Multi Token Based Location Sharing for Multi UAV Systems

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Abstract: Today, Unmanned Aerial Vehicles (UAVs) are widely used in many different areas of military and civilian applications. Developments in the UAV technology and cheapening of the cost provide opportunity to widespread use of multiple UAVs. Communication is the most important problem in the multi-UAV systems. Flying Ad hoc Network (FANET), is the most significant development method for the solution of communication problem in multi-UAV systems. It is necessary to ensure the realization of coordinated flight of UAVs in FANET. UAVs need to know the position information of each other to also ensure coordination between themselves. Token packet usage is one of the solution to sharing of coordinated information. In this method, the exchange of information between UAVs is performed by circulating a token packet in FANET. The number of UAVs increases, the size of the token containing the location information of all UAVs will also increase. Because of this increase, token will complete its circulation in FANET in a long time. For this reason, after a certain number of UAV, one token will not be sufficient. In multi-UAV systems, UAVs can learn the details of each position with multiple token circulation. In existing studies, it was assumed that UAVs move with constant topology. In addition to this, in these studies there has been assumed that 100% of the packets transmitted. In this study, multiple token structure has been implemented for UAVs acting with a dynamic topology. Also different bit error rate (BER) values are discussed in the case of the package could not be sent. In these cases, the resend packet is provided and these cases effect on the results is observed. Thus, the use of multiple tokens structure in the multi-UAV systems is obtained with more accurate results.

Key words: Multi token circulation, flying Ad Hoc network (FANET), location information sharing, bit error rate (BER).

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1. Introduction

UAVs are widely used in many different areas of military and civilian applications day by day [1], [2]. For instance, search and rescue [3], monitoring [1], discovery [3], management of forest fires [2], surveillance and monitoring of borders [4] are diverse application areas of UAVs. The most noticeable benefits of UAVs are eliminating the risk factors of human life, having low cost, and easy deployment features [1], [2]. The use of multiple UAVs is spreading with the developments in UAVs technology, and cheapening its cost. There are many advantages of multi-UAV systems [5]. Cost, flexibility, continuity, speed are the major benefits of these systems [5]. Meanwhile, protocols that enable communication between the UAVs are becoming more complicated with the use of multiple UAVs. This case turns into one of the major problems encountered. For this reason communication is one of the challenges to be solved in multiple UAV systems [6].

The most basic method used to provide the communication among UAVs is the infrastructure based approach. However, infrastructure based approach has several drawbacks such as constraints of coverage area, environmental obstacles in signal transduction. Because of these drawbacks, there is a need to an alternative communication method instead of infrastructure based approach. FANET structure shown in Fig. 1 provide an alternative solution for multi UAV communication [5].

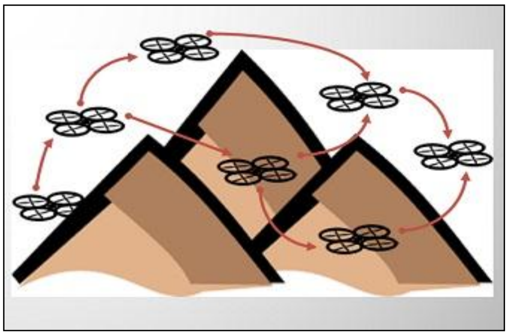


Fig. 1. Flying ad hoc network (FANET).

In FANET structure, UAVs need to learn the location information of each other, in order to perform seamlessly flight. Token based models is used for the circulation of certain data in multi-UAV systems [7], [8]. However, information located in the package is priority information that is used for the access to the transmission line. This information is significantly smaller than the location information and the circulation of this information is provided by a single coin.

In FANET, the UAVs' location information is desired to circulate among a large number of UAVs. As the packet size is increased, a single coin is not sufficient to circulate between the UAVs. By circulating the multiple coin packages among UAVs that include the location information of UAVs, provide to obtain coordinate information of each UAV [1], [3].

