Performance Analysis of Frame Structure for Efficient Data Transmission in TDMA-based UAS Networks

Jun-Woo Cho, and Jae-Hyun Kim
Department of Electronics and Computer Engineering
Ajou University
Suwon, Korea
{cjw8945, jkim}@ajou.ac.kr

***Abstract*—In this paper, we analyze the performance of a frame structure for efficient data transmission of Time Division Multiple Access (TDMA)-based Unmanned Aerial System (UAS) in the data gathering environment. For performance analysis, we consider the UAS network in the data gathering scenario and a simple TDMA structure that assigns subframes to each node, including Ground Control Station (GCS), and Unmanned Aerial Vehicles (UAVs). Then we derive the energy consumption model of the UAV and calculate the total energy consumption of UAVs and the throughput of UAS network.**

Keywords*—*UAV; UAS; Energy consumption; TDMA; Pathloss

I. INTRODUCTION

Since Unmanned Aerial Vehicle (UAV) has many advantages as communication nodes, there is a growing interest in Unmanned Aerial System (UAS) networks in recent decades. In particular, UAS has become a hot issue as 3GPP created standards for Non-Terrestrial Networks (NTN). The main advantages of it are network configuration time, network structure flexibility, communication range scalability, and lower cost than satellites [1].

As the number of UASs increases, appropriate multiple access methods are required. Recently unclassified [2] considers Time Division Multiple Access (TDMA) as a multiple access scheme for UAS networks. TDMA has been used for military data links such as Link-16 because of its ability to control a large number of nodes in a limited frequency band.

However, there are some things to consider when designing a TDMA-based UAS network.

- The Unmanned Aerial Vehicle (UAV) should periodically receive and send control messages such as telecommand (Tc) and telemetry (Tm) to the ground control station (GCS). The requirements of control messages depend on its operation mode, such as takeoff and landing modes, monitoring modes, relay modes, etc. Thus the frame structure should include all of these [3].
- The UAV operation mode determines the communication ability of the UAV. For example, in surveillance mode, data collected from the recon payload must be sent to the GCS in real-time. frame structure should include all these operating mode requirements.
- Also, UAVs must overcome energy constraints. This is because they are powered by fuel or secondary cells. If the UAV consumes less energy, it can perform more missions [1].

The main contribution of this paper is the performance analysis of total energy consumption of UAVs and the throughput of UAS network according to the number of UAVs. In TDMA, even if the number of UAVs is at least too large, the performance of the entire network may be degraded. Therefore, an appropriate amount of UAVs must be derived for efficient data transmission.

II. RELATED WORK

A. TDMA Based UAS Network

Reference [2] defines a standard line of sight interoperation command and control data link (IC2DL) for an Unmanned System that supports Unmanned System interoperability between NATO partners. The communication reference model is based on the OSI model, and TDMA is considered the MAC protocol of the Data link layer. Also, the message structure, transmission procedure, and synchronization process of IC2DL are mentioned.

The authors of [4] proposed a dynamic resource allocation algorithm that satisfies the network environment and data requirements in UAS networks. The algorithm proposed in [4] dynamically changes the size of the timeslot based on the data requirements (bandwidth, throughput, etc.).

B. Energy Consumption Model for UAV

The authors of [5] proposed a UAV deployment for minimizing the power consumption of UAVs using the Air-to-Ground (A2G) model proposed in [6]. They proposed the UAV power consumption model from the Shannon capacity formula.

The authors of [7] considered the power consumption model of UAV in terms of communication as well as mobility.

The authors gratefully acknowledge the support from Nano UAV Intelligence Systems Research Laboratory at Kwangwoon University, originally funded by Defense Acquisition Program Administration (DAPA) and Agency for Defense Development (ADD).

The communication energy consumption model of UAV is derived from the free-space channel model. The mobility energy consumption model of UAV is considered a UAV flight environment like velocity, altitude, wind speed, air density, etc.

The authors of [8] considered the processing energy consumption model of UAV in addition to [d]. Besides, [8] also proposed the communication energy consumption model of UAV based on the resource allocation structure.

III. System Model

A. UAS Network Environment and Frame Structure

Consider a Ground Control Station (GCS), I UAVs, and J data gathering areas where UAVs collect data are in the UAS network, as shown in Fig. 1. U is the set of UAVs, and M is the set of data gathering areas. The GCS and the data gathering area is located at the xy-plane, with it located at position $\boldsymbol{p}^s = (x^s, y^s, 0)$, and $\boldsymbol{p}_j^m = (x_j^m, y_j^m, 0)$, with $j \in J = \{1, ..., J\}$, respectively. The UAV is located at the 3D-plane, with it located at position $\boldsymbol{p}_i^u = (x_i^u, y_i^u, H)$, with $i \in I = \{1, ..., I\}$. H is the fixed altitude of UAVs. We assumed that UAVs are hovering in a fixed position above the data gathering area, i.e., $(x_i^u, y_i^u, 0) = (x_j^m, y_j^m, 0)$. d_i^s is the three-dimensional (3D) distance between the GCS and the UAV i.

