Device Scheduling Under Age of Information Constraints

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Abstract

With the rapid proliferation of Internet of Things (IoT) devices and their stringent data freshness requirements for critical applications such as healthcare and vehicular networks, efficient scheduling algorithms are essential. In this paper, we propose a scheduling algorithm designed for such dynamic environments, aiming to minimize bandwidth usage while meeting the diverse Age of Information constraints of multiple IoT devices. Numerical results demonstrate that the proposed algorithm achieves significant bandwidth savings over existing methods.

Ⅰ. Introduction

Rapid growth of IoT applications—spanning autonomous driving, industrial automation, tele-health, and remote patient monitoring [1]—has made timely data delivery paramount, with Age of Information (AoI) emerging as the key freshness metric [2]. In networks where devices unpredictably join and leave, satisfying diverse AoI requirements under strict bandwidth constraints is especially challenging. To address this, we propose a scheduling policy that dynamically adjusts both the scheduling interval and resource allocation for active devices. Our scheme seamlessly integrates new arrivals, minimizes overall bandwidth consumption, and delivers superior AoI performance while accommodating devices joining and leaving the network.

Ⅱ. Problem Formulation

We consider an IoT network with N IoT devices. Each IoT device n generates an information packet which must be sent to a central access point (AP) using K orthogonal wireless resource blocks (RBs). We assume that the transmission time is divided into slots of equal length, each sufficient for one packet transmission. All packets generated by devices have same size and require one slot for transmission. Let $\Delta_n(t)$ denote the AoI of device n at the AP at time slot t. Each device is subject to have a strict AoI constraint, represented by $d_n \in \mathbb{Z}^+$. Let $D = \{d_1, d_2, \ldots, d_N\}$ be the vector containing the AoI constraints of N devices, where $\Delta_n(t) \leq d_n \, \forall \, t$. Given the limited availability of wireless resources, our focus is to find a scheduling policy π that can establish a schedule for devices with the minimum utilization of wireless resources while ensuring that the AoI constraints are satisfied.

Ⅱ. Device Scheduling Policy

To enforce AoI constraints under scarce wireless resources, at each slot t we first identify the active devices $S(t)$ and isolate those yet to be scheduled, $S_u(t)$, with corresponding AoI deadlines $D_u(t)$; we then compute the minimal time-slot horizon $\tilde{T}$ and number of channels K required for all devices in $S_u(t)$ to meet their deadlines. We represent the available resource blocks over this horizon by a $K \times \tilde{T}$ matrix $V = [v_{k,\tau}]$, where $v_{k,\tau} = n$ if RB (k,τ) is assigned to device n, else 0, and populate it by scheduling devices one by one in descending order of their remaining RB needs α_n, scanning channels and time slots until every device in $S_u(t)$ has been allocated sufficient blocks. This procedure guarantees that no device's AoI $\Delta_n(t)$, exceeds its constraint while minimizing total RB usage. For example, when eight unscheduled devices have AoI limits $\{2,2,3,9,15,16,19,19\}$, our policy yields $\tilde{T} = 10$ and $K = 2$, producing a compact 2×10 assignment matrix that meets all deadlines with the fewest resource blocks. Once this schedule completes, it is simply repeated for any devices still in the network.

Ⅲ. Conclusion

This paper has addressed the critical challenge of scheduling device updates to simultaneously minimize bandwidth consumption and preserve data freshness. We show that the proposed algorithm achieves optimal bandwidth utilization under all Age of Information constraints, even in dynamic settings with stochastic device arrivals and variable active periods.

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