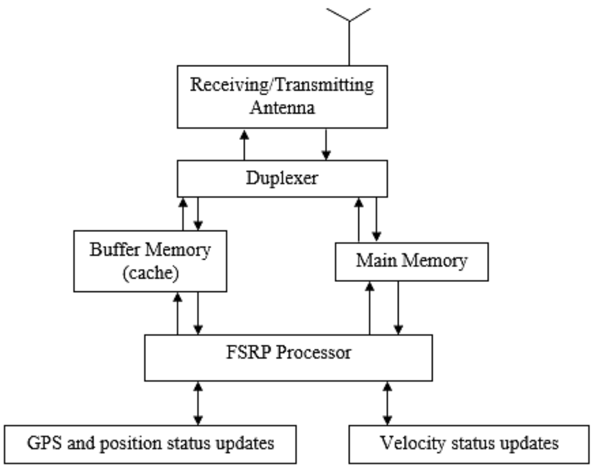


Figure 2. Architecture of the FSRP

2. FSRP Description

In FSRP, the nodes are categorized as the client or the server that acts as either the source node, intermediate node or the destination node. The HELLO control packet is usually flooded on the network when the server needs to send a captured packet to a destination [23-25]. The RREQ in the FSRP is modified with the sender's position, velocity and captured data size. For each of the "HELLO RREQ" message received, the destination IP, position and velocity are recorded in the routing table. Based on this information, the server determines the intermediate peers. It communicates an RREP message by connecting the immediate peers using the received neighbor UAV information. This prevents link breakage and route. However, an RRER message will be triggered if the destination IP addresses are unreachable.

The FSRP is a data and timed controlled routing protocol that depends on the size of the captured data and the velocity of the nodes to establish a connection for information sharing. It uses two types of memory which are the cache for the routing updates and the main memory for storing the captured data content to be exchanged. The protocol design introduced a minimum separation distance d_{min} which is the initial separation distance between nodes and should be maintained throughout the operation time of the UAV. This is one of the most important parameters that constitute the formulation of the interface protocol. The Li-Fi transceiver circuitry is the communication medium for all processes to occur. The simulation parameters used to simulate the FSRP is presented in Table 1. These parameters will be used in simulating the FSRP with the developed LVCA algorithm with a view to benchmarking its improvements against the conventional FSRP.

Table 1. FSRP 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 a connection	5MB
Time in an idle position	60secs
Transport protocol	UDP

3. Interface Protocol Design: The LVCA

The LVCA develop in this paper governs the communication between the FSRP protocol and the transceiver circuit as well as reducing the impact of link failure due to the crash of randomly moving nodes to the barest minimum. Thereby, functioning as an intervehicle communication system as depicted in Figure 3. Figure 3 shows the block diagram of the LVCA. Due to this fact, the LVCA is functioning as an intervehicle communication system, the LVCA makes use of an acceleration and deceleration model associated with a speed changing cycles which are:

- Start: UAVs begins a movement
- Stop: UAVs in a static position
- Slow down: UAVs in motion decrease speed
- Speed up: UAVs in motion increase speed
- Change direction: rotate clockwise or anticlockwise

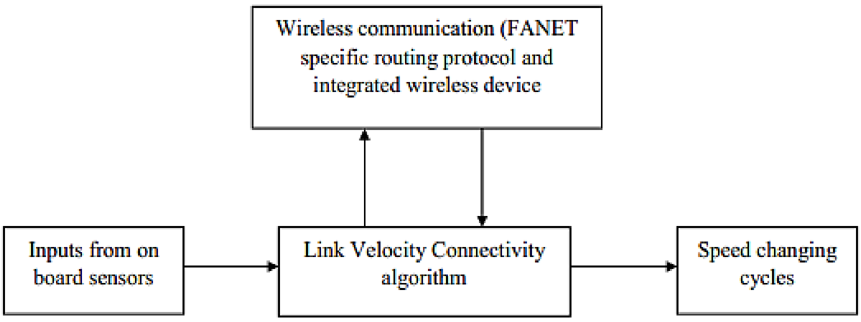


Figure 3. LVCA block diagram

In order to achieve this, the initial speeds and final speeds during acceleration and deceleration are the key information required by the LVCA. This is expected to be supplied by the onboard velocity sensors. In the LVCA, the effect of movement of the nodes is dependent on the distance between the neighbor node (nj) and node (ni). To realize this, a distance sensitivity function (dsf) is introduced. The distance sensitivity function (β) controls the velocity change by navigating between the speed changing cycles (stopping, increasing or reducing speeds). Therefore, β is the product of a trigger function denoted as α and change in time as presented in the following expression:

$$\beta = \alpha * \Delta t \tag{1}$$

where β is the distance sensitivity function and α is the trigger function.

This speed changing cycle is only achievable if and only if $\beta < 1$. The characteristics of the LVCA are as depicted in Figure 4. The expressions required to calculate the distance and velocity between the nodes are presented in [6, 10]. Therefore, the decay velocity can be generated using:

$$V_n^1 = V_n(1 - \beta) \tag{2}$$

where: V_n^1 is the decayed velocity; this is satisfied if $\beta < 1$
V_n is the actual velocity in which the UAVs are moving
β is the distance sensitivity function.

However, in this paper, the distance sensitivity function was set to 0.5 so that the decay velocity will be 10m/s and the actual velocity of 20m/s. The initial separation distance (d_{min}) as presented in [1] can be satisfied at the initial deployment of the nodes on the network. The smaller the distance sensitivity function, the longer it will take to attain a velocity close to zero. Hence, for the concept to be developed completely, it is necessary that the assumption of the information about the confined area in which the UAVs are in operation are already obtained using the GPS, onboard velocity and displacement estimators. Therefore, the position of two UAVs in the confined area are (x_1,y_1) and (x_2,y_2), moving at speeds V_1 and V_2 in θ_1 and θ_2 directions.

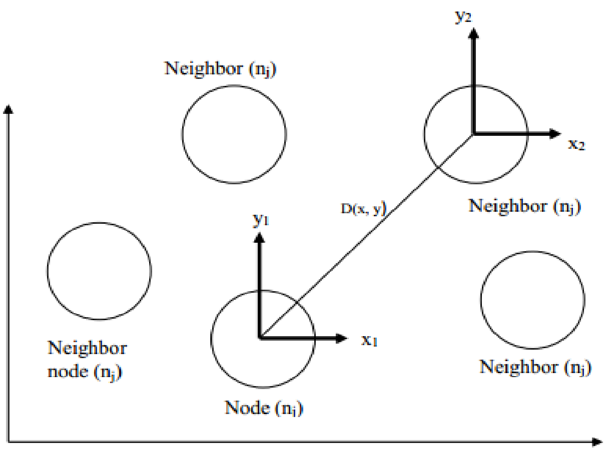


Figure 4. LVCA characteristics

3.1. LVCA Operation Sequence

The sequence of the LVCA is presented as follows:

a. Inputs: distance, speed, and position // this is the required input that is fed into the LVCA. The updates of the speed and position are expected to be received by the onboard sensors and the distance between the UAVs are estimated as presented in (3):

$$D(x,y) = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \tag{3}$$

where D(x,y) is the distance between two nodes and x,y,z are the coordinates.

b. Computed Distance: The distance being computed is used for three special cases, which are:
- UAV stops.
- UAV motion: (a) increase in speed and (b) the decrease in speed.
- Direction change.

The increase and decrease in speed are used to ensure that the distance between the nodes is greater than d_{min} as presented in the logic diagram in Figure 5.