Instead of using real data some assumptions are performed in the developed systems using multiple tokens model [1], [3]. UAVs are circulated by fixed topology is one of these assumptions. Propagation delay time of tokens in token transmission time is considered to be zero. Another assumption is the delivery of information package of tokens is accepted 100%. In our study, by adding the propagation delay time to token transmission time, more realistic results are obtained. Furthermore, instead of a fixed topology, a dynamic topology is used for UAVs flight in the developed model. For this reason, the neighborhood is changed dynamically in the proposed model. Finally, in the developed model we also consider the situations when the tokens are not transmitted due to several errors. In these cases, how to send the tokens again is discussed and multiple token based model is developed to obtain more realistic results.

In the second part, multiple token structure in the UAVs is explained. In this structure, transmission time, dynamic topology, and bit error rate concepts are integrated to the model. Obtained performance values are presented in the third section. In the fourth and the last part, the results and evaluations are stated.

2. Multi Token Structure

Multiple UAVs which are located in the FANET structure, need the location information of each other to achieve a smooth and coordinated flight. In this section, sharing location information between the UAVs in FANET is obtained by multiple token structure.

UAVs are the vehicles with a high degree of mobility. Therefore, a rapid location changes occur in FANET. Token based approach is one of the methods used for UAVs to learn the location information of each other [7], [8]. As the number of UAVs is increased in FANET, the token size that includes the location information is increased. Also, the number of UAVs are increased where the token need to visit. These increases will extend the circulation time between the UAVs and thus to learn the coordinate information will be delayed for UAVs. In such a case, it will not be able to provide a safe multi-flight. In multi UAV systems after a certain number of UAVs, only one token will not be enough. In this case, the number of tokens circulating in the network is increased in a parallel and optimal manner as the number of UAVs in FANET which constitute the basic structure of the multiple tokens.

Due to increasing the number of tokens in conjunction with the increased number of UAVs, UAVs learn the location information of each other more accurately. However, as the number of tokens in the network are increased, the possibility of collision of tokens is revealed. The collision will cause loss or incorrect messages received. In this case, UAVs will learn incorrect or delayed location information of each other.

In the scenarios performed in this study, to avoid collisions when multiple tokens are used in multi tokens systems, we assumed that separate channels are used and the UAVs have the hardware to support such a structure. In the proposed model, UAVs which are located in FANET, learn the location information of each other with multiple tokens structure. This structure is shown in Fig. 2.

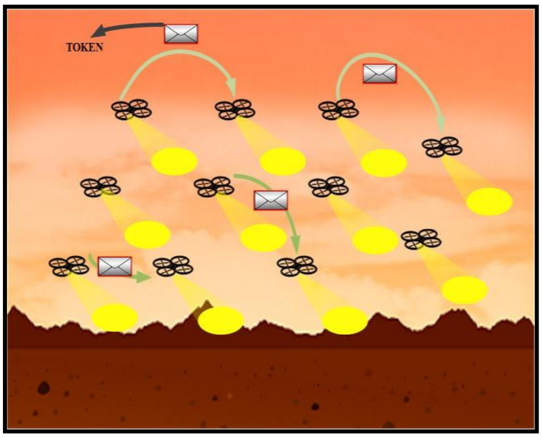


Fig. 2. Multiple tokens structure in FANET.

There are four different areas in the token package as shown in Fig. 3. Multiple tokens circulation is performed in FANET. Thus, to distinguish tokens between each other, unique values are kept as token number in the first section. The second section contains the UAVs' source address part in the token. With this information, UAVs will be aware of incoming data that is reached from which UAV. The third section is composed of destination address information of the UAV where the token is sent. In the last section, the location information of all UAVs in FANET is involved. When token is circulating through the network, the UAV that holds the token, adds its current location information. Also, the UAV compares the information in token's memory with the information in its memory. Then updates the information with the current one in its memory or in token's memory. One counter variable is used for the comparison operation. As the location information is changed, the counter value will be increased and the information will be updated with the highest counter value.

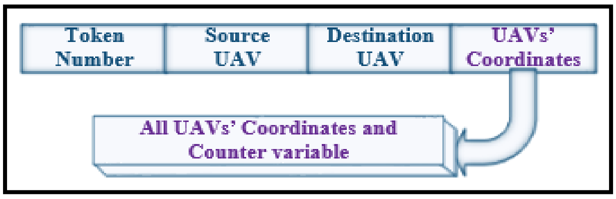


Fig. 3. Content of token.

