XR-specific C-DRX Enhancement for UE power saving in 5G NR

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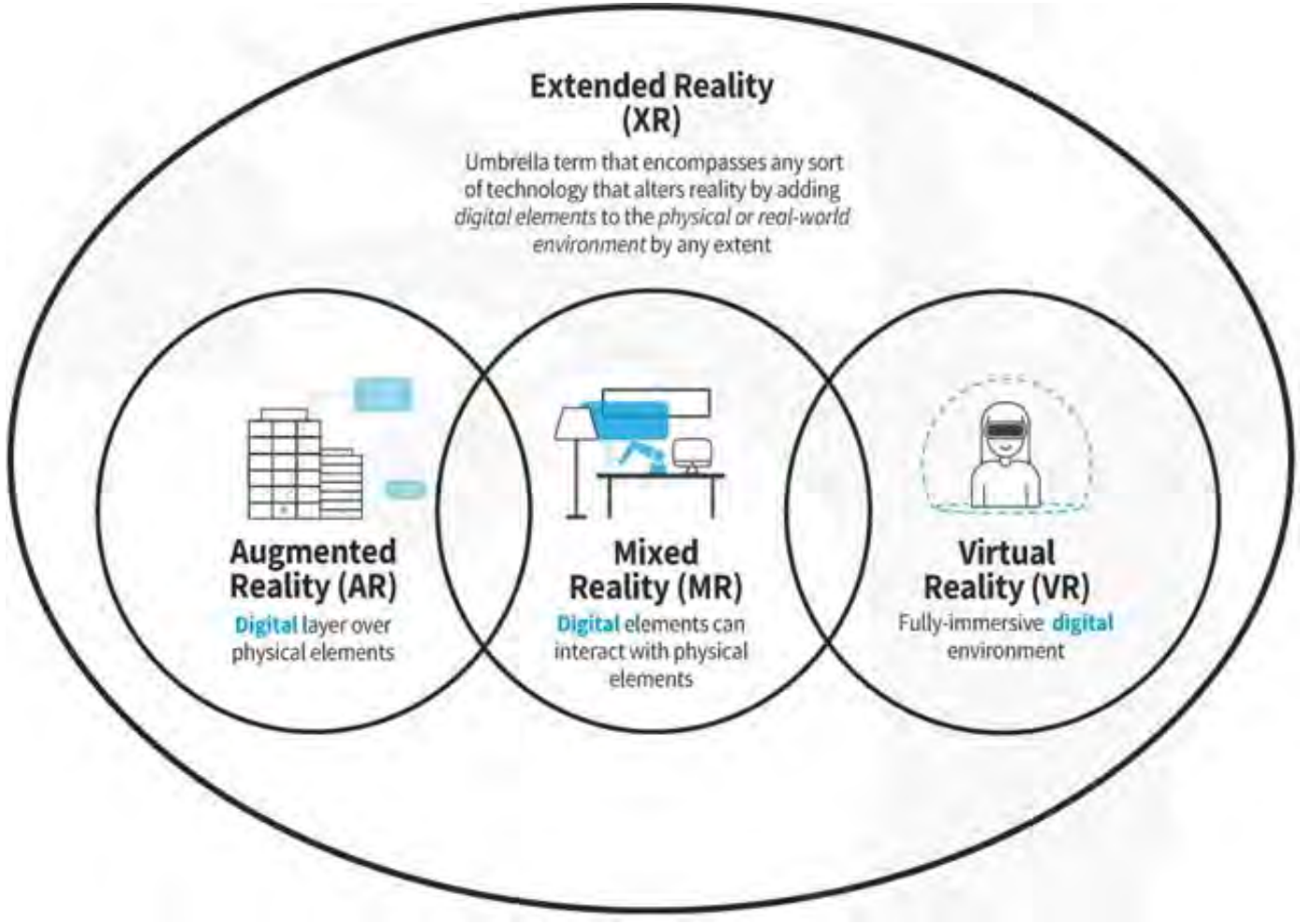
Introduction

Extended Reality (XR)

- Extended Reality (XR) is an umbrella term encapsulating Augmented Reality (AR), Virtual Reality (VR), Mixed Reality (MR), and everything in between.
- AR is the integration of digital information with the user's environment in real time. e.g. Snapchat
- VR is a computer-generated environment with scenes and objects that appear to be real, making the user feel they are immersed in their surroundings. e.g. Car racing game
- MR is a hybrid of augmented reality and virtual reality e.g. furniture fitting

