AoI Based UAV Wireless Communications Networks

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***Abstract*—This paper presents the potential application of Age-of-Information (AoI) in Unmanned Aerial Vehicles (UAVs) assisted wireless networks. Specifically, the study utilizes the Average Age of Information (AAoI) and Peak Average Age of Information (PAAoI) metrics to measure information freshness in such networks. This study analyzes the impact of several factors on AAoI and PAAoI, including Active Probability, Block Length, Number of Nodes, Power, and Update Size. The findings underscore the significance of AAoI and PAAoI in the design of future mission-critical wireless networks.**

***Index Terms*—Age of Information, Peak Average Age of Information, Wireless Networks and Block Length.**

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs), commonly called drones, have brought about a significant revolution across diverse industries by offering highly efficient and cost-effective solutions [1]–[5]. Their potential in various applications, including aerial photography, disaster management, environmental monitoring, and delivery services, has garnered widespread recognition. Among recent advancements in this field, integrating UAVs into wireless networks as mobile base stations (BSs) stands out as a transformative development that can revolutionize connectivity and ensure real-time data freshness in the ever-evolving Internet of Things (IoT) landscape [6]–[11].

Despite the promising prospects of UAV-aided wireless communication, several challenges exist. One of the main challenges in UAV communication is the preservation of information freshness at the destination, particularly considering that most UAV-assisted communication networks serve mission-critical purposes. On the other hand, the Age of Information (AoI) is a critical metric in time-sensitive applications, where the timeliness of the information can be as important as the information itself [12]–[14]. Moreover, AoI has gained significant attention due to its ability to accurately measure the freshness of information at monitoring points, surpassing the limitations of traditional end-to-end latency [15], [16]. In recent years, there has been significant research interest in estimating the AoI within UAV-aided communication networks. For example, in a recent study [15], [17], an AoI-based wireless communication system was introduced, employing UAVs as relays to investigate the influence of UAV deployment on the freshness of the information. These studies contribute to understanding AoI dynamics in UAV-assisted wireless networks. By exploring factors such as computing resources, UAV deployment strategies, and relay configurations, researchers aim to enhance overall performance and information freshness in future wireless communication systems.

In the realm of disaster-resilient wireless networks, the integration of Simultaneous Wireless Information and Power Transfer (SWIPT) with Intelligent UAV deployment, complemented by a focus on the AoI, represents a revolutionary advancement [4], [10]. This synergy is pivotal in creating a robust communication infrastructure that is not only sustainable but also efficient in maintaining the freshness of information, a critical factor in disaster management. Intelligent UAV deployment, optimized through real-time analytics and adaptive strategies, ensures effective coverage in disrupted or inaccessible areas. Incorporating SWIPT allows these UAVs to harvest energy while simultaneously processing and disseminating vital information. This capability is crucial for sustaining operations in prolonged emergency scenarios [18]. Moreover, by prioritizing AoI, this integrated approach guarantees that the information relayed is not only timely but also relevant, which is essential for coordinating swift and effective disaster response strategies [19], [20].

This study focuses on the exploration of AoI metrics, specifically the Average Age of Information (AAoI) and Peak Age of Information (PAAoI), within the context of a wireless network that employed UAVs. The analysis conducted provides profound insights into the performance characteristics of UAV-assisted wireless networks, thereby offering crucial guidance for their design and optimization.

II. AGE OF INFORMATION METRICS IN UAV-ASSISTED WIRELESS NETWORKS

Consider a simplified communication system consisting of a source-destination pair. In this system, the source transmits timely updates to a network, delivering these updates to the destination. When the generation time of the most recent

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update received by the destination at timestamp t denotes $g(t)$. The AoI can be then described as $\Delta(t) = t - g(t)$.

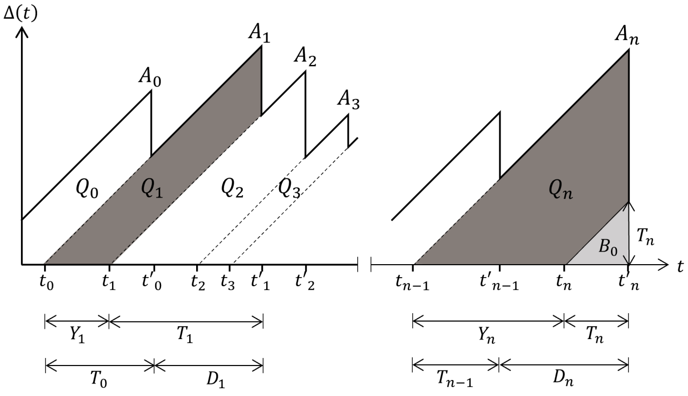

Fig. 1. Example of age evolution

As shown in Fig. 1 $t_0, t_1, \ldots$ are arrival times of updates from a source, and $t'_0, t'_1, \ldots$ is the time they are received on the monitor. Y_n is the inter-arrival time, D_n is the inter-departure times between two updates and T_n is the system time of the n_{th} update. A_n is the corresponding age peak. The aging process $\Delta(t)$ peaks the instant before the service completion at time t'. Suppose that our interval of observation is $(0, \tau)$ and $N(\tau) = \max\{n \,|\, t_n \leq \tau\}$ is the number of updates by time τ. Then, time average AoI can be calculated as

$$\Delta_\tau = \frac{1}{\tau} \int_0^\tau \Delta(t)\, dt, \tag{1}$$

where $\Delta(t)$ represents the age of a status update at time t. Furthermore, The integral in (1) decomposes the polygon area $\bar{Q}_0$, the sum of the trapezoidal areas, $Q_j \longrightarrow 1 \leq j \leq N(\tau)$ and B_0 triangular area of width T_n. Then, (1) can be reformulated as follows $\Delta_\tau = \frac{1}{\tau}\left[\bar{Q}_0 + B_o + \sum_{j=1}^{N(\tau)} Q_j\right]$.