After updating token's memory or its memory by UAV, the token is sent to another UAV. The token is send to the UAV which is selected according to the neighbor of the UAV that keeps the token. However, under the selection process, if there are more than one neighbor, one of the UAVs is selected except the UAV from where the token came from.

While UAV which holds the token choose one of the neighbor and send the token, other neighbors which the destination address is not target can hear the token as shown in Fig. 4. This case is considered as an advantage. The UAV which overhear the token can updates its memory with the current information on the token. However, if this UAV has more current information, the token cannot be updated because the token is not hold by the UAV which overhear the token.

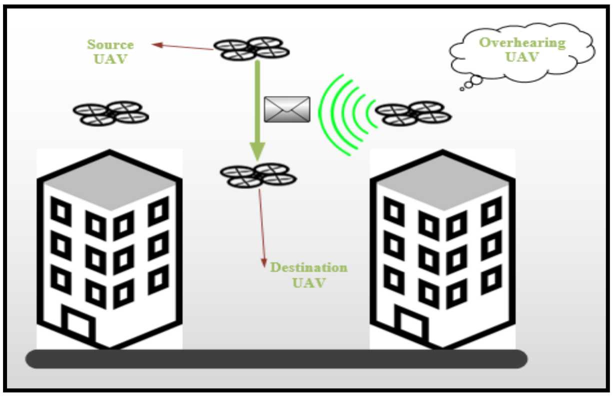


Fig. 4. Overhearing UAV.

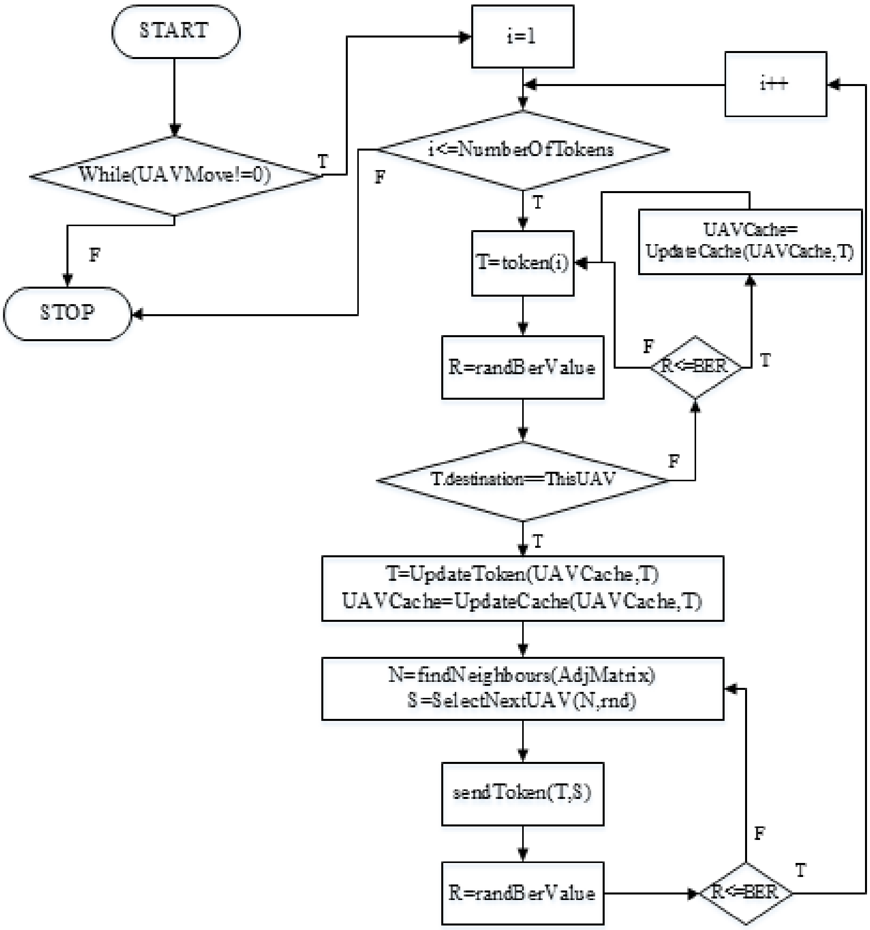


Fig. 5. Flow chart of the proposed multi-tokens structure.

