Logic Controller-Based Discontinuous Reception (DRX) System for NR

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Abstract. In Long Term Evolution (LTE) system, discontinuous reception (DRX) mechanism is widely used as a reliable and effective means of reducing energy consumption. Moving to 5G New Radio, the application scenarios of massive MachineType of Communication (mMTC) have become increasingly clear, which will support ultra-large-scale device accessing into the network. Therefore, the need for energy efficiency improvement of terminal equipment is becoming more and more urgent under 5G NR. In this paper, a logic controller-based DRX system was proposed to make original DRX more efficient. With logic controller, DRX parameters can be adaptively adjusted by learning the information of historical delay time and packets arrival rate. And then, a better performance of energy conservation will be achieved. Simulation results show the performance improvement of the proposed DRX system.

1. Introduction
As the Fifth Generation Mobile Communication Technology (5G) continues to use for commercial purposes, massive MachineType of Communication (mMTC), one of three generic services, make business models getting increasingly complicated and business scenarios more extensive. Because of the need of supporting ultra-large-scale device accessing into the network, energy consumption of terminal equipment has become a point that cannot be ignored. In Long Term Evolution (LTE) system, Discontinuous reception (DRX) system is widely used as a reliable and effective means of reducing energy consumption. Therefore, it will be continuously used as an improvement method of energy efficiency in 5G New Radio (NR) system.

The core idea of discontinuous reception mechanism is to allow user equipment (UE) to enter a periodic monitoring state by using the characteristics of the data packets intermittent arrival during transmission. The rest of time when there is no data packet receiving requirement, UE can turn off its transceiver and get into the sleep state to reduce energy consumption. However, since UE in sleep state cannot handle data packets that arriving in this phase in time, a delay time problem of data packet reception will occur. It is necessary to solve the problem of balance between energy efficiency improvement and time delay guarantee in DRX. Therefore, a lot of researchers begin to investigate DRX mechanism for performance improving at present. In [1] Tirronen illustrate longer DRX cycle can reduce the power consumption at the expense of increased delay time in machine-to-machine (M2M) communications. In [2] Wang proposed a novel DRX mechanism with switching DRX cycles, which could translate states according to the packet arrival rate. In [3] Jin developed an analytical model to analyse the trade-off of latency and power consumption. In [4] Zhou modelled the DRX mechanism by semi-Markov chain and research an accurate relationship between the power efficiency
and time delay. Unfortunately, those research work only study under a stationary traffic pattern whose information is already known. However, in NR system, traffic models are complex and changeable. Thus, it is beneficial to design an adaptive DRX mechanism which can modify its parameters to achieve better power efficiency by studying traffic patterns.

In this paper, logic controller (LC) is introduced to adaptively modify DRX parameters and the simulation time is divided into several decision windows. In a current window, there will be two logic controllers: delay time logic controller and packet arrival logic controller. On the one hand, time delay in this decision window will adaptively control the value of DRX cycle $T_{cycle}$. On the other hand, the traffic pattern, judged by packet arrival rate, will adaptively control the value of DRX Inactivity timer $T_{in}$ and the short cycle timer $M$ by using logic algorithm. Finally, all DRX parameters will update in the next decision window. Those adaptively parameters will help DRX mechanism save more power based on guaranteed delay time.

The remainder of this paper is organized as follows. Section 2 introduces the DRX mechanism and shows the proposed logic controller-based DRX. Section 3 presents the results and discussions. Section 4 concludes this paper.

2. Materials and Related Works

2.1. Discontinuous reception mechanism

DRX is an effective method to reduce the energy consumption of UE and has been widely used in NR system. The basic idea of DRX mechanism is that UEs only work in periodic monitoring. Due to the intermittent arrival of the data packet, it allows devices to turn off its transceiver circuit when there is no data transmission. However, using this system will cause an increase in delay time, which in turn will not guarantee the quality of service (QoS) of UE. Therefore, a reasonable scheduling algorithm in DRX should take into consideration to achieve better performance of power saving and time delay.