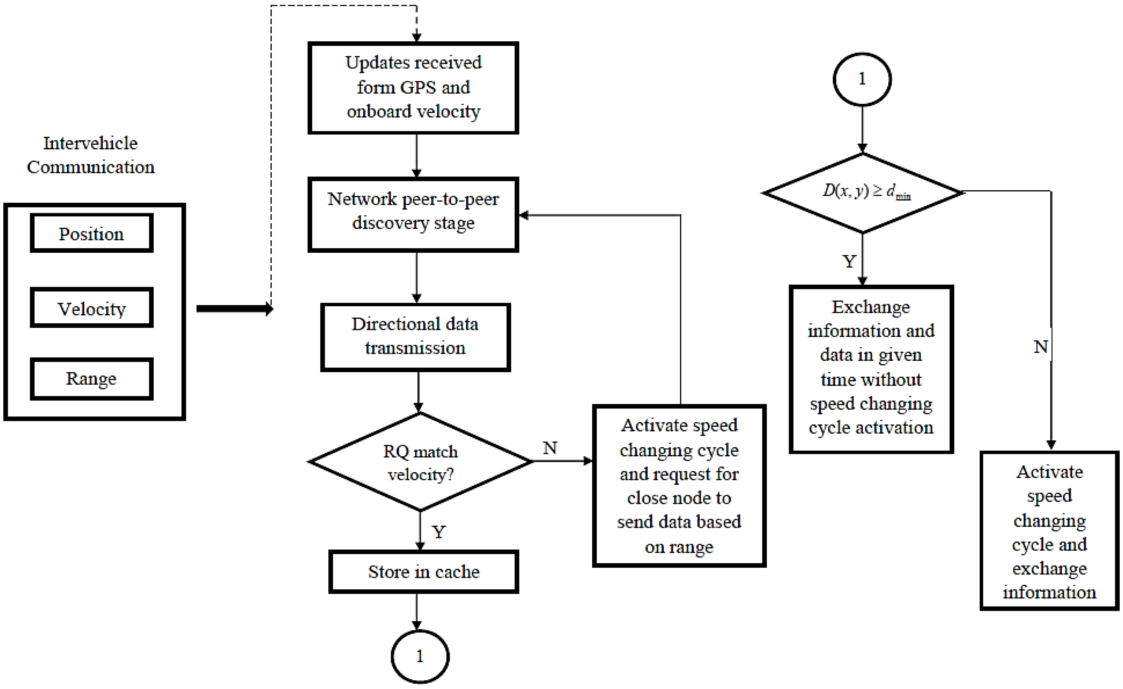


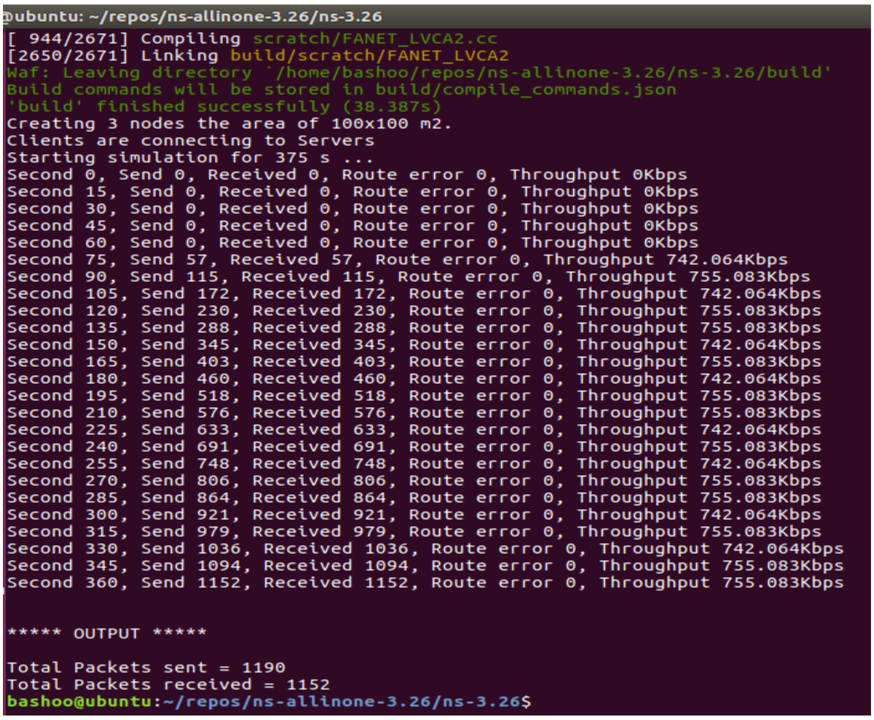
Figure 5. Logic diagram of the LVCA

3.2. LVCA Algorithm

a. If captured data matches movement velocity, store all estimated values obtained using the onboard sensors in the cache. Else, activate speed changing cycle and reduce current velocity to the decayed velocity computed using (2).
b. If $D(x, y) = d_{\min}$ a warning message should be issued which is displayed as a message, thus computing the decayed velocity using (2). The UAV should reduce speed or turn by π/2 if approaching at an angle of 90^0 whilst exchanging information. This is because the LVCA is considering only perpendicular intersections.
c. If $D(x, y) < d_{\min}$ between two or more UAVs, compute the decayed velocity using (2). The UAV should reduce speed whilst information is exchanged.
d. If $D(x, y) \geq d_{\min}$ exchange information without activating the speed changing cycle.
e. Goto (1) to repeat the cycle.
f. The LVCA was simulated with the FSRP routing protocol in the NS3 as an additional script written for the routing protocol.

4. Result and Discussions

The simulation parameters used are presented in Table 1. During the simulation time, a total of 1190 packets were sent and 1152 packets were received, which amounts to 96.81% packet delivery ratio as depicted in Figure 6. In the simulation of the FSRP alone, the total packets sent over time were 1190 packets and 1144 packets were received. This amounted to 96.13% packet delivery ratio as depicted in Figure 7.

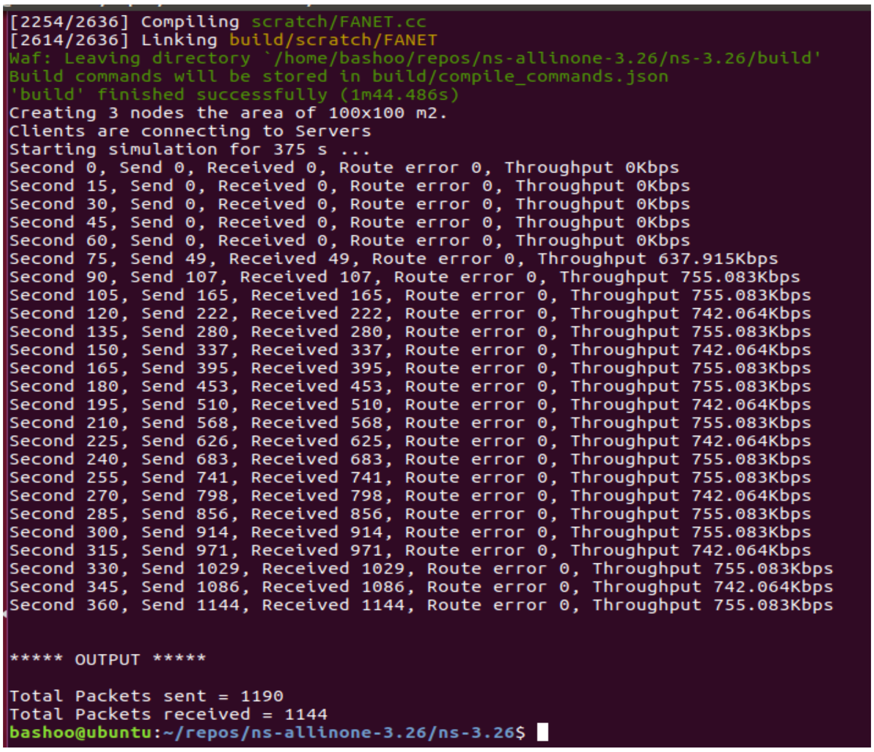


```
@ubuntu: ~/repos/ns-allinone-3.26/ns-3.26
[ 944/2671] Compiling scratch/FANET_LVCA2.cc
[2650/2671] Linking build/scratch/FANET_LVCA2
Waf: Leaving directory `/home/bashoo/repos/ns-allinone-3.26/ns-3.26/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (38.387s)
Creating 3 nodes the area of 100x100 m2.
Clients are connecting to Servers