Flow chart of the proposed model is given in Fig. 5. During the movement of the UAVs, they will listen the communication line and if there is any token that is coming to the UAV, the UAV will handle the token. Then if the information of token is more current, the UAV will update its memory, and if the information of UAV is more current then the UAV will transfer its current information to the token.

After the update process the tokens will be sent to one of the selected neighbors. If there are several neighbors, UAV will send the token to another UAV excluding the token came from. With the bit error rate, it will be determined whether the token is received or not. If the token is not received by a UAV, it will be sent to another neighbor.

In the token based approach, one of the parameters affecting the performance of the system is the transmission time. Transmission time in communication networks is defined that the time between beginning of the token sending and the moment of arrival of token's last bit to the target node.

As shown in equation 1 the packet size and bit transmission rate are the most important parameters used to calculate the transmission time. The packet delivery time is calculated by adding the propagation delay of the packet to the packet transmission time. The propagation delay is calculated by communication range is divided by a constant value used for wireless communication as shown in equation 2 [9].

$$\text{Packet Transmission Time} = \text{Packet Size}/\text{Bit Rate} \tag{1}$$

$$\text{Propagation Delay} = \frac{\text{Communication Range}}{3\times10^{8}} \tag{2}$$

Transmission time is much larger than processing time. For this reason, processing time is negligible when it taken with the transmission time [9]. In this respect, the processing time is neglected and the transmission time for token is calculated with propagation delay and transmission time in this study.

UAVs movement in dynamic topology is another issue that must be observed in the model of multiple tokens. When UAVs fly with a changing topology instead of a fixed topology, neighboring states will be changed dynamically during the flight. In this case, to monitor performance results of the multiple token based model in the dynamic topology, UAVs which are moving in grid topology will pass through the line topology after a certain time as shown in Fig. 6.

One of the issues to be considered in token based approach is the bit error rate (BER). BER refers to the ratio of deteriorated or incorrectly detected bits of sent data in digital data transmission [10]-[12]. We need to ensure that the token sent from one UAV to another UAV in the FANET, is arrived to destination seamlessly and accurately. If the token could not be sent or sent incorrectly, in these cases the package will need to be sent again. For each package, bit error control must be done. In the study, different values of BER are taken to monitor the effects of these values on the performance results.

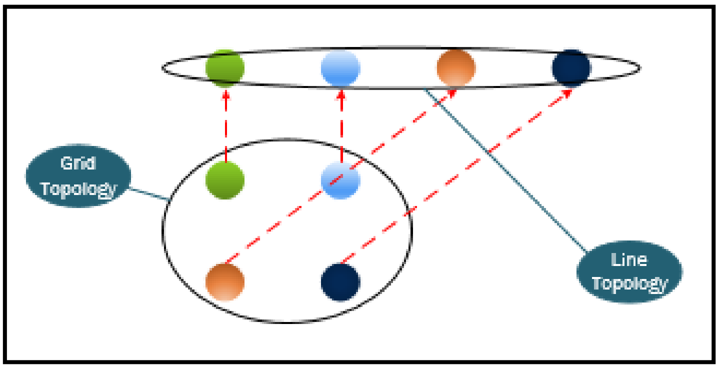
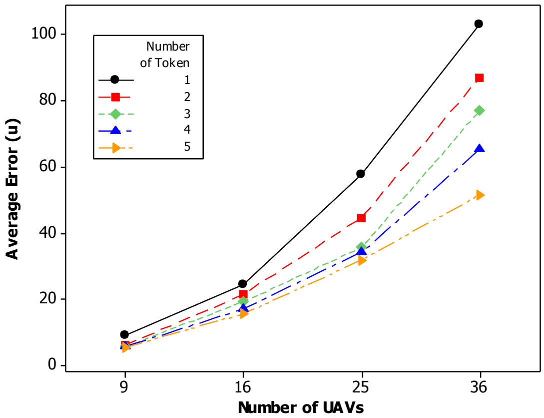