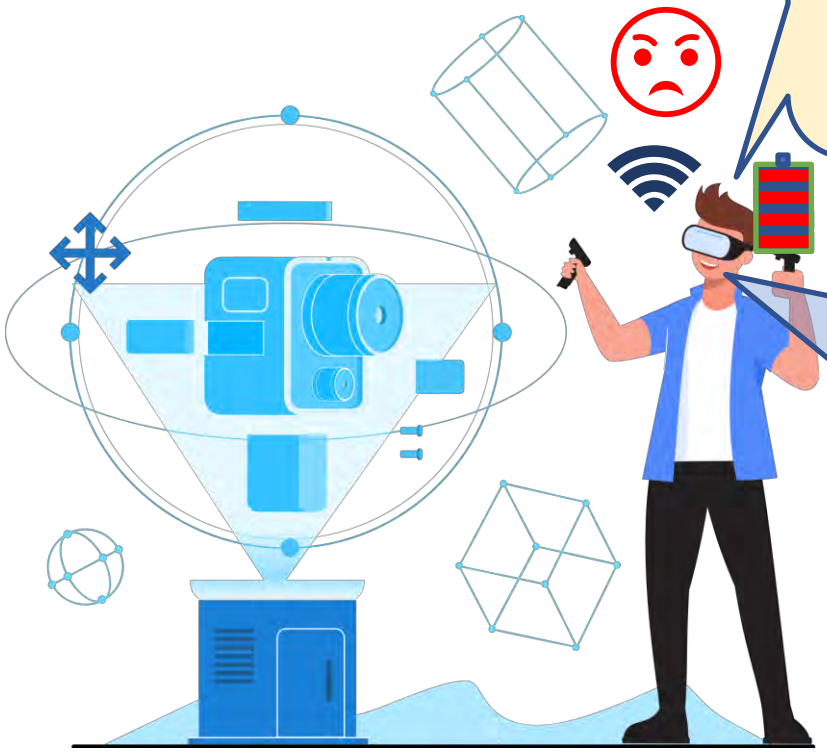


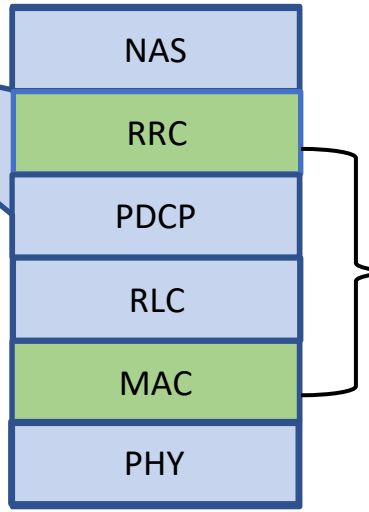
Source: https://www.interaction-design.org/literature/article/beyond-ar-vs-vr-what-is-the-difference-between-ar-vs-mr-vs-vr-vs-xr

Energy Efficiency for Extended Reality (XR)

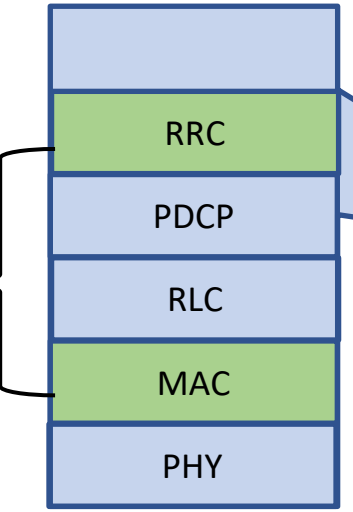
- XR UE
- Limited Battery
- XR is time critical and bandwidth hungry
- Efficient energy saving scheme required

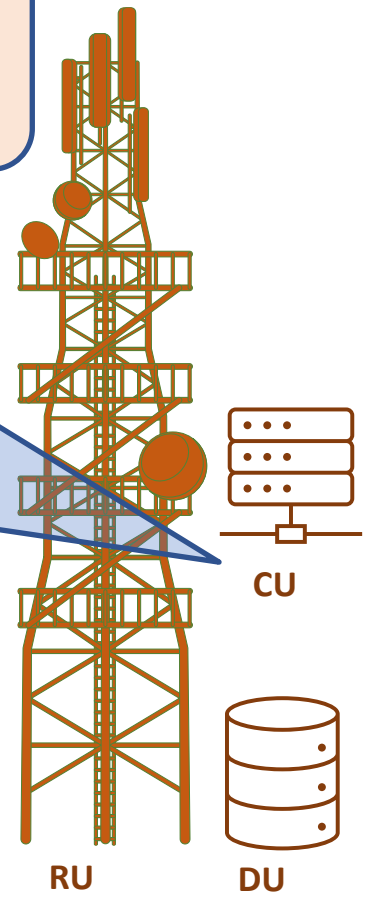
Propose Method and system modifications for improved energy saving during XR sessions





