Power Efficiency and Delay Tradeoff of Energy Efficient Ethernet Protocol

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Outline

- Power Saving Problem
- System Modeling
- Performance Tradeoff
- Conclusion

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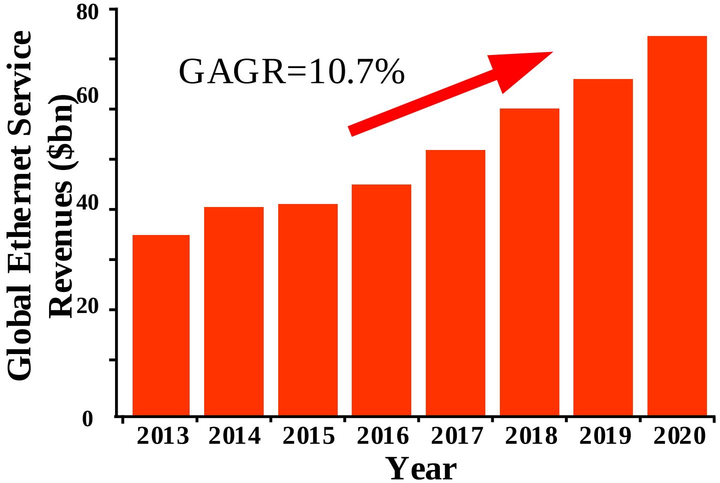
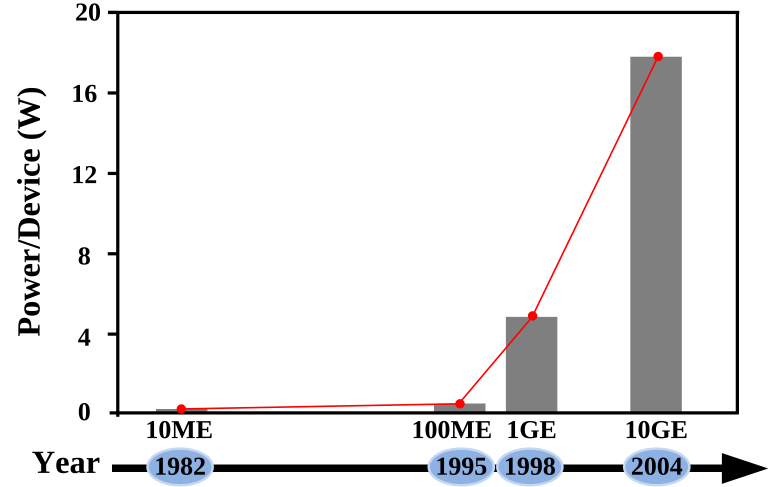
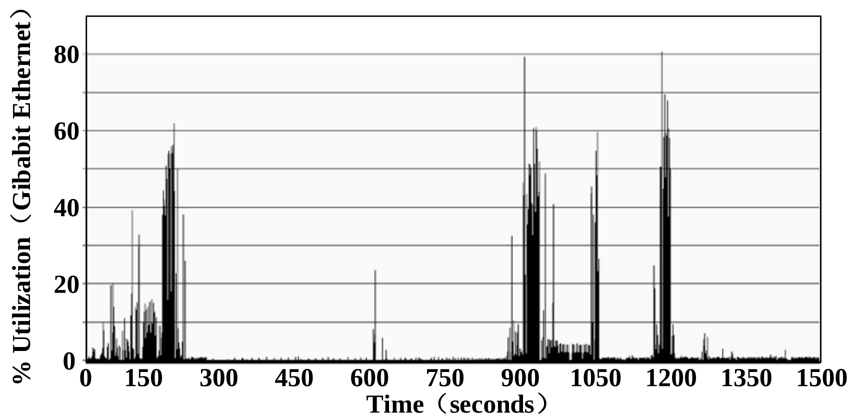
Features of Ethernet