Starting simulation for 375 s ...
Second 0, Send 0, Received 0, Route error 0, Throughput 0Kbps
Second 15, Send 0, Received 0, Route error 0, Throughput 0Kbps
Second 30, Send 0, Received 0, Route error 0, Throughput 0Kbps
Second 45, Send 0, Received 0, Route error 0, Throughput 0Kbps
Second 60, Send 0, Received 0, Route error 0, Throughput 0Kbps
Second 75, Send 57, Received 57, Route error 0, Throughput 742.064Kbps
Second 90, Send 115, Received 115, Route error 0, Throughput 755.083Kbps
Second 105, Send 172, Received 172, Route error 0, Throughput 742.064Kbps
Second 120, Send 230, Received 230, Route error 0, Throughput 755.083Kbps
Second 135, Send 288, Received 288, Route error 0, Throughput 755.083Kbps
Second 150, Send 345, Received 345, Route error 0, Throughput 742.064Kbps
Second 165, Send 403, Received 403, Route error 0, Throughput 755.083Kbps
Second 180, Send 460, Received 460, Route error 0, Throughput 742.064Kbps
Second 195, Send 518, Received 518, Route error 0, Throughput 755.083Kbps
Second 210, Send 576, Received 576, Route error 0, Throughput 755.083Kbps
Second 225, Send 633, Received 633, Route error 0, Throughput 742.064Kbps
Second 240, Send 691, Received 691, Route error 0, Throughput 755.083Kbps
Second 255, Send 748, Received 748, Route error 0, Throughput 742.064Kbps
Second 270, Send 806, Received 806, Route error 0, Throughput 755.083Kbps
Second 285, Send 864, Received 864, Route error 0, Throughput 755.083Kbps
Second 300, Send 921, Received 921, Route error 0, Throughput 742.064Kbps
Second 315, Send 979, Received 979, Route error 0, Throughput 755.083Kbps
Second 330, Send 1036, Received 1036, Route error 0, Throughput 742.064Kbps
Second 345, Send 1094, Received 1094, Route error 0, Throughput 755.083Kbps
Second 360, Send 1152, Received 1152, Route error 0, Throughput 755.083Kbps

***** OUTPUT *****

Total Packets sent = 1190
Total Packets received = 1152
bashoo@ubuntu:~/repos/ns-allinone-3.26/ns-3.26$
```