Implements C-DRX for energy savings in 5G NR





5G NR Control Plane Protocol Stack

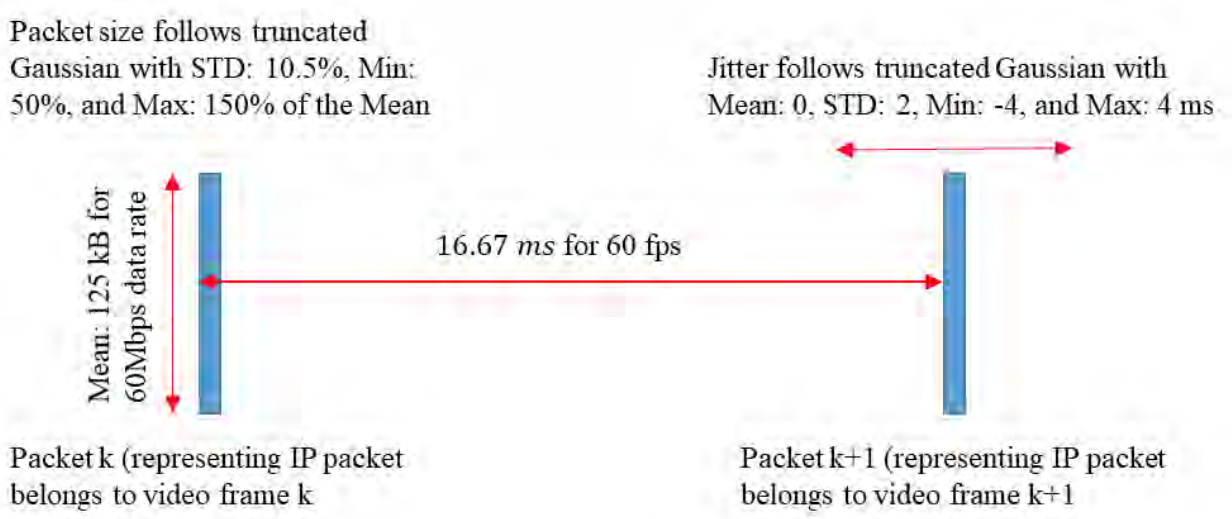
gNB (RU+DU+CU)

RRC – Radio Resource Control, MAC – Media Access Control, DRX – Continuous Mode Discontinuous Reception, NAS – Non-Access Stratum, PDCP – Packet Data Convergence Protocol, RLC – Radio Link Control

Background

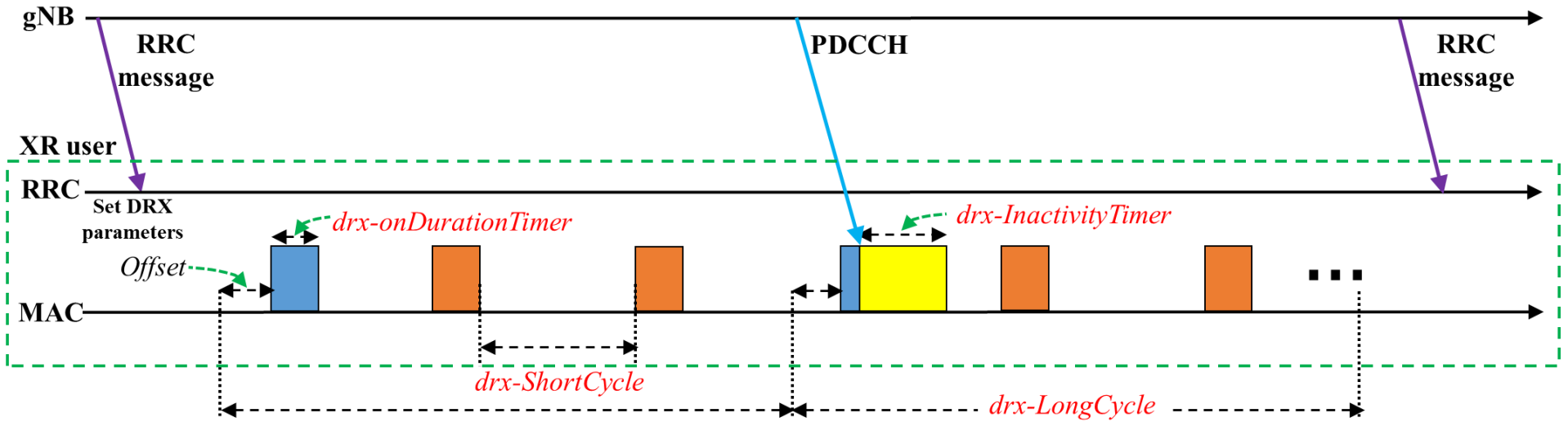
XR traffic characteristics [1]

- XR traffic can be modeled by pseudo-periodic arrivals
- XR devices generates frames in every $\frac{1}{r_f}$, where r_f is the frame rate
- Due to encoding, compression, routing, and processing the XR frames reach base station with a jitter
- Jitter follows truncated Gaussian between -4 ms to 4 ms with mean 0 and standard deviance 2
- Mean frame size is $\frac{r_d}{r_f}$, r_d is data rate
- Frame size follows truncated Gaussian between 50% and 150% of the mean with standard deviance 10.5% of the mean



C-DRX

- C-DRX- method of saving UE power by allowing the UE to periodically enter into a sleep mode
- Long DRX cycle time and ON duration is configured with ***drx-LongCycle*** and ***drx-onDuration***
- The location of the ON duration is configured with the help of ***drx-LongCycleStartOffset*** and ***drx-SlotOffset***
- ***drx-LongCycleStartOffset*** indicates starting sub-frame of the ON duration from a DRX cycle
- ***drx-SlotOffset*** indicates the slot number of the start of ON duration from the beginning of the starting sub-frame
- If no PDCCH is received during the on-timer, then the XR user (UE) enters into a sleep mode
- Otherwise, inactivity timer, configured by ***drx-InactivityTimer***, starts
- If no PDCCH is received during inactivity timer then UE enters into sleep mode, and otherwise, restart the inactivity timer



Sleep modes [4]

