A Subgrouping Method for Ultra-Low Power Consumption of IoT Devices in Wireless Environments

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Abstract **This paper proposes a dynamic subgrouping method to overcome the limitations of conventional dual subgrouping approaches that combine Low Power Wake-Up Signal (LP-WUS) and Physical-layer Early Indication (PEI) for ultra-low power operation of IoT devices in wireless environments. Traditional fixed-K-value subgrouping fails to account for dynamic network characteristics such as device behavior patterns, mobility, and time-varying traffic load, leading to increased paging false alarms and reduced power efficiency. To address this, we present a method that dynamically configures PEI subgroups based on device features such as traffic frequency, DRX cycles, mobility patterns, and service types, while also adjusting the size and distribution of LP-WUS subgroups in real-time according to traffic load and device density within a cell. Furthermore, by calculating the K value dynamically based on real-time network status, the proposed approach minimizes inter-group interference and enables flexible group management. This strategy reduces paging false alarms and unnecessary wake-up signals, effectively lowering the power consumption of IoT devices while enhancing the overall efficiency of wireless networks.**

Keywords— *Internet of Things(IoT), Low power wackup signal, IoT device power saving, LP-WUS Sub-grouping*

I. INTRODUCTION

As the number of IoT devices grows rapidly, power efficiency in wireless environments has become a critical challenge. In particular, the paging process requires devices to periodically activate their RF modules, leading to increased battery consumption. To address this, 3GPP has introduced a dual subgrouping approach that combines Low Power Wake-Up Signal (LP-WUS) and Physical-layer Early Indication (PEI) to reduce unnecessary wake-up events. However, existing methods rely on fixed grouping criteria and static parameters (such as a fixed K value), failing to account for device mobility, traffic patterns, and time-varying network load. This results in higher false paging rates and reduced power efficiency. This study proposes a dynamic subgrouping method that configures PEI subgroups based on various device characteristics, such as traffic frequency, DRX cycles, and mobility patterns, while also adjusting the size and distribution of LP-WUS subgroups in real-time according to traffic load. This approach aims to minimize unnecessary wake-up signals and power consumption of IoT devices, thereby improving the overall efficiency of wireless networks[1][2][3][4].

II. RELATED WORK

To improve paging efficiency for low-power IoT devices, recent studies have proposed a dual subgrouping approach that combines Low Power Wake-Up Signal (LP-WUS) and Physical-layer Early Indication (PEI). In this method, the first stage uses LP-WUS to pre-select a subset of devices that may need to wake up, while the second stage employs PEI to further divide this subset into more refined subgroups to determine the final paging targets.

A. A dual subgrouping approach that combines Low Power Wake-Up Signal (LP-WUS) and Physical-layer Early Indication (PEI)

Using the LP-WUS (Low Power Wake-Up Signal) subgrouping method, devices are first selectively woken up. For those that have been activated in this first stage, a second-stage PEI (Physical-layer Early Indication) subgrouping is applied to determine the final paging targets. By applying these two subgrouping stages, only the necessary devices will monitor the paging channel, enabling more efficient transmission and reception of wake-up signals. The 3GPP standard formalizes this mechanism by defining a UE_ID-based subgrouping formula in TS 38.304, which has been adapted for LP-WUS. This approach uses a K value to ensure that LP-WUS and PEI subgrouping can operate independently of each other[5].

$$\text{SubgroupID}_{\text{LP-WUS}} = \left(\left\lfloor \frac{\text{UE\_ID}}{N \cdot N_s \cdot K} \right\rfloor \bmod \text{subgroupsNumForUEID\_LP-WUS} \right) + (\text{subgroupsNumPerPO\_LP-WUS} - \text{subgroupsNumForUEID\_LP-WUS})$$

N denotes the total number of paging frames during a DRX cycle, Ns represents the number of paging occasions per paging frame, and K is a fixed parameter used to prevent interference between LP-WUS and PEI subgroups, which is defined as a value equal to or greater than 8. The figure below illustrates the dual subgrouping approach. In the current standard, device subgroup allocation typically relies on methods such as round-robin assignment or DRX cycle–based grouping. However, these approaches do not consider the specific characteristics of devices and therefore have several inherent limitations[6].