Figure 6. Output result of simulating the FSRP with the developed LVCA



```
[2254/2636] Compiling scratch/FANET.cc
[2614/2636] Linking build/scratch/FANET
Waf: Leaving directory `/home/bashoo/repos/ns-allinone-3.26/ns-3.26/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (1m44.486s)
Creating 3 nodes the area of 100x100 m2.
Clients are connecting to Servers
Starting simulation for 375 s ...
Second 0, Send 0, Received 0, Route error 0, Throughput 0Kbps
Second 15, Send 0, Received 0, Route error 0, Throughput 0Kbps
Second 30, Send 0, Received 0, Route error 0, Throughput 0Kbps
Second 45, Send 0, Received 0, Route error 0, Throughput 0Kbps
Second 60, Send 0, Received 0, Route error 0, Throughput 0Kbps
Second 75, Send 49, Received 49, Route error 0, Throughput 637.915Kbps
Second 90, Send 107, Received 107, Route error 0, Throughput 755.083Kbps
Second 105, Send 165, Received 165, Route error 0, Throughput 755.083Kbps
Second 120, Send 222, Received 222, Route error 0, Throughput 742.064Kbps
Second 135, Send 280, Received 280, Route error 0, Throughput 755.083Kbps
Second 150, Send 337, Received 337, Route error 0, Throughput 742.064Kbps
Second 165, Send 395, Received 395, Route error 0, Throughput 755.083Kbps
Second 180, Send 453, Received 453, Route error 0, Throughput 755.083Kbps
Second 195, Send 510, Received 510, Route error 0, Throughput 742.064Kbps
Second 210, Send 568, Received 568, Route error 0, Throughput 755.083Kbps
Second 225, Send 626, Received 625, Route error 0, Throughput 742.064Kbps
Second 240, Send 683, Received 683, Route error 0, Throughput 755.083Kbps
Second 255, Send 741, Received 741, Route error 0, Throughput 755.083Kbps
Second 270, Send 798, Received 798, Route error 0, Throughput 742.064Kbps
Second 285, Send 856, Received 856, Route error 0, Throughput 755.083Kbps
Second 300, Send 914, Received 914, Route error 0, Throughput 755.083Kbps
Second 315, Send 971, Received 971, Route error 0, Throughput 742.064Kbps
Second 330, Send 1029, Received 1029, Route error 0, Throughput 755.083Kbps
Second 345, Send 1086, Received 1086, Route error 0, Throughput 742.064Kbps
Second 360, Send 1144, Received 1144, Route error 0, Throughput 755.083Kbps

***** OUTPUT *****

Total Packets sent = 1190
Total Packets received = 1144
bashoo@ubuntu:~/repos/ns-allinone-3.26/ns-3.26$
```