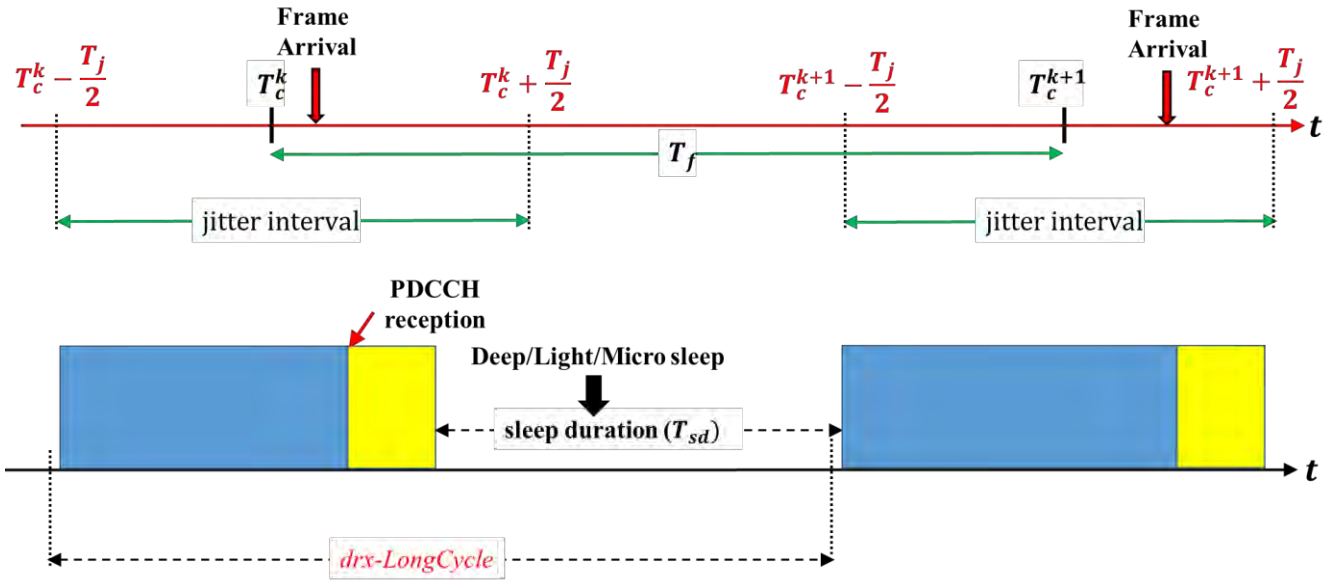
Sleep modes	Relative Energy/slot	Transition Energy	Transition time (ms)
Deep sleep	1	450	20
Light sleep	20	100	6
Micro sleep	45	0	0

- Deep sleep has the highest energy saving figure, while Micro sleep has the lowest
- Transition energy and transition time of Deep sleep is much higher than Micro sleep
- Selection of sleep mode as a function of sleep duration is important
- If sleep duration is high then Deep sleep is better while for short sleep duration Micro sleep is better
- Need to calculate threshold of sleep duration for deep and light sleep

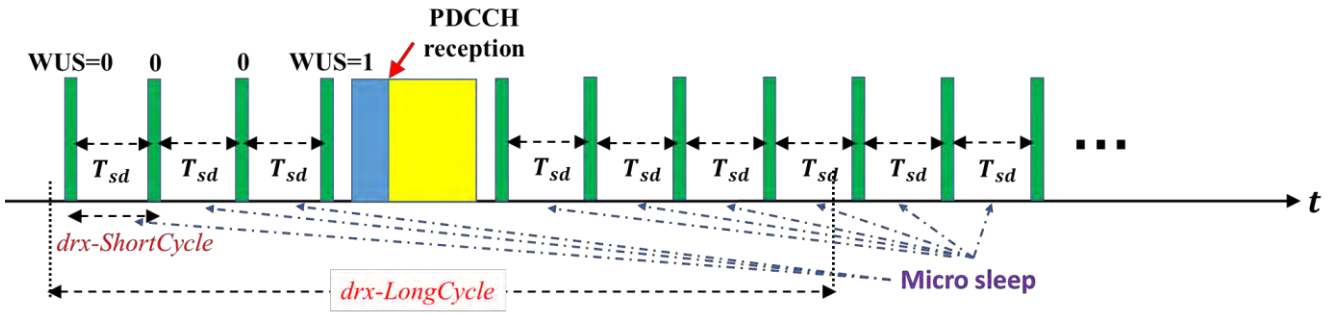
Motivation

Existing methods and their drawbacks

- For traditional C-DRX, ON-Timer should be the same as the jitter interval
- Poor energy savings figure
- To improve energy saving, periodic wake-up is required
- Proposed method of [2-3] use dense placement (every 2-3 ms) of Wake-up Signal (WUS)
- ON duration starts when WUS=1
- WUS period can be informed by ***drx-ShortCycle***
- Only Micro sleep can be employed, causing poor energy saving