We consider the UAV's buffer size is infinite, and there is only a downlink transmits data from UAV to GCS. That is, UAV collects data from the data gathering area in advance and transmits every time within their communication capacity boundary C_i^u. We assume frequency division duplex (FDD) with equal bandwidth, B, allocated for downlink.

The frame structure for UAS system is shown in Fig. 2. The Frame is divided into GCS subframe and I UAV subframes. T_f is the frame length, and GCS subframe length and UAV subframes length are equal. The frame length is set by the characteristics of the UAV control messages. Table 1 shows that the Information Exchange Requirements (IERs) matrix for UAS network [3].

B. Energy Consumption Model

1) Communication energy consumption model: The energy consumption model for communication of a UAV, within the allocated subframe, can be derived [8]:

$$E_i^c = \frac{N_0\, B\, T_f}{PL_i^s\,(I+1)} \left(2^{\frac{C_i^u\,(I+1)}{B T_f}} - 1 \right). \tag{1}$$

TABLE I
IERs MATRIX

Information description	Type of information	Frequency	Data rate
Command sensor	C2	5-10 Hz	5 kbps
Report UAV status	C2	5-10 Hz	5 kbps
Command UAV, T/O	C2	20-25 Hz	25 kbps
Report UAV, T/O	C2	20-25 Hz	25 kbps
Collect Sensor data	sensor	on Request	50 kbps
Relay voice	voice	on Request	5 kbps

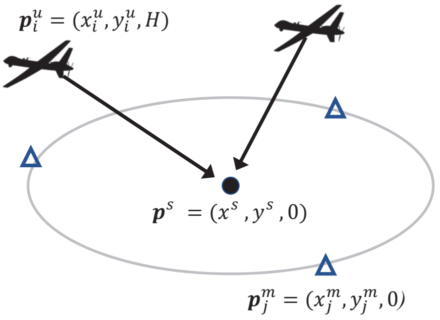

Fig. 1. UAS Network

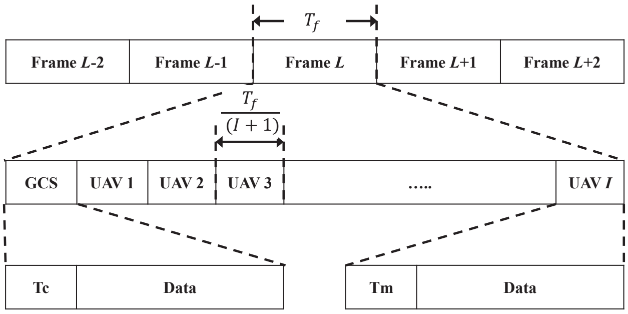

Fig. 2. Frame structure

where N_0 is an additive white Gaussian Channel noise with zero mean and power spectral density [dBm/Hz], and PL_i^s is the Free-space pathloss between GCS and UAV which can be expressed as follow:

$$PL_i^s = \frac{P_0}{d_i^s}. \tag{2}$$

where P_0 is the received power at the reference distance 1 m for a transmission power of 1 W.

2) Hovering energy consumption model: The energy consumption model for UAV hovering time, within the allocated frame can be derived [9]:

$$E_i^f = k T_f \sqrt{\frac{1}{r}\left(\frac{mg}{o}\right)^3}. \tag{3}$$

where k is the air density dependent coefficient, r is the radius of wing, m is mass of UAV, g is gravitational acceleration, and o is the number of wings in UAV. We consider that even if a UAV has completed data transmission, UAV hovering time remains until the end of that frame.

IV. Performance Analysis

To analyze the total energy consumption of UAVs and the throughput UAS network, we perform the simulation using MATLAB. The simulation parameters are shown in Table 2, refers to [1], [8], [9]. We consider three data gathering areas and set the total amount of data in each data gathering area to