The radio resource control (RRC) layer configures the system parameters of DRX in NR network. According to the difference of RRC states, DRX mechanism judges whether UE is in RRC_Idle or RRC_Connected, respectively. In idle state, UE only register a unique identification code in 5G Core and have not processed a communication. In connected state, DRX will help UE to periodically monitor the physical downlink control channel (PDCCH) to detect whether a data packet arrives. To simplify the scenario analysis, this paper only considers the state switching of the terminal after the DRX mechanism is turned on in RRC_Connected state. The relevant timers used in DRX mechanism are shown as follows [5]:

- On-duration timer: In the initial stage of each DRX cycles, UE wakes up to receive package from monitoring PDCCH.
- Inactivity timer: When UE successfully decode UL or DL message from PDCCH, it will start this timer. Until there is no new packet and Inactivity timer end can UE turns into sleep. It is the same like an extension of On-duration timer.
- Short cycle timer: When UE have not received packet in this number of cycles, it switches to long DRX cycle from short DRX cycle.

DRX mechanism use a combination of timers and DRX cycles under RRC_Connected state and base station (BS) will also maintain the same DRX mode as UE. So that it can ensure whether transmitting data in DRX active state or no data transmission during sleep time, respectively.

When DRX mechanism is initiated in UE, it applies to start short cycle timer firstly. However, no matter in long or short cycle, DRX will start On-duration timer and monitoring PDCCH in the beginning of DRX cycle. On the one hand, if there is no new packet received or handled and timer is over, UE will turn into sleep in the rest time of this DRX cycle. On the other hand, if there are new packets receiving or not yet processed, UE will handle those data and start Inactivity timer. Until there is no new packet and Inactivity timer end can UE turns into sleep. Otherwise, UE will start a new Inactivity timer and continue to monitor. After a period, this cycle is over and a new DRX cycle will
begin with On-duration timer starting. When short cycle timer countdown to 0, UE will switch to long DRX in next cycle. As shown in Fig. 1.

![DRX mechanism](image)

**Figure 1. DRX mechanism**

### 2.2. Logic controller-based DRX mechanism

To increase the power efficiency improvement as much as possible based on ensuring the delay time, logic controller-based DRX mechanism is proposed in this paper. By dynamic adjusting DRX timers and parameters, the system will be suitable for current traffic pattern, so that energy consumption can be reduced. In the novel adaptive algorithm, time of operating DRX system is divide into several decision windows (DW), so that each DW includes many DRX cycles. The statistical data of delay time and packets arrival rate during current DW is calculate in BS.

Furthermore, each decision window consists of delay time logic controller (DTLC) and packets arrival rate logic controller (PARLC). In delay time controller, the data of delay time is used to control the length adjustment of DRX cycle, which is also applied as input for packets arrival rate logic controller. In the second controller, we can use arrival rate of packet to predict the traffic pattern in next DW. And then, with adaptive DRX cycle, controller will output the adjustment of inactivity timer and short cycle timer, respectively. By using logic controller, proper DRX timers and parameters can bring better performance.

### 2.3. Delay time logic controller (DTLC)

Because of allowing UE turn off and getting into sleep, DRX mechanism result in an increase in time delay, which in turn will not guarantee the QoS. The packets drop problem in buffer of BS is also possibly leaded by large packets latency. To resolve the balance between energy saving and latency, statistical data of packets delay time is applied to adjust the parameter of DRX cycle. The reason is that length of DRX cycle is the key factor most directly affects whether the data packet can be handled in time.

The average packet delay time that calculated by BS in current DW is feed into DTLC for logic control. The control process uses membership function to compute the membership degree of delay time. The function of average packet delay time is illustrated in Fig. 2. Furthermore, the value of membership parameters, obtained by QoS data, can be tuned through simulation.