Traditional C-DRX Method



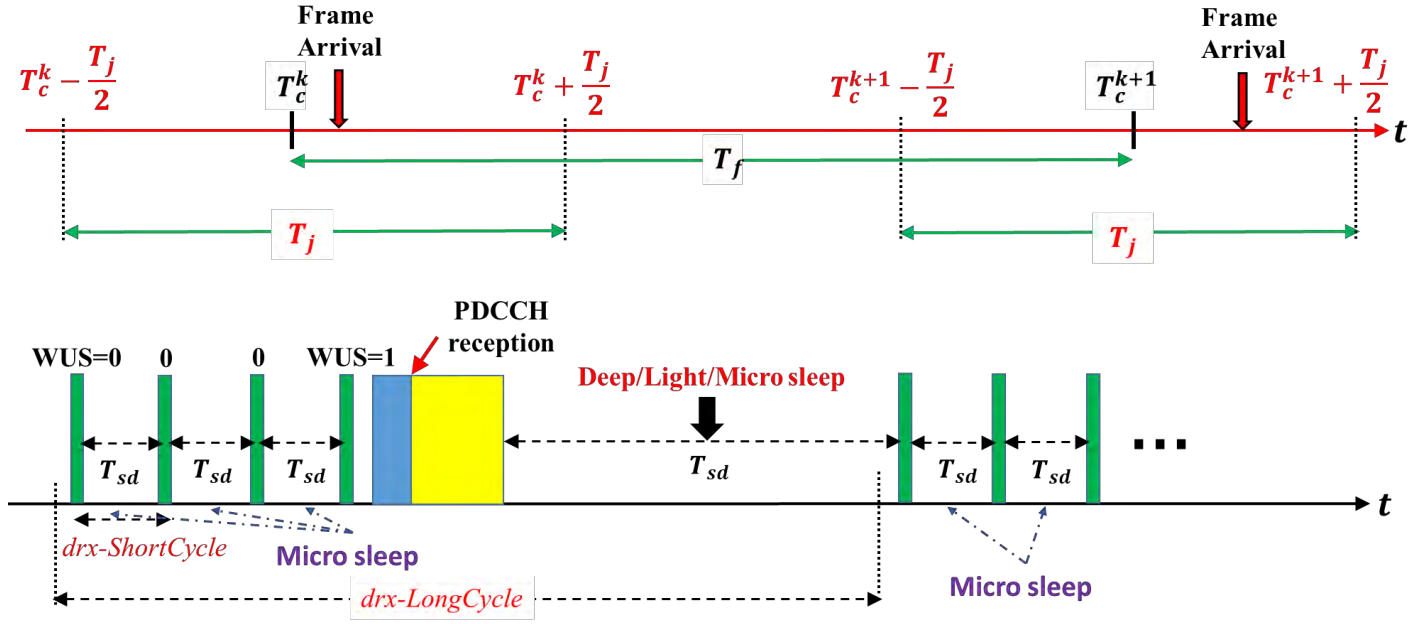
Method proposed by [2-3]

Scope of Improvement

- XR frames cannot arrive in between $T_c^k + \frac{T_j}{2}$ and $T_c^{k+1} - \frac{T_j}{2}\ \forall k$ (T_j – Jitter interval)
- WUS messages during this period can be skipped
- XR device must start periodic WUS at $T_c^k - \frac{T_j}{2}\ \forall k$
- WUS skipping increases sleep duration
- Sleep duration during WUS skipping is different for different drx cycles
- Dynamic selection of sleep mode is required

➢ Objectives:

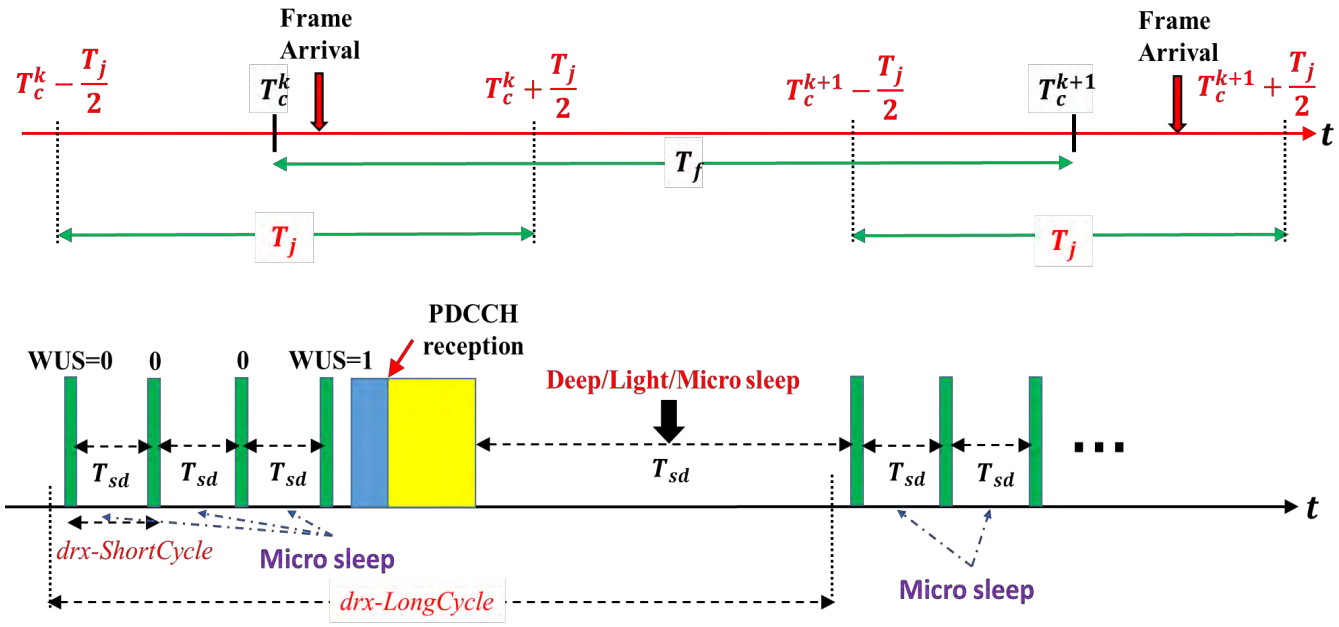
❑ **How to enable WUS skipping**
❑ **How to select sleep modes**