Alternatively, (II) can be written as $\Delta_\tau = \frac{\bar{Q}_0 + B_o}{\tau} + \frac{N(\tau)}{\tau} + \frac{1}{N(\tau)} \sum_{j=1}^{N(\tau)} Q_j$. Then, the trapezoidal area can be calculated as:

$$Q_n = \sum_{j=1}^{N} Q_j = \frac{1}{2}\left[(t'_n - t_n) + (t_n - t_{n-1})\right]^2 - \frac{1}{2}(t'_n - t_n)^2 \tag{2}$$

Substituting $t'_n - t_n = T_n$ and $t_n - t_{n-1} = Y_n$ to (2), Q_n can be derived as follows :

$$Q_n = T_n Y_n + \frac{Y_n^2}{2}. \tag{3}$$

The time average Δ_τ tends to the ensemble average age as τ tends to infinity as $\Delta = \lim_{\tau\to\infty} \Delta_\tau$. Hence, AAoI can be derived as follows:

$$\text{AAoI} = \Delta = \lim_{\tau\to\infty} \frac{1}{E[Y_n]} E[Q_n] \tag{4}$$

Then, (4) can be reformulated using (3) as follows [1]:

$$\text{AAoI} = \Delta = \frac{E[Q_n]}{E[Y_n]} = \frac{E[T_n Y_n] + \frac{E[Y^2]}{2}}{E[Y_n]} \tag{5}$$

Moreover, the peak age of information at the t'_n can be calculated as follows:

$$A_n = T_{n-1} + D_n \quad \text{or} \quad A_n = Y_n + T_n. \tag{6}$$

Suppose that our interval of observation is $(0, \tau)$ and $N(\tau) = \max\{n \,|\, t_n \leq \tau\}$ is the number of updates by time τ. The time average peak age of a status update system can be formulated as follows:

$$A_\tau = \lim_{\tau\to\infty} \frac{1}{N(\tau)} \sum_{n=1}^{N(\tau)} A_n \tag{7}$$

Furthermore, (7) can be reformulated using (6) as $A_\tau = E[A_n] = E[T_{n-1}] + E[D_n] = E[T_n + Y_n]$. Then, the difference between AAoI and PAAoI can be calculated as

$$\Delta - A_\tau = \lambda \left(E[T_n Y_n] + \frac{E[Y_n^2]}{2} - E[Y_n]E[T_n] - E[Y_n^2] \right), \tag{8}$$

where $\lambda = \frac{1}{E[Y_n]}$.

III. SIMULATION RESULTS

In this section, numerical results are presented to validate the theoretical derivations. Fig. 2 illustrates the impact of source active probability on the difference between AAoI and PAAoI. The results indicate that as Active Probability increases, the difference between PAAoI and AAoI increases for both theoretical and simulated values.

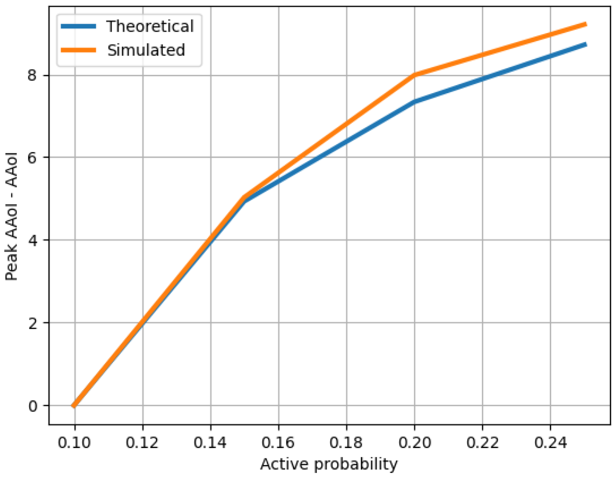

Fig. 2. Difference between PAAoI and AAoI vs Active probability

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[1] When $\tau \to \infty$, $\frac{\overline{Q}_0 + B_0}{\tau} \to 0$, $\frac{N(\tau)}{\tau} \to \frac{1}{E[Y_n]}$ and $\frac{1}{N(\tau)} \sum_{j=1}^{N(\tau)} Q_j \to E[Q_n]$

IV. CONCLUSION

In conclusion, this paper presented AAoI and PAoI in a wireless network assisted by UAVs. By studding the factors such as Active Probability, Block Length, Number of Nodes, Power, and Update Size, this study aimed at improving the significance of AAoI and Peak PAAoI in the future wireless network design. The findings support the adoption of these metrics to improve information freshness and network performance. In the future, a comparative analysis of the impact of Active Probability, Block Length, Number of Nodes, Power, and Update Size on AAoI and PAAoI will be conducted. In addition, we will present a new theoretical framework to validate these findings.

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