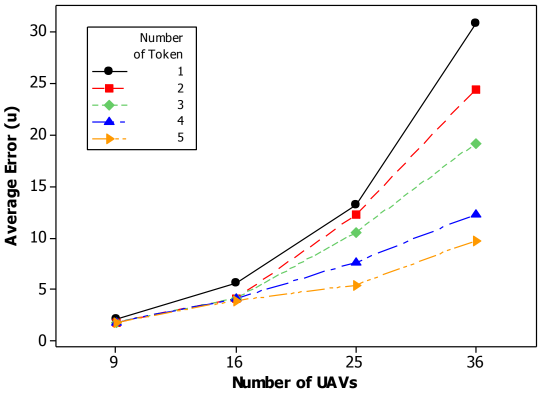
Fig. 6. Grid to line topology.

3. Performance Results

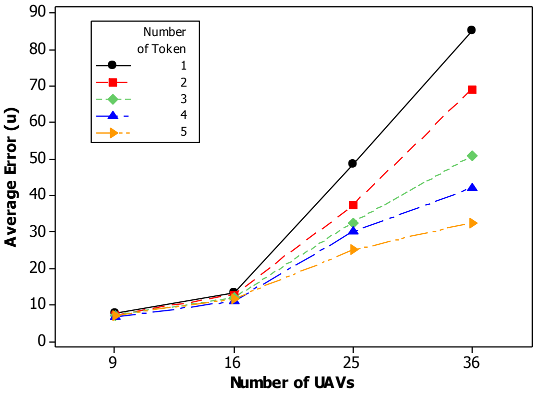
The BER value is taken as 10^{-4} and the speed of UAV is 5 u/s for all graphs shown in Fig. 7. The graphs in the Fig. 7 shows the average error values for different topologies. As shown in these graphs, since the number of UAVs increases, the effect of increment of the number of tokens is greater. Due to limited neighborhoods, highest average error value is in the line topology. When the number of UAVs is greater than 20-25, significant effect of number of token is seen in all topologies.



a) Line topology



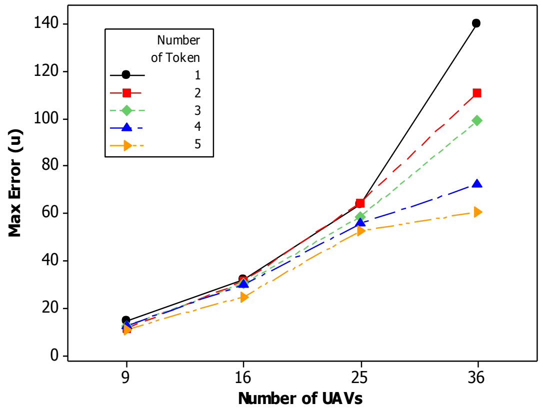
b) Grid topology



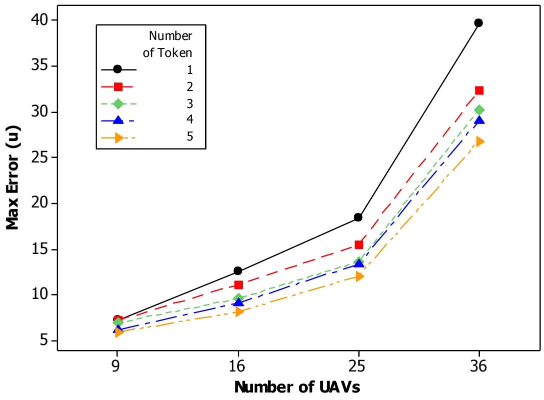
c) GridToLine topology

Fig. 7. Average error.