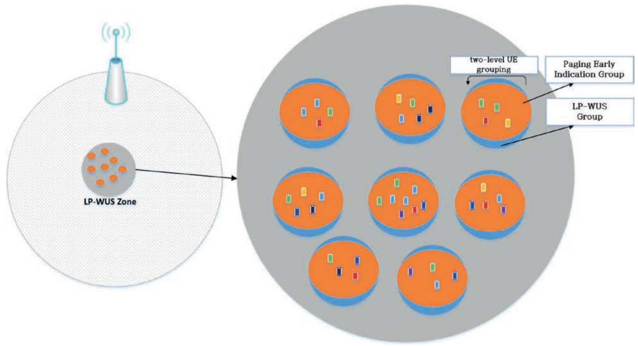

Figure 1. Two-Stage Static Subgrouping (Existing Method)

The two-stage subgrouping method that applies LP-WUS and PEI subgroups is effective in reducing the false paging rate of devices. However, if many devices are concentrated within the LP-WUS domain and an appropriate subgrouping strategy is not applied, a large number of devices may end up assigned to a single subgroup, leading to unnecessary wake-ups and degraded performance. This issue arises from allocating subgroups without considering various factors such as UE mobility or traffic transmission characteristics[7][8].

III. PROPOSED METHODS

In this section, we propose a dynamic subgrouping method that defines LP-WUS and PEI subgroups tailored to device characteristics by considering factors such as traffic patterns, mobility, and average data transmission intervals (DRX cycles), and allocates devices to these defined subgroups accordingly.

A. Formula for Dynamic Subgrouping

In the existing UE_ID-based subgrouping method, a fixed coefficient K is used to prevent overlap between LP-WUS and PEI subgroups. However, this fixed K value cannot reflect diverse network environments or dynamic UE traffic distributions, leading to reduced efficiency or increased false paging rates. When the number of UEs or traffic density changes over time, a large K can cause over-fragmentation and waste resources, while a small K can increase overlap and false wake-ups. Therefore, a formula that dynamically adjusts K based on real-time network conditions (e.g., UE count, traffic load, paging frequency) is needed. This patent proposes a dynamic K calculation that optimizes LP-WUS and PEI subgroup distribution to maintain paging efficiency and maximize UE power savings. The following shows the formula for dynamic K.

$$\mathrm{SubgroupID}_{\mathrm{LP\text{-}WUS}} = \left(\left\lfloor \frac{\mathrm{UE\_ID}}{N \cdot N_s \cdot K_{\mathrm{dyn}}} \right\rfloor \bmod \mathrm{subgroupsNumForUEID\_LP\text{-}WUS} \right) + \left(\mathrm{subgroupsNumPerPO\_LP\text{-}WUS} - \mathrm{subgroupsNumForUEID\_LP\text{-}WUS} \right)$$

$K_{\mathrm{dyn}} = \left\lceil \frac{C \cdot D}{U} \right\rceil$, C represents the number of UEs within the current cell boundary, D indicates the value for time-based power saving, and U denotes the number of paged UEs over a given period.