market is huge and still grows rapidly



power per device increases very fast also

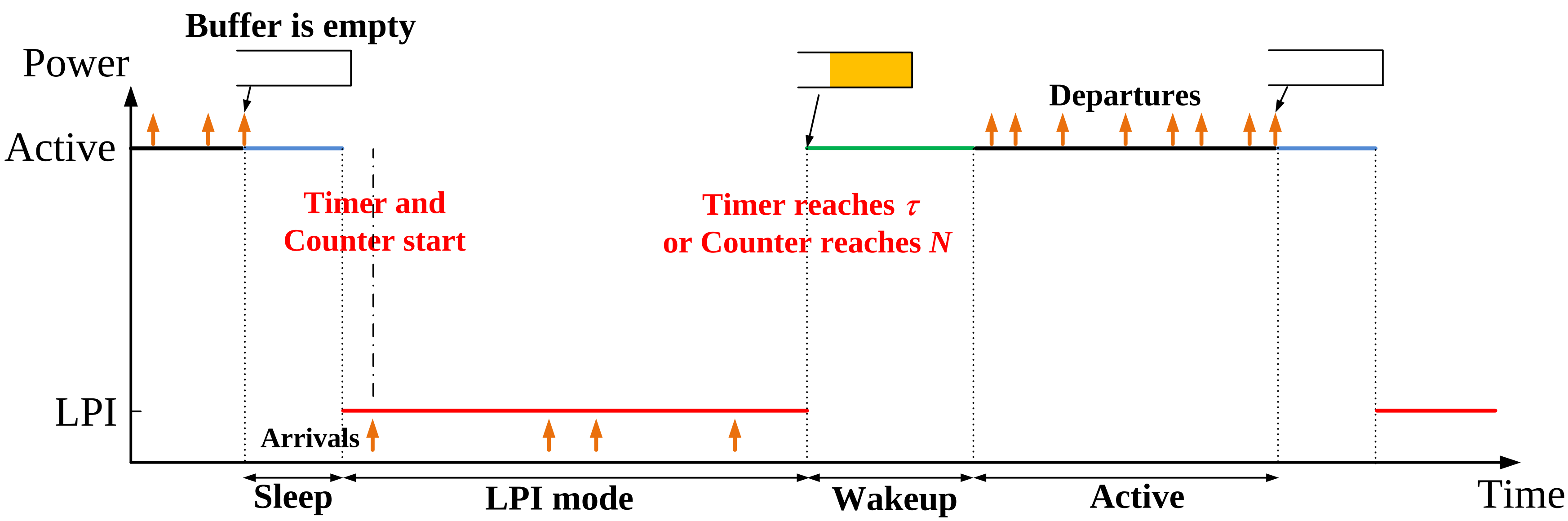


utilization ratio is small (5%~30%)

- P. J. Winzer, "Beyond 100G Ethernet," *IEEE Communications Magazine*, vol. 48, pp. 26–30, July 2010.
- P. Reviriego, K. Christensen, J. Rabanillo, and J. A. Maestro, "An initial evaluation of Energy Efficient Ethernet," *IEEE Communications Letters*, vol. 15, pp. 578–580, May 2011.
- B. Kohl, "10GBASE-T power budget summary," 2007.

EEE Protocol

- Go to sleep when idle



- Sleeping strategies:
  - τ&N policy: τ and N are finite
  - τ policy: $N \to \infty$
  - N policy: $\tau \to \infty$

Problem

- Tradeoff between power efficiency and delay
  - N and $\tau \uparrow \rightarrow$ LPI Length $\uparrow \rightarrow$ power efficiency $\uparrow$

    $\rightarrow$ delay $\uparrow$

- What are the rules to select N and τ?