Proposed Enhanced C-DRX Method

Outline of the proposed enhance C-DRX method

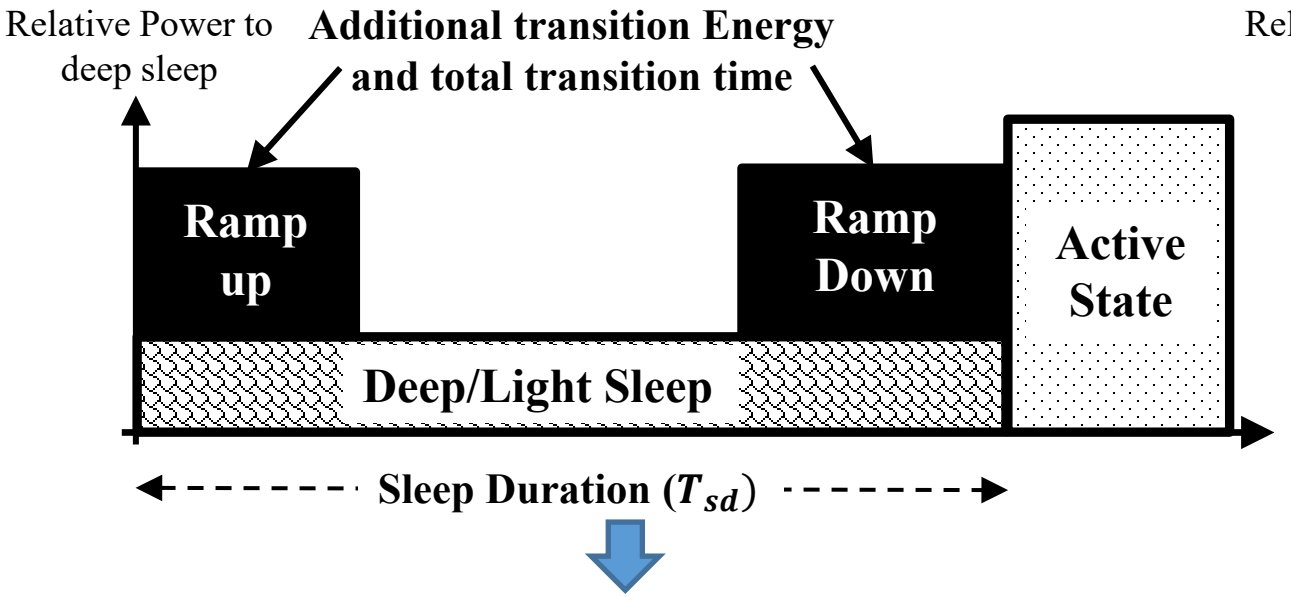
- An XR device periodically wakes up to receive a WUS message until it receives a PDCCH message
- Configure periodic WUS with *drx-ShortCycle*
- The periodic WUS for the k^{th} drx cycle starts at $T_c^k - \frac{T_j}{2}$
- During two consecutive WUS message Micro sleep is employed
- If WUS=1, the XR device skips all future WUS messages till the ON period of the next long cycle i.e., sleep till $T_c^{k+1} - \frac{T_j}{2}$
- Before entering sleep, choose the most efficient sleep mode

