A highly reliable power saving method for IoT devices in a wireless environment

Minsuk Choi
AI Convergence Security Research Section
Electronics and Telecommunications Research Institute
Daejeon, Republic of Korea
yerocker@etri.re.kr

Jaedeok Lim
AI Convergence Security Research Section
Electronics and Telecommunications Research Institute
Daejeon, Republic of Korea
jdscol92@etri.re.kr

Abstract **During recent 3GPP standards meetings, diverse approaches were put forward to mitigate power consumption during state transitions (Connected/Idle) in IoT devices. Notably, the UE assistance information and Data-Inactivity methods were introduced to enhance power efficiency through the RRC Release procedure. However, these methods were found to be constrained by specific scenarios. This paper addresses the limitations of the UE assistance information and Data-Inactivity method while presenting a novel approach that boosts battery efficiency compared to existing methods and addresses issues encountered in exceptional situations. Furthermore, as a future study, we propose exploring a method to bolster security and enhance the stability of the procedure outlined in this paper.**

Keywords*— *Stability of IoT Devices, Power saving method, Formal method, 5G security

I. INTRODUCTION

The rapid development and diverse applications of mobile communication IoT devices have led to ongoing studies aimed at mitigating the side effects they bring. Among these, the persistent challenge of IoT device battery efficiency has garnered significant research attention, with efforts focused on analyzing the issue from multiple perspectives and devising strategies to improve overall efficiency. [1]

In the recent 3GPP standard meeting, numerous contribution reports were presented to address the power consumption issue during state transitions (Connected/Idle) in IoT devices. Typically, an IoT device establishes a link with a base station and core network in an RRC Connected state to receive services. When no further service is required, the IoT device transitions to an idle state, and the base station initiates the RRC Release procedure to terminate the connection. However, this procedure incurs power consumption due to its time duration. Hence, several studies are underway to tackle these challenges. To address this issue, we propose a novel mechanism for transmitting UE assistance information messages, enabling IoT devices to transition to the idle state more rapidly and reducing battery consumption compared to existing methods. Additionally, we suggest a method for effectively transmitting UE assistance information utilizing the existing message framework. In future research, our focus will be on exploring formal methods to ensure highly reliable message transmission between IoT devices and base stations. By adopting these approaches, we aim to optimize power efficiency during state transitions, enhance the speed of IoT device transitions to the idle state, and ultimately mitigate battery consumption. [2][3]

II. RELATED WORK

In the current method, the RRC release procedure is utilized to terminate the wireless connection between the IoT device and the base station. However, this procedure leads to increased power consumption. To address this issue, an alternative approach was introduced, simplifying the procedure by eliminating the ack/nack message transmitted from the IoT device during the RRC Release procedure. While this simplification effectively reduces power loss, it gives rise to a state mismatch problem between the IoT device and the base station due to the absence of the RRC Release message. To resolve this problem, two proposed methods have been put forward. [4]

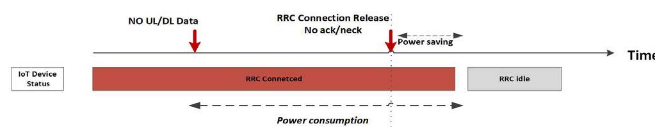

Figure 1. RRC connection No ack/nack mechanism

A. DataInactivityTimer Method

The IoT device incorporates a DataInactivityTimer that initiates when the service is terminated, triggering a transition from RRC Connected to RRC Idle. By allowing the timer to expire, the IoT device smoothly transitions to the idle state, mitigating the occurrence of a state mismatch problem even if a message is lost during the RRC Release procedure. However, it is important to note that increasing the frequency of state transitions due to the timer value setting can potentially lead to an increase in power consumption. [5]

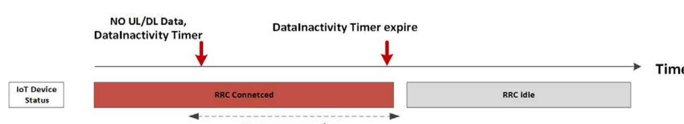

Figure 2. DataInactivityTimer mechanism

B. UE assistance information Method

When an IoT device no longer requires a service, it initiates an RRC release procedure by transmitting a UE assistance information message to the base station. The release assistance indication (RAI) is defined in the 3GPP TS 24.301 document, presenting a procedure for transmitting release-related information from the IoT device to the base station. [6]

8	7	6	5	4	3	2	1	
Release assistance indication IEI				0 Spare	0 Spare	DDX		octet 1

Figure 9.9.4.25.1: Release assistance indication information element

Table 9.9.4.25.1: Release assistance indication information element

Release assistance indication value

Downlink data expected (DDX)

Bits
2 1
0 0 No information available
0 1 No further uplink or downlink data transmission subsequent to the uplink data transmission is expected
1 0 Only a single downlink data transmission and no further uplink data transmission subsequent to the uplink data transmission is expected
1 1 reserved

Bits 3 and 4 of octet 1 are spare and shall be encoded as zero.