Overview

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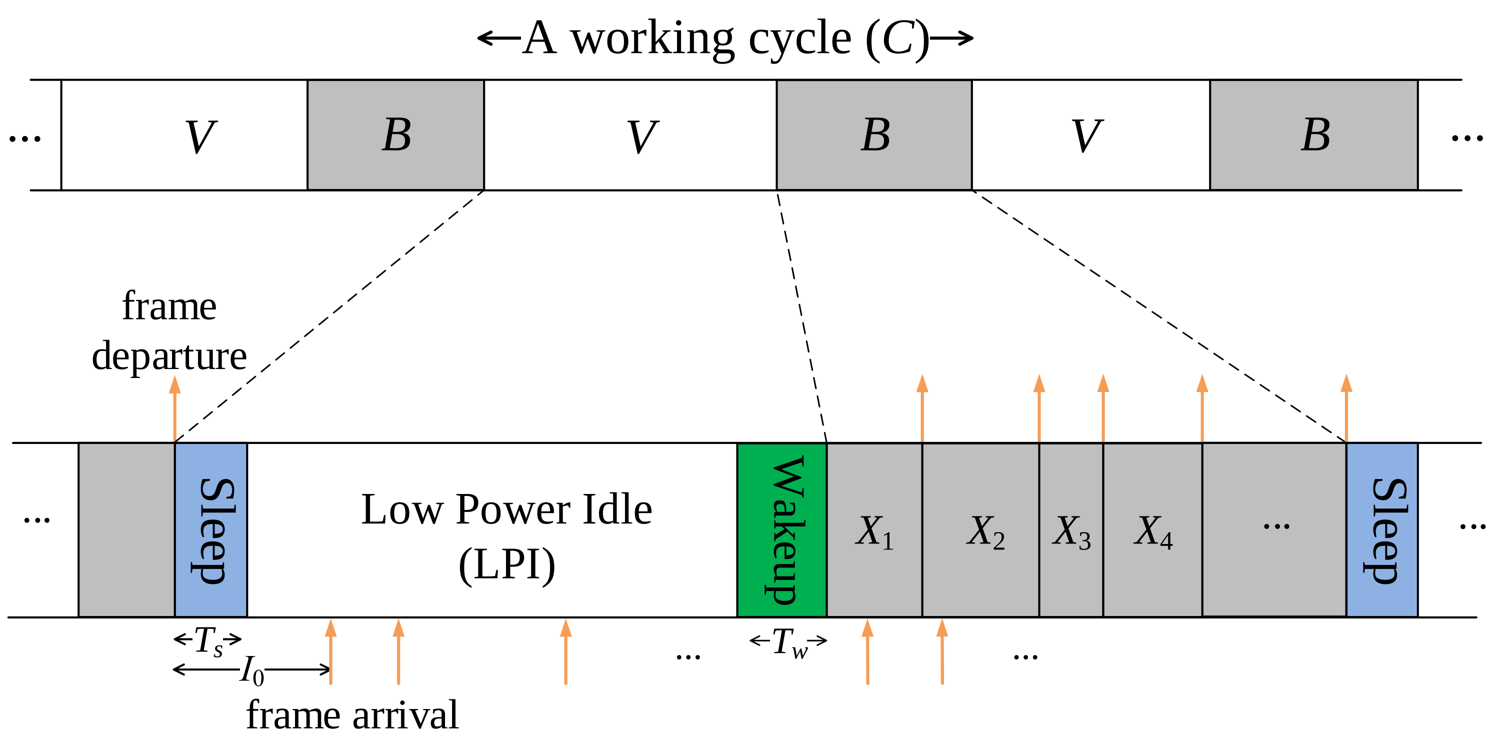
New Feature of EEE Queuing Systems

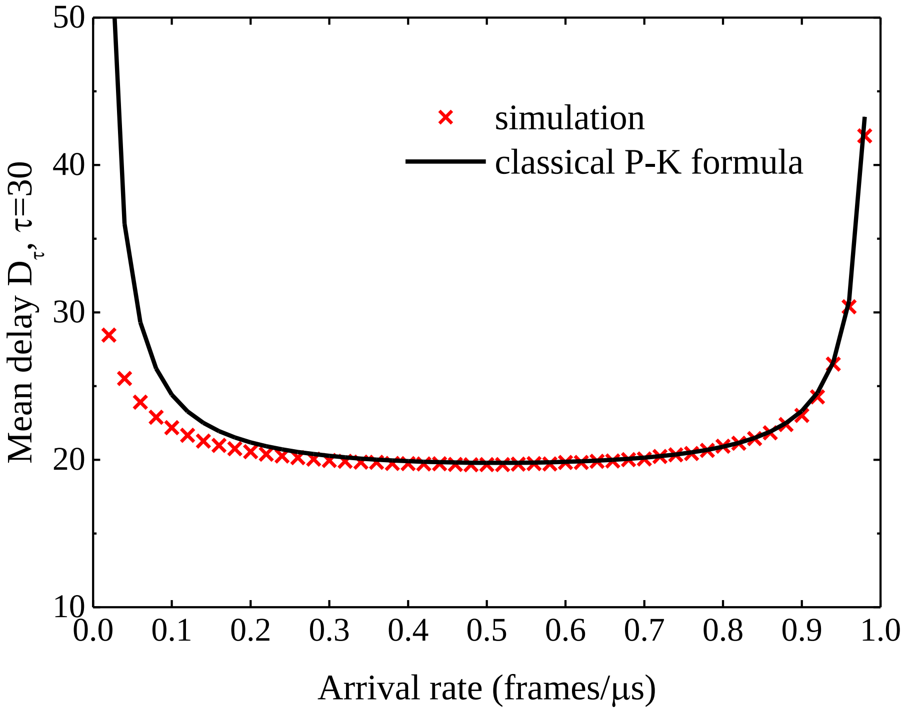
- EEE protocol is an M/G/1 queue with vacations modulated by arrival process



Failure of Classical Analytical Method

- Example: classical P-K formula fails to describe the mean delay of EEE protocol

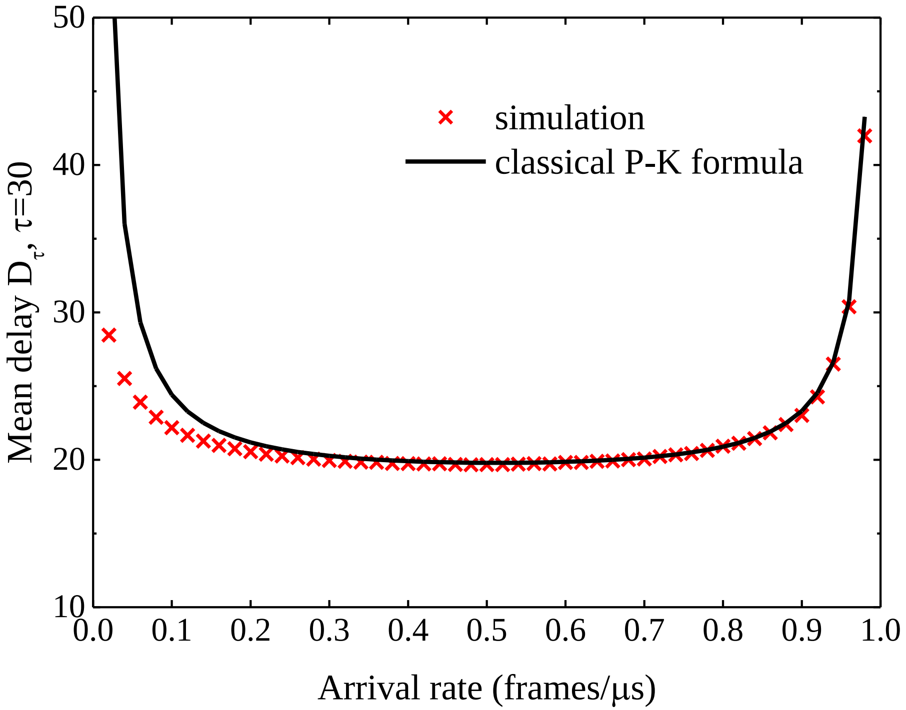
$$D = \frac{\lambda \overline{X^2}}{2(1-\rho)} + \frac{\overline{V^2}}{2\bar{V}} + \bar{X}$$



Failure of Classical Analytical Method

- Example: classical P-K formula fails to describe the mean delay of EEE protocol

$$D \neq \frac{\lambda \overline{X^2}}{2(1-\rho)} + \frac{\overline{V^2}}{2\overline{V}} + \bar{X}$$



Overview of Our Modeling Approach

Distribution of the number of arrivals during vacation time