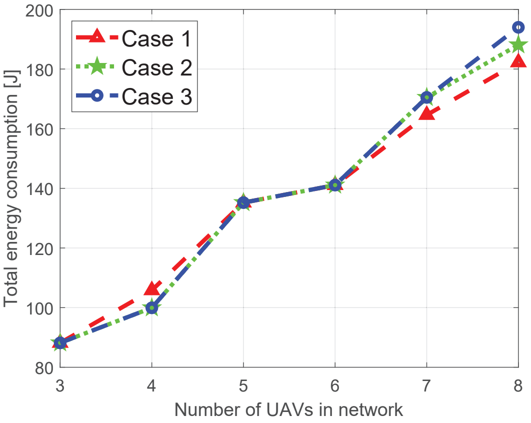

Fig. 3. Total energy consumption

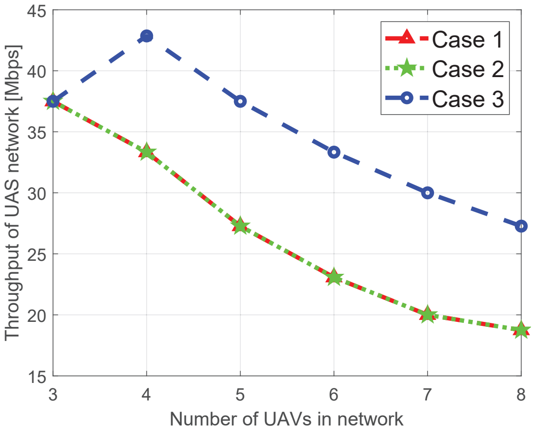

Fig. 4. Throughput of UAS network

2 Mbits, 4 Mbits, 6 Mbits respectively. And we set the UAV communication capacity to 100 Mbps.

The number of UAVs varies from case to case. the number of UAVs is set to increase for each data gathering area. By the total amount of data, it is divided into **Case 1**, **Case 2**, and **Case 3**. The initial number of UAV in each data gathering area is set to 1.

Fig. 3. shows the total energy consumption of UAVs. It is calculated as follow:

$$E_I^T = \sum_{i=1}^{I} \left(E_i^c + E_i^f \right) l_i. \tag{4}$$

where l_i is the number of frames when data transmission of UAV i is complete.

The decrease in subframe length increases the UAV data transmission time and hovering time. Thus, the total energy consumption increases as the number of UAVs increases.

Fig. 4. shows the throughput of UAS network. The throughput decreases in Case 1 and Case 2. However, unlike Fig. 3, Case 1 and Case 2 have the same throughput. The 6 Mbit data gathering area has the highest value, thus the total number of frames is most affected by that area.

Comparing the two results, except for case 3, the higher the energy consumption, the lower the throughput. However, in Case 3, it is different because the hovering energy is higher than the communication energy. In the 6 Mbit data gathering area, increasing the number of UAVs from 3 to 4 reduces the number of frames from 7 to 4, but the number of frames increases to 8 because of the increased number of UAVs.

TABLE II
PERFORMANCE ANALYSIS ENVIRONMENT

Parameter	**Values**	**Parameter**	**Values**
p^s	(10,10,0)	h_u	10 m
B	40 MHz	N_0	-174 dBm/Hz
P_0	-2.306 dB	d_i^s	14.14 m
T_f	40 ms	Tc/Tm	40 kbps
g	9.8 m/s^2	k	0.363562
r	0.3 m	o	4

V. CONCLUSION

In this paper, we analyzed performance of frame structure for efficient data transmission. As a result of the performance analysis, the energy consumption of UAVs and the throughput of UAS network accroding to the number of UAVs can be confirmed. In the future, we will propose the optimal frame structure for UAS network based on this method.

ACKNOWLEDGMENT

The authors gratefully acknowledge the support from Nano UAV Intelligence Systems Research Laboratory at Kwangwoon University, originally funded by Defense Acquisition Program Administration (DAPA) and Agency for Defense Development (ADD).

REFERENCES

[1] J. W. Cho, and J. H. Kim, “Performance comparison of heuristic algorithm for UAV deployment with low power consumption,” *in Proc. IMCOM 2019*, Phuket, Thailand, Jan. 2019.

[2] NATO Satndardization Agency, “AEP-77 (Vol.1) - Interoperable command and control data link for unmanned systems (IC2DL),” Nov. 2016.

[3] NATO Standardization Agency, “STANAG 4586 (Edition 3) - Standard Interfaces of UAV Control System (UCS) for NATO UAV Interoperability,” NSA/1235(2012)4586, Nov. 2012.

[4] H. R. Cheon, J. W. Cho, and J. H. Kim, “Dynamic resource allocation algorithm of UAS by network environment and data requirement,” *in Proc. ICTC 2017*, Jeju, Korea, Oct. 2017.

[5] J. W. Cho, and J. H. Kim, “Performance comparison of Heuristic algorithm for UAV deployment with low power consumption,” *in Proc. ICTC 2018*, Jeju, Korea, Oct. 2018.

[6] M. Mozaffari, W. Saad, M. Bennis, and M. Debbah, “Mobile unmanned aerial vehicles(UAVs) for energy-efficient internet of things communications,” *IEEE Transactions on Wireless Communications*, vol. 16, no. 11, pp. 7574-7589, Mar. 2018.

[7] Y. Zeng, R. Zhang, and T. J. Lim, “Throughput maximization for UAV enabled mobile relaying systems, IEEE Transaction on Communications, vol. 64, no. 12, pp. 49834996, Dec. 2016.

[8] S. Jeong, O. Simeone, and J. Kang, “Mobile edge computing via a UAV-mounted cloudlet: optimization of bit allocation and path planning,” *IEEE Transactions on Vehicular Technology*, vol. 67, no.3, pp. 2049-2063, Mar. 2018.

[9] [Online]. Available: http://www.starlino.com/power2thrust.html. Accessed: Sep. 21. 2019.