Figure 3. TS 24.301 Release assistance indication

Frequent and irregular patterns in the data within this method lead to frequent state transitions, causing a decrease in efficiency. [7]

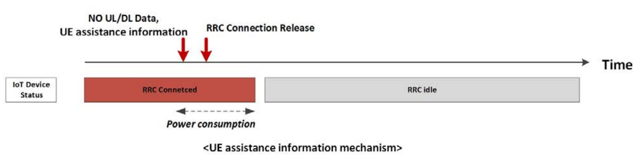

Figure 4. UE assistance information mechanism

III. PROPOSED METHODS

In this chapter, a method is proposed to address the power consumption issue associated with the DataInactivityTimer and UE assistance information mechanism discussed in the preceding chapter.

A. Multiple DataInactivityTimers

The Multiple DataInactivityTimers method offers the advantages of the DataInactivityTimer approach by addressing the state inconsistency issue encountered in the UE assistance information method. Additionally, it resolves the performance degradation problem associated with the DataInactivityTimer method. This method dynamically sets the DataInactivityTimer value based on the traffic pattern. While several approaches exist for defining the DataInactivityTimer value, this paper proposes a method that aligns with the mobile communication standard document. Within the 5G NR architecture, which encompasses multiple interfaces between UE, gNB, and 5G, two methods are proposed. The first method involves defining a timer per PDU session and associating it with specific applications.

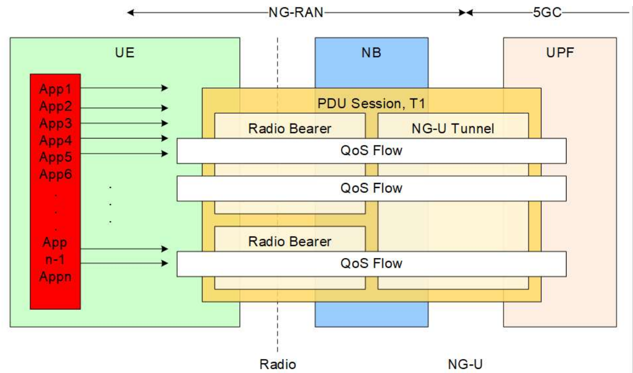

Figure 5. Mapping between application and PDU session timers

Figure 5 and Figure 6 illustrate the process of defining T1 within the PDU session and assigning the corresponding application to T1. Furthermore, the second method involves defining a timer for each QoS flow within the PDU session and associating the appropriate application with the timer defined in the QoS Flow.

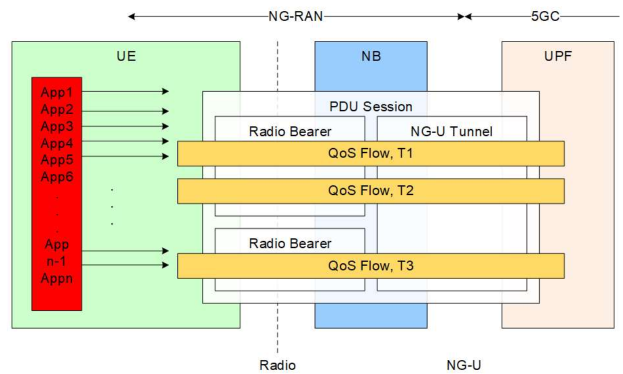

Figure 6. Mapping between applications and QoS Flow timers

The performance of the system can be influenced by factors such as the method of timer definition, the number of allocated timers, and the traffic pattern of the application. While allocating a large number of timers can enhance performance, it also introduces complexity. Thus, there is a need for an optimization method to allocate appropriate timers efficiently.

B. Formal method for Stability of IoT Devices

In order to provide stability and reliability of the method proposed in this paper, a security-enhanced protocol can be used. However, problems caused by errors in the implementation stage become factors that make low stability. The main idea behind formal methods is to use mathematical models, formal languages, and logical reasoning to describe and analyze the behavior of a system. By mathematically representing the system's requirements, design, and execution, formal methods enable the detection of potential errors or inconsistencies early in the development process, thereby reducing the likelihood of costly failures or vulnerabilities in the final product. Some key aspects and techniques associated with formal methods include formal specification and model checking. Based on these technologies, it provides high reliability by supplementing the shortcomings of the existing method by proving and proving the performance of the entire system. The application of formal verification for IoT devices will continue as a future study. [8]

IV. SIMPLE SIMULATION

The simulation conditions were set as follows: a total of 10 virtual applications were created, generating IP packets ranging from 128 bytes to 1400 bytes using the IXIA Packet generator. The data transmission occurred at random time intervals between 1 second and 10 seconds. Method 1 utilized a single DataInactivityTimer, while Method 2 employed Multiple DataInactivityTimers with 3 PDU sessions assigned to 3 timers. Method 3 utilized Multiple DataInactivityTimers with 5 timers allocated to 5 QoS flows. Figure 7 shows the results depicting the number of state transitions for each method.