B. Dynamic Subgrouping Method

This section proposes a dynamic dual subgrouping method that simultaneously considers UE behavior patterns and time-based network load. The proposed approach independently configures time-based LP-WUS subgroups and behavior-based PEI subgroups, adjusting their size and distribution according to network conditions to significantly reduce paging false alarms and minimize UE power consumption.

a. User Characteristic-Based PEI Subgrouping Method

To minimize the power consumption of user equipment (UE) and improve paging efficiency, we propose a method for dynamically assigning PEI (Physical-layer Early Indication) subgroups based on each UE's behavioral and service characteristics. The network comprehensively considers the following factors to determine the appropriate PEI subgroup for each UE dynamically:

- **Past traffic frequency**: Number of UL/DL traffic events or average data volume over a given period
- **DRX cycle and RRC state history**: Patterns of periodic UE activity
- **UE mobility patterns**: Frequency of inter-cell movement, cell dwell time, handover history
- **Service type or QoS profile**: Responsiveness requirements of services used (e.g., URLLC, mMTC, eMBB)
- **Recent paging events and RF activation history**: Paging frequency, wake-up logs
- **UE location stability**: Duration of stay within the same cell or tracking area (TA)
- **UE capability information**: LP-WUR receiver sensitivity, battery status, dual-receive support, etc.
- **Time-based traffic characteristics**: Periods of the day when UE activity is concentrated

Based on this information, UEs with high data transmission frequency or requiring real-time responsiveness are assigned to small, dedicated PEI subgroups for faster paging, while inactive or low-traffic UEs are grouped into larger subgroups to prioritize power savings. This multidimensional classification better reflects real network conditions than static UE_ID-based grouping, minimizing unnecessary RF activations and reducing overall power consumption. Moreover, PEI subgrouping can be dynamically adjusted in real time to adapt to changing user behavior and service requirements, ensuring greater flexibility and efficiency.

b. Traffic Characteristic-Based LP-WUS Subgrouping Method

The first approach increases the number of LP-WUS subgroups (up to 8) during periods of low traffic load to maximize power-saving by enabling more devices to enter ultra-low-power modes. Conversely, during high traffic periods requiring lower latency, it reduces the number of subgroups to improve paging resource efficiency. The second approach focuses on assigning devices to subgroups by dynamically balancing subgroup membership based on real-time device density and traffic load, preventing over-concentration in specific groups. The network defines a time period T, measures the number of active devices CT at that time, and dynamically sets the number of subgroups NSG(T) by considering a power optimization weight WT for that period.

$$N_{SG}(T) = \left\lceil \frac{C_T \cdot W_T}{U_{opt}} \right\rceil$$

U_{opt} defines the optimal number of devices per subgroup to dynamically calculate NSG(T). Based on this formula, the final expression for assigning subgroups reflects the device density at a specific time T to ensure balanced distribution.

$$\mathbf{SubgroupID}_{\mathbf{LP\text{-}WUS}} = (\mathbf{Hash}(UE\_ID + T + D_T) \quad \mathbf{mod}\ N_{SG}(T))$$

By applying subgrouping as defined in the formula, considering both time periods and the real-time density of active devices within the cell, it is possible to balance load across subgroups. This approach prevents device concentration in specific subgroups at certain times, minimizes false paging rates, and effectively reduces power consumption.

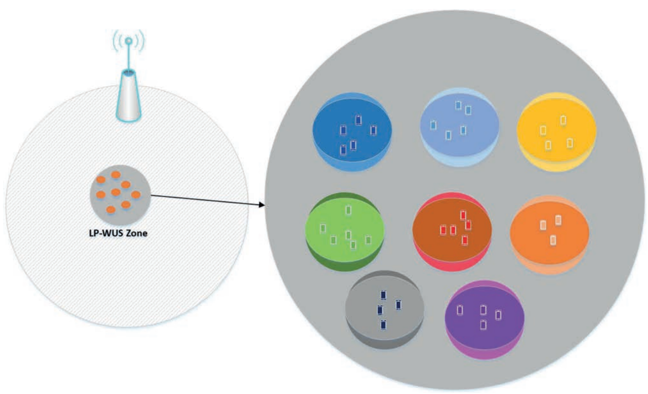

Figure 2. Dynamic Subgrouping Method (Proposed Method)

The figure illustrates the proposed method applied in this paper, showing how devices within an LP-WUS region are allocated to one of eight subgroups. By assigning each device to the most suitable subgroup based on its characteristics, this approach can mitigate the problem of subgroup congestion. Moreover, applying LP-WUS and PEI techniques tailored to device properties is expected not only to reduce unnecessary wake-up alarms and battery consumption but also to improve overall network efficiency.