Then, the previously obtained membership degree can be used to compute the mapping degree of adjustment rule as Table 1. The corresponding action denotes by the rule can adjust the length of DRX short cycle, where +1 means extend DRX short cycle length with 10ms and +2 means extend DRX short cycle length with 20ms, respectively. On the contrary, -1 denotes reduce DRX short cycle length with 10ms. Anyway, length of DRX short cycle is still in the range of 40ms to 160ms. Furthermore, DRX long cycle is always three times the length of short DRX cycle.
2.4. Packet arrival rate logic controller (PARLC)

BS can observe the data packets from network and record its arrival time. And then, the traffic pattern can be predicted by computed packets arrival rate. With the input of adjustment DRX cycle from DTLC and packets arrival rate, PARLC can output adaptive short cycle timer and inactivity timer.

Short cycle timer means how fast DRX system translate short cycle to long cycle. Through this idea, controller uses Eq. (1) to calculate short cycle timer $M$:

$$M = \left\lfloor \frac{T_{cycle} \cdot e}{T_{rate}} \right\rfloor$$  \hspace{1cm} (1)

Where $T_{cycle}$ is defined as length of DRX short cycle and $T_{rate}$ is the packet arrival rate. $L$ denotes the proportion of DRX long/short cycle. In this paper, DRX long cycle is always three times the length of short DRX cycle, so that $L = 3$. The value should round down before assignment. When packets arrive sparsely and DRX short cycle is much smaller than arrival rate, it means that UEs can turn into DRX long cycle quicker with more energy saving and unaffected time delay. On the contrary, if packets arrive time is similar as DRX short cycle, long DRX cycle that may cause large latency should be abandoned. So that PARLC use the ratio of DRX short cycle and packet arrival rate to control the short cycle timer. Besides, if the ratio is small, due to there is a high probability that no more data packets will be received, a long inactivity timer is useless. And if the ratio is large, inactivity timer should be longer for preparing to receive data packets. The formula for calculating inactivity timer is shown in Eq. (2). And the Parameters value of inactivity timer $T_{in}$, can be tuned through simulation and QoS data. Finally, all new parameters will update in the next decision window.

$$T_{in} = \begin{cases} 
5, & M \leq 3 \\
7, & M \leq 6 \\
10, & \text{otherwise}
\end{cases}$$  \hspace{1cm} (2)

3. Simulation Result and Discussions

To evaluate the performance of logic controller-based DRX mechanism and conservational DRX mechanism, simulation is conducted on MATLAB codes. The whole time of simulation is 1800m (30min) and have been divided into five time-intervals. In the first three intervals, the traffic patterns
are FTP Model 3, which follow Poisson distribution with parameter $\lambda = \{100, 200, 400\}$. In the last two interval, the traffic patterns are HTTP with reading time parameter $D_{pc} = \{2000, 4000\}$. The other parameters are summarized in Table 2.

| Parameters                  | Value         |
|-----------------------------|---------------|
| Decision window             | 5000ms        |
| Original DRX short cycle    | [40, 80, 120, 160]ms |
| On duration timer           | 5ms           |
| Inactivity timer            | 10ms          |
| Short cycle timer           | 6             |

The simulation results of average power consumption and average delay time are shown in Fig. 3 and Fig. 4, respectively. It is shown that the performance of logic controller-based DRX mechanism is better than conservational DRX, no matter in energy saving or in delay time. Because of adaptive adjusting parameter during data reception, the proposed mechanism can extend DRX cycle and get into DRX long cycle fast when the packets in time-intervals are sparse. On the contrary, it can also reduce DRX cycle and refuse to turn to DRX long cycle when the packet arriving frequently. The dynamic parameters make logic controller-based DRX mechanism indeed save more power with guaranteed delay time.

![Figure 3. Average power consumption](image1)

![Figure 4. Average delay time](image2)

4. Conclusions

In this paper, a modified DRX mechanism basing on logic controller is proposed. With adaptive parameters, DRX can be suitable for different traffic patterns. And the result shows better performance by using logic controller-based DRX mechanism both in energy saving and delay time, which proves that it is feasible in NR system.

References

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