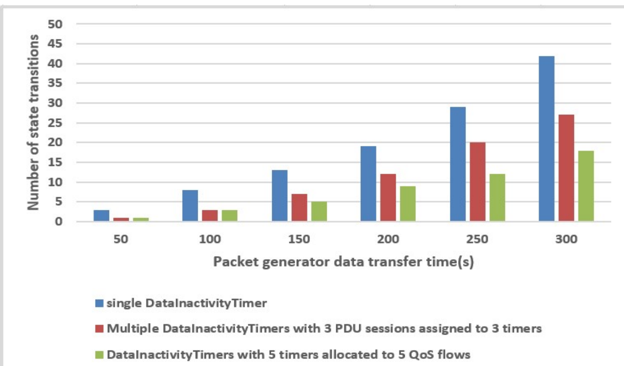

Figure 7. Number of state transitions per method

The significant performance disparity observed over time can be attributed to the gradual increment in the volume of traffic.

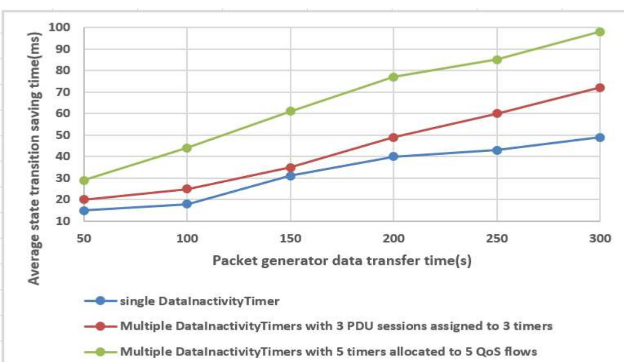

Figure 8. Power savings over time per method

Figure 8 illustrates the simulation results, revealing intriguing insights. Initially, Method 1 and Method 2 demonstrate similar values up to the 150-second interval, with Method 2's performance exhibiting an upward trend starting at the 200-second mark. Notably, Method 3 consistently outperforms other methods from the initial 50-second interval to the 300-second interval. The analysis of these results highlights the effectiveness of configuring multiple timers tailored to application characteristics, leading to improved performance and reduced state transitions in IoT devices. It is worth noting that although an increased number of timers yields benefits, such as enhanced performance and reduced state transitions, it necessitates adequate resource allocation and careful management due to heightened operational complexity. Thus, setting appropriate timers becomes crucial in balancing these factors effectively.

V. CONCLUSION

Research has focused on enhancing battery efficiency in IoT devices by reducing the RRC release procedure. The DataInactivityTimer method and the UE assistance information method are effective approaches for reducing RRC release procedure and improving energy efficiency. However, challenges arise when dealing with diverse data patterns and inconsistent device states. To address this issue, this paper proposes the Multiple DataInactivityTimers method. Simulation results demonstrate the promising performance of the proposed method. Nonetheless, further research is required to effectively manage multiple timers and optimize their quantity. Moreover, as a future study, applying the formal method proposed in Section B of Chapter 3 will be explored to foster the development of more reliable and stable IoT devices.

ACKNOWLEDGMENT

This work was supported by Institute of Information & communications Technology Planning & Evaluation (IITP) grant funded by the Korea government(MSIT) (No. 2022-0-00103, Development of security verification technology against vulnerabilities to assure IoT/IIoT device safety).

REFERENCES

[1] IT WORLD, http://www.itworld.co.kr/news/114234.

[2] Qualcomm Inc, "Fast Transition to RRC_IDLE or RRC_INACTIVE", 3GPP TSG RAN WG2 Meeting #105bis, R2-1903046, 2019.

[3] Marcus Vinícius G. Ferreira, Flávio H. T. Vieira, Alisson A. Cardoso, "Resource scheduling scheme for 5G mmWave CP-OFDM based wireless networks with delay and power allocation optimizations", ETRI Journal, Volume 45, Issue 1, 05 February 2023.

[4] ZTE Corporation, "Efficient transition from RRC_CONNECTED to RRC_IDLE/RRC_INACTIVE", 3GPP TSG RAN WG2 Meeting #105bis, R2-1903620, 2019.

[5] Vivo, "Efficient transition from RRC_CONNECTED to RRC_IDLE ", 3GPP TSG RAN WG2 Meeting #105bis, R2-1903198, 2019.

[6] Xiaomi Communications, "Considerations on UE assisted RRC state transition", 3GPP TSG RAN WG2 Meeting #105bis, R2-1903913, 2019.

[7] Prashanth Lingala; Pavan Reddy M; Saidhiraj Amuru; Kiran Kuchi, "Energy and Delay Efficient Intelligent Release Assistant Indication Scheme for NB-IoT", COMSNETS 2022, pp. 246-250, January 2022.

[8] Javad Dogani, Mahdieh Farahmand, Hassan Daryanavard, "A new method to detect attacks on the Internet of Things (IoT) using adaptive learning based on cellular learning automata", ETRI Journal, Volume 44, Issue 1, 21 December 2021.