Figure 7. Output result of simulating the FSRP without the developed LVCA

Comparing the results of the FSRP alone and that of FSRP with the LVCA, a percentage improvement of 0.65% was recorded. Figure 8 depicts the comparison of the results obtained. The obtained throughput values of the LVCA with the routing protocol are found to fluctuate between 742 kbps and 755 kbps as information is being exchanged on the network as presented in Figure 9. This is the same as that obtained while using the FSRP alone. The coordination and collaboration between nodes are noticed in the generated positions by the network simulator.

The significance of the plot of the throughput against time is that it shows how packets behave on the network. It can be seen that as nodes join or leave the network, the variation in throughput is flatlined. This means that the data exchange will be successful amongst communicating UAVs.

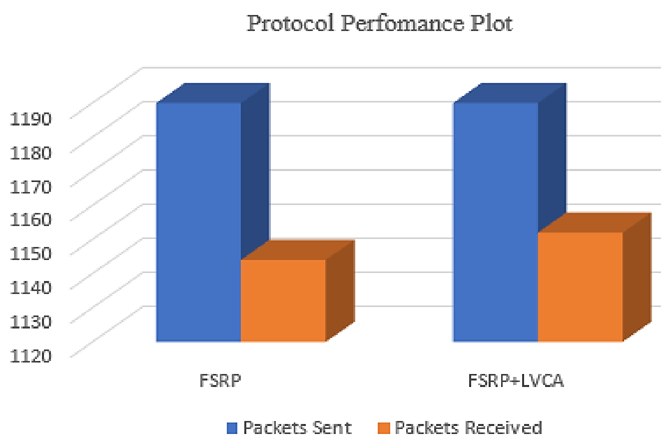


Figure 8. Performance of FSRP and FSRP+LVCA

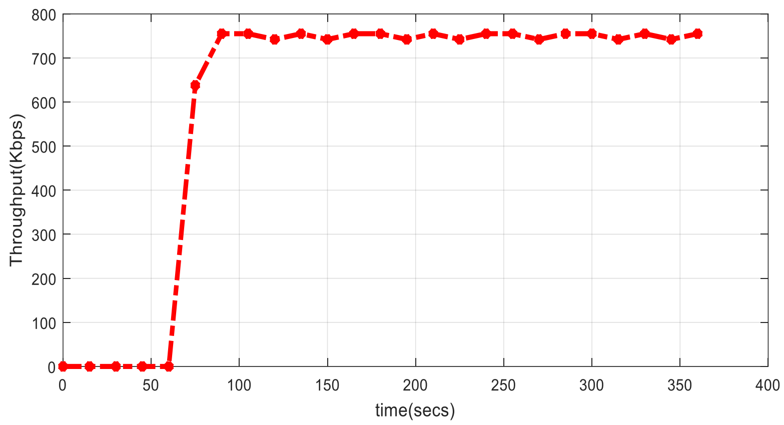


Figure 9. Plot of throughput against time

4. Conclusion

The aim of this paper which was to develop an interface protocol referred to the link velocity connectivity algorithm (LVCA) for Li-Fi based indoor FANETs has been largely met. The interface protocol ensured coordinated movement and information sharing between nodes and recorded an improvement of 0.65% as compared to when using the FSRP alone. As such, further works will consider implementing the FSRP with the LVCA on an FPGA for real-life applications.

Acknowledgment

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