Smart DRX Wakeup Signal Control with Latency-Aware DCP Signaling in B5G/6G Multi-Service Scenarios

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Abstract

To enhance the power efficiency in user equipment (UE), the 3rd Generation Partnership Project (3GPP) has introduced the Downlink Control Information for Power Saving (DCP) signal, which serves as a Wake-Up Signal (WUS) integrated into the Discontinuous Reception (DRX) mechanism. We propose a novel DCP-DRX scheduling framework that dynamically adapts to the DRX cycle along with the latency requirements of multi-service scenarios. Results demonstrate that the Dynamic DRX cycle and latency-aware DCP scheduling approach achieves a notable increase in UE sleep duration, exceeding **10%** improvement in power savings, while maintaining acceptable latency levels across diverse service profiles.

Ⅰ. Introduction

To enhance power efficiency, 3GPP has progressively introduced power-saving mechanisms, including advanced DRX techniques in 6G. These include wake-up signals, go-to-sleep signals, paging early indications, and ultra-low power secondary wake-up signals to reduce UE energy consumption.

In [1], a buffer-aware DCP scheduling mechanism is proposed, where the gNB keeps the UE dormant when its buffer is empty, minimizing unnecessary wakeups. For example, as shown in Fig. 1, DCP signaling can consolidate packet delivery into a single DRX cycle [2]. To balance latency and energy efficiency, [3] presents a Latency-Aware DCP (LADCP) scheduler for single-service scenarios.

With smart city deployments introducing diverse service demands—from mission-critical to delay-tolerant data—maintaining power efficiency becomes increasingly complex [4]. This work proposes a dynamic scheduling mechanism that adapts DCP signaling to varying latency needs across multiple services. Extending LADCP to multi-service environments, the proposed method achieves notable power savings, validated through theoretical and empirical analysis.

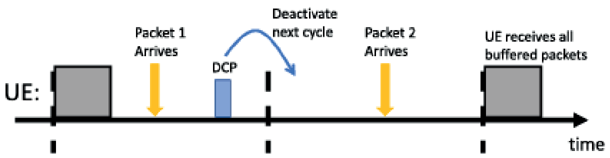


Fig.1. Example of deferred scheduling by DCP

Ⅱ. System Model

We consider a multi-service scenario using Latency-Aware Discontinuous Reception (LADCP), where each service has its own packet arrival process and QoS requirements. Packets arrive according to a Poisson process with rate, and each service is allocated a DRX cycle and an inactive timer. The UE switches between the **Active**, **Monitoring**, and **Sleeping** states based on packet arrival and timer expiration.

Markov Chain Model

We modeled UE behavior in DRX cycles using discrete-time Markov chains with two primary states: activated and deactivated cycles. In the activated state, the UE follows normal DRX behavior, turning off the RF module after the inactivity timer expires. In the deactivated state, the UE remains in sleep mode without receiving data. Deactivation is triggered when the prior cycle's Decision Period Control Point (DCP) indicates no buffered packets.

To facilitate analysis, we introduced a new state called Buffered, which functions like the Deactivated state but with packets already present in the gNB buffer. This state captures scenarios where packets arrive after a defined latency, prompting transmission to be deferred by one cycle. Buffered cycles are treated as a special case of Deactivated, with the next state always transitioning to Active. The steady-state probabilities of individual model states can be determined by solving the balance equations of the Markov chain.