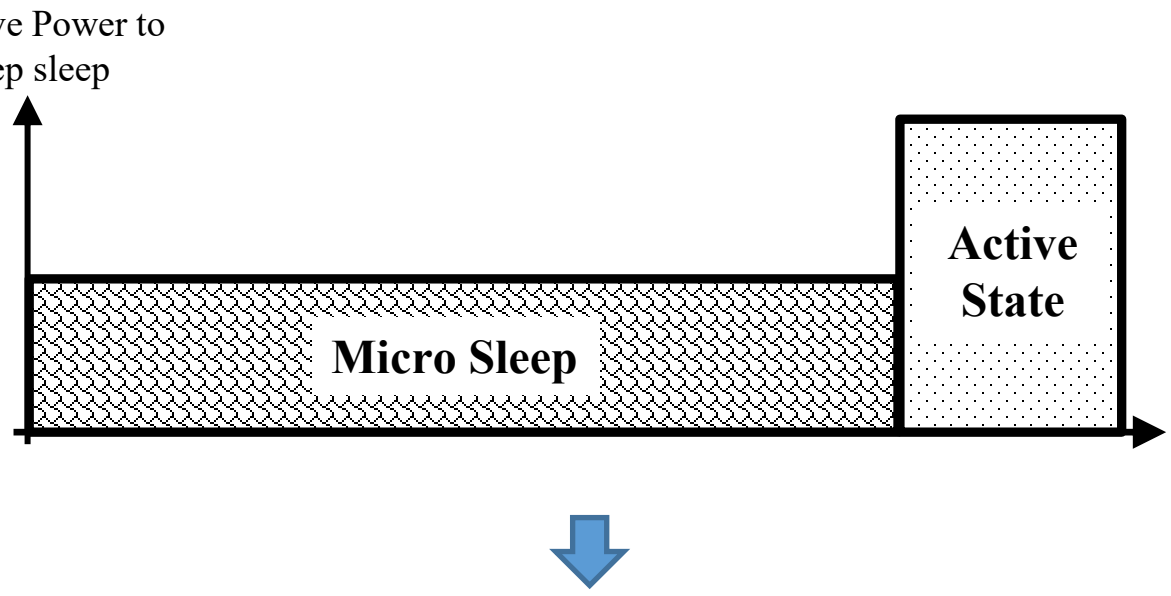


Configuration of RRC for WUS skipping

Parameters	Configuration
drx-LongCycleStartOffset	Configure such that the long drx cycle starts at the beginning of jitter interval
drx-SlotOffset	
drx-LongCycle	Same as existing method
drx-onDuration	
drx-InactivityTimer	
drx-ShortCycle	Set as interval between two consecutive WUS messages
drx-ShortCycleTimer	$\left\lceil \frac{\text{jitter duration}}{drx-ShortCycle} \right\rceil$
drx-method-indicator	0- Legacy C-DRX 1- Invented method

Calculation of threshold for deep (T_{ds}) and light sleep (T_{ls})





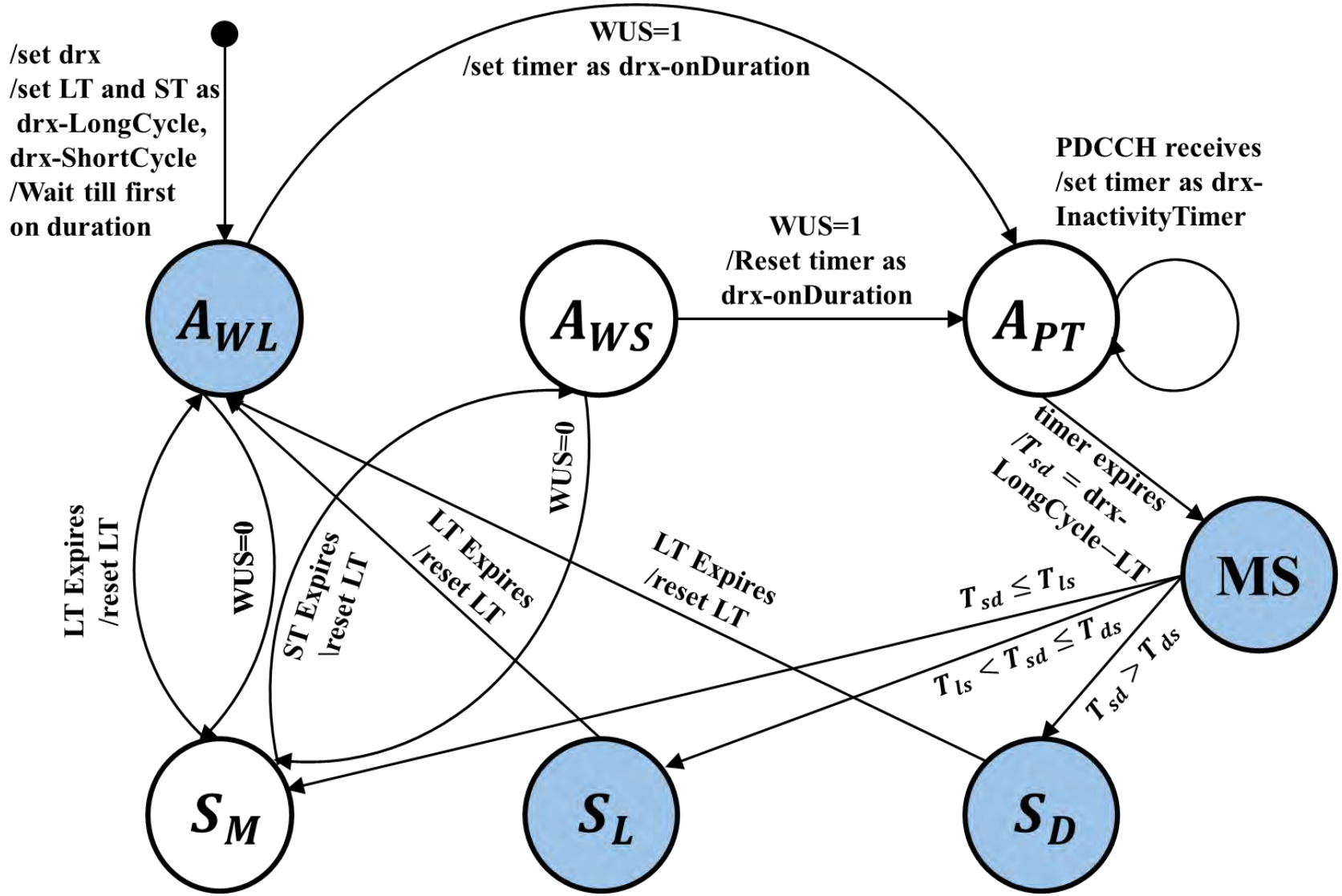
$$E_s = 2^{\mu} E_{ps}^{s} T_{sd} + \mathrm{E_t^s} \text{ for s} = \text{ds. fs}$$