IV. SIMPLE SIMULATION

In this paper, paging efficiency and power savings are identified as key performance metrics for large-scale IoT networks, and simulations were conducted to evaluate the effectiveness of the proposed dynamic subgrouping method by measuring the False Wake-Up Rate and average power consumption per UE under various UE densities and traffic load conditions, and comparing them to the static approach. The first simulation evaluated the False Wake-Up Rate, which represents the proportion of devices unnecessarily activated by wake-up signals and serves as a key metric for assessing paging efficiency. Simulation results show that the proposed dynamic subgrouping method reduces the False Wake-Up Rate by over 40% compared to the conventional static approach across various UE density scenarios, with particularly significant improvements observed under high-density conditions.

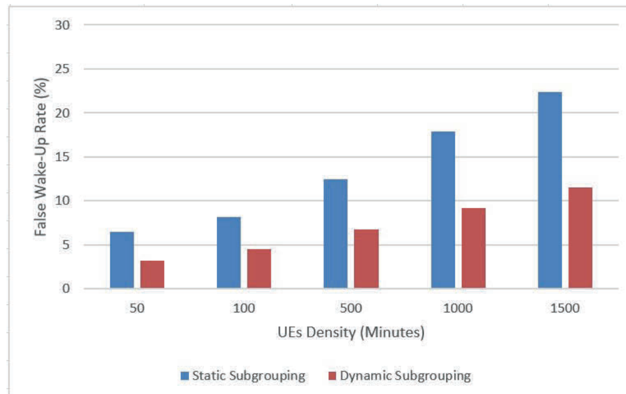

Figure 3. False Wake-Up Rate Result

The second simulation evaluated the Average Power Consumption per UE, which measures the mean energy usage of devices and is a critical indicator of battery efficiency in IoT networks. Simulation results demonstrate that the proposed dynamic subgrouping method achieves 20–30% lower average power consumption per UE compared to the static approach under various traffic load conditions, highlighting its effectiveness in reducing overall energy usage, especially during high-load periods.

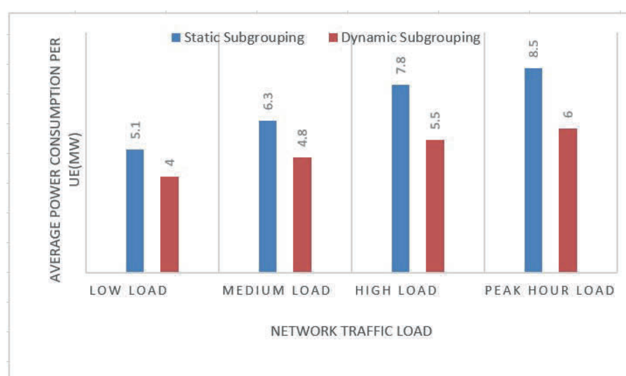

Figure 4. Average Power Consumption Result

Simulation results show that the proposed dynamic subgrouping reduces the false wake-up rate by over 40% compared to static grouping, particularly under high-density scenarios. It also achieves 20–30% lower average power consumption per UE under varying traffic loads, demonstrating its effectiveness in real-world network conditions.

V. CONCLUSION

his paper proposed a dynamic subgrouping method to improve power efficiency in IoT devices. Simulation results showed that the proposed approach effectively reduces the False Wake-Up Rate and lowers average power consumption per UE compared to conventional static grouping. These results demonstrate that the method can achieve both paging efficiency and power savings in large-scale IoT networks. However, future work is needed to address challenges such as real-time applicability in diverse network environments, optimization of computational complexity, and integration with standardization efforts.

ACKNOWLEDGMENT

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