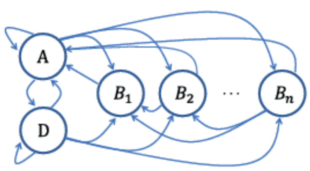


Fig.2. Discrete Markov Model for LADCP

$$\begin{cases} \pi_A = \pi_A P_{AA} + \pi_D P_{DA} + \sum_{i=1}^{n} \pi_{B_i} P_{B_i A} \\ \pi_D = \pi_A P_{AD} + \pi_D P_{DD} \\ \pi_{B_i} = \pi_A P_{AB_i} + \pi_D P_{DB_i} + \sum_{j=i+1}^{n} \pi_{B_j} P_{B_j B_i} \end{cases} \quad (1)$$

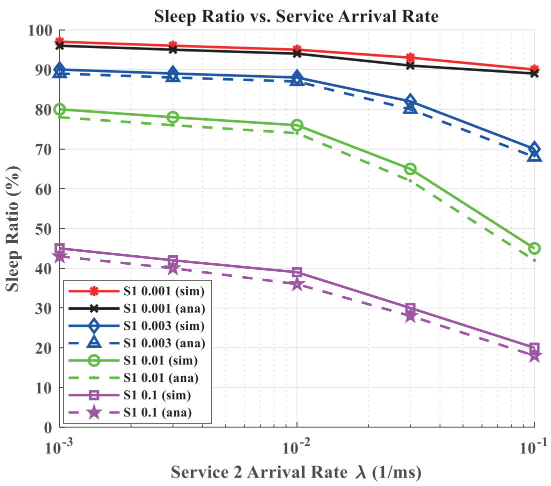
UE Sleep Ratio and Power Consumption

Using the closed-form steady-state probabilities, we can derive the average sleep ratio of the UE by first evaluating the expected proportion of time spent in different RF states during a DRX cycle. From these ratios, the average sleep ratio AAA of the UE can be computed using the steady-state probabilities.

$$r_S = \pi_A r_{S|A} + \pi_D r_{S|D} + \sum_{i=1}^{n} \pi_{B_i} r_{S|B_i} \quad (2)$$

If the configured UE active state power (Pa), DCP-receiving power (Pd), and dormant state power (Ps) are given, the expected UE power consumption can also be calculated.

$$\bar{W} = W_A \pi_A r_{A|A} + W_P \left(\pi_A r_{P|A} + \pi_D r_{P|D} + \sum_{i=1}^{n} \pi_{B_i} r_{P|B_i} \right) + W_S \left(\pi_A r_{S|A} + \pi_D r_{S|D} + \sum_{i=1}^{n} \pi_{B_i} r_{S|B_i} \right) \quad (3)$$

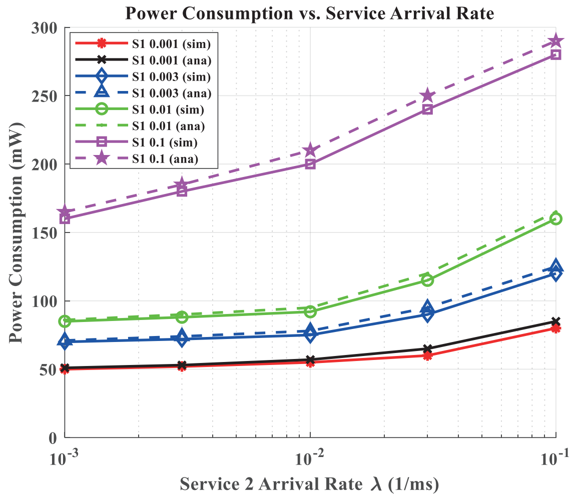


III. Simulation Results

We consider a single UE using two services: Service 1 with a latency requirement of 400 ms and Service 2 with 800 ms. The DRX cycle length is set to 320 ms based on the minimum latency. Each cycle has three fixed DCP transmission instants spaced 30 ms apart, starting from 240 ms. Both the inactivity timer and ON duration timer are configured to 40 ms for modeling simplicity.

IV. Conclusion

In this work, we proposed a scheduling strategy that defers packet transmissions based on service-specific latency requirements, improving UE sleep ratio and power efficiency. Our extended model for multi-service scenarios introduces a Latency Budget (LB) variable and achieves over 10% higher sleep ratio compared to legacy DRX and DCP-DRX. Simulation results validate the accuracy and energy-saving effectiveness of our approach. Future work can explore service variability and reliability for enhanced robustness.



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