$$E_{mi} = 2^{\mu} E_{ps}^{mi} T_{sd}$$

$$E_{ds} > E_{ls} \Rightarrow T_{ds} = \max\left(\frac{E_t^{ds} - E_t^{ls}}{E_{ps}^{ls} - E_{ps}^{ds}} 2^{-\mu}, T_t^{ds}\right) \text{ and } E_{ls} > E_{mi} \Rightarrow T_{ls} = \max\left(\frac{E_t^{ls} 2^{-\mu}}{E_{ps}^{mi} - E_{ps}^{ls}}, T_t^{ls}\right)$$

E_{ps}^{s} – Relative energy /slot for sleep mode s (= deep (ds), light (ls) or micro (mi) sleep), E_t^s – Transition energy for s (= ds, ls), T_t^s – Transition time for s (= ds, ls)
E_s –Total Energy consumption over T_{sd} if sleep mode s (= ds, ls) employed, E_{mi} – Total Energy consumption over T_{sd} if micro sleep is employed

State Diagram of the proposed method

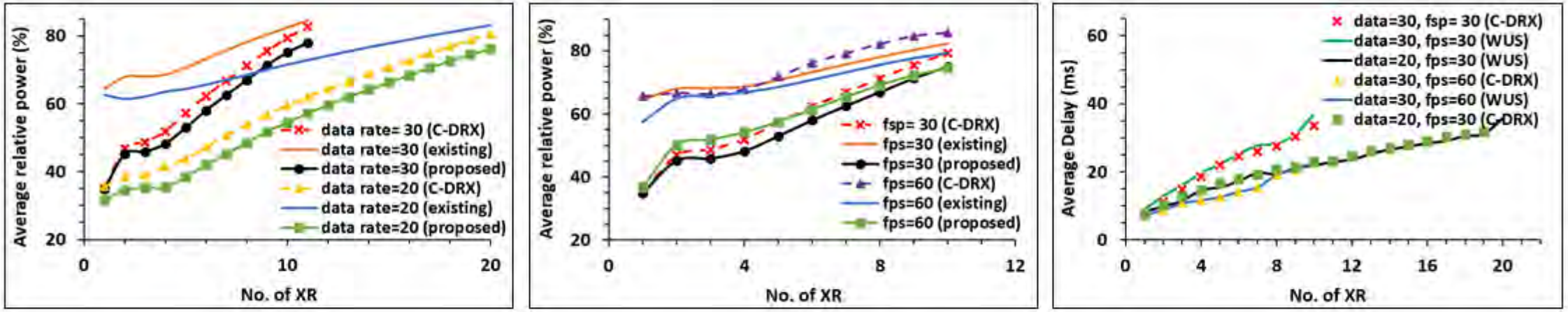


A_{WL} – Active mode for long drx
A_{WS} – Active mode for short drx
A_{PT} – Active mode for Packet transmission
S_M – Micro Sleep
S_L – Light Sleep
S_D – Deep Sleep
MS – Mode Selection

- A_{WL}, A_{WS} are active mode to receive WUS message
- A_{PT} is active mode if enters into ON duration
- MS is a temporary state to run mode selection algorithm

Performance Evaluation

Results and discussion



- (a) and (b) shows a significant improvement in energy efficiency as compared to traditional C-DRX and the method proposed in [2-3], without increasing the average delay significantly as shown in (c)
- Increment in power savings over traditional C-DRX method is due to periodic micro sleep over jitter duration
- Increment over the method of [2-3] is due to WUS skipping over the time interval between the finish of transmission of the current frame and the beginning of the next cycle
- As frame rate decreases, this enhancement in power saving as compared to [2-3] increases
- As frame rate decreases, this enhancement in power saving as compared to traditional C-DRX decreases

Conclusion

Concluding statements

- Here, we have proposed an enhanced C-DRX power-saving mechanism for XR applications in 5G NR UE
- The proposal is to skip unnecessary WUS messages after a frame transmission
- This enables choosing different sleep modes depending on the duration of WUS skipping
- The proposed method provides significant improvement (up to 25% for the frame rate of 30) in energy savings
- Enhancement in energy saving as compared to traditional C-DRX increases with the decrement of frame rate
- Enhancement in energy saving as compared to existing proposal of [2-3] increases with the increment of frame rate

Thank You

References

1. 3GPP Technical Report TR 38.838, Study on XR Evaluations for NR.

2. D. Li, H. You, W. Jiang, X. Chen, C. Zeng and X. Sun, ”Enhanced Power Saving Schemes for eXtended Reality,” 2021 IEEE 32nd An- nual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), 2021, pp. 1-6.

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4. 3GPP Technical Report TR 38.840, Study on User Equipment (UE) power saving in NR.