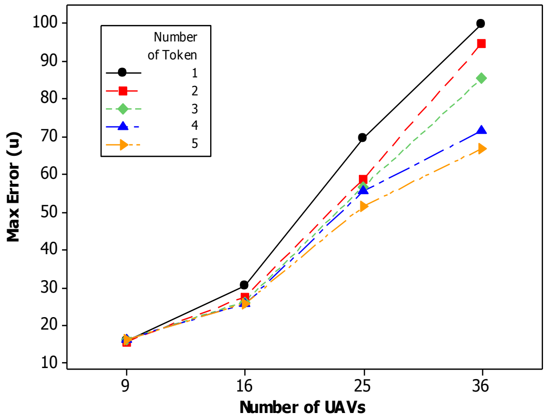
In Fig. 8, maximum error values of different topologies is shown. Especially, in the line topology after the certain number of UAV the maximum error value is very high in a single token based circulation. When the number of token is 4 or 5, a significant decrease in the error value is observed.



a) Line topology



b) Grid Topology



c) GridToLine topology

Fig. 8. Maximum error.

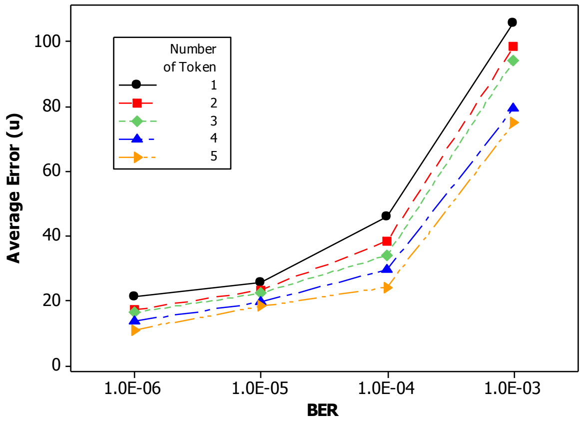
In the simulation environment, the parameter values that are used to obtain graphical results of the study are shown in Table 1.

Number of UAVs is 25 and UAV speed is 5 u / s for all graphs shown in Fig. 9. In these graphs, average and maximum error values for different values of BER is observed. The topology is GridToLine in these graphs.

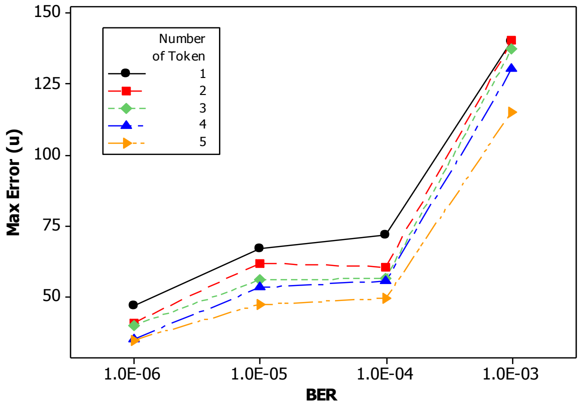
When the BER value is 10^{-3} both average and maximum error values are quite high. Because of the high BER value, tokens are send again many times. For this reason, circulation time of tokens take a long time.

Table 1. The Parameters Used in the Simulation

Number of UAVs	9-16-25-36
Number of Tokens	1-2-3-4-5
UAVs Speed	5 u/s
Topology	Grid, Line, GridToLine.
Bit Error Rate (BER)	10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}
Communication Range	5 u
Channel Transmission Speed	11 Mbps
Simulation Time	60 s



a) Average error



b) Maximum error

Fig. 9. Effects of BER.

4. Conclusion

Due to developments and lower cost in UAV technology, multiple UAVs are being used more widely. Multiple UAVs are used in the form of even swarms. Thus, complex and long term tasks are performed in a shorter time and more efficiently with multiple UAVs. In the multiple UAV concept, one of the most effective method used to ensure communication between the UAVs is FANET structure. In the FANET structure, the UAVs need to know location information of each other. With the use of token based approach, location information between UAVs can be circulated. In this study, the circulation of coordinate information of UAVs in FANET was carried out with multiple token based approach. By this means, with the use of multiple tokens across multiple UAVs, the location information can be circulated with less error as shown in this study. In addition to this model, multiple token structure is performed with the transmission time, dynamic topology and bit error rate. For this reason, more realistic simulation environment is generated. In this way, effects of the dynamic topology and a different BER values on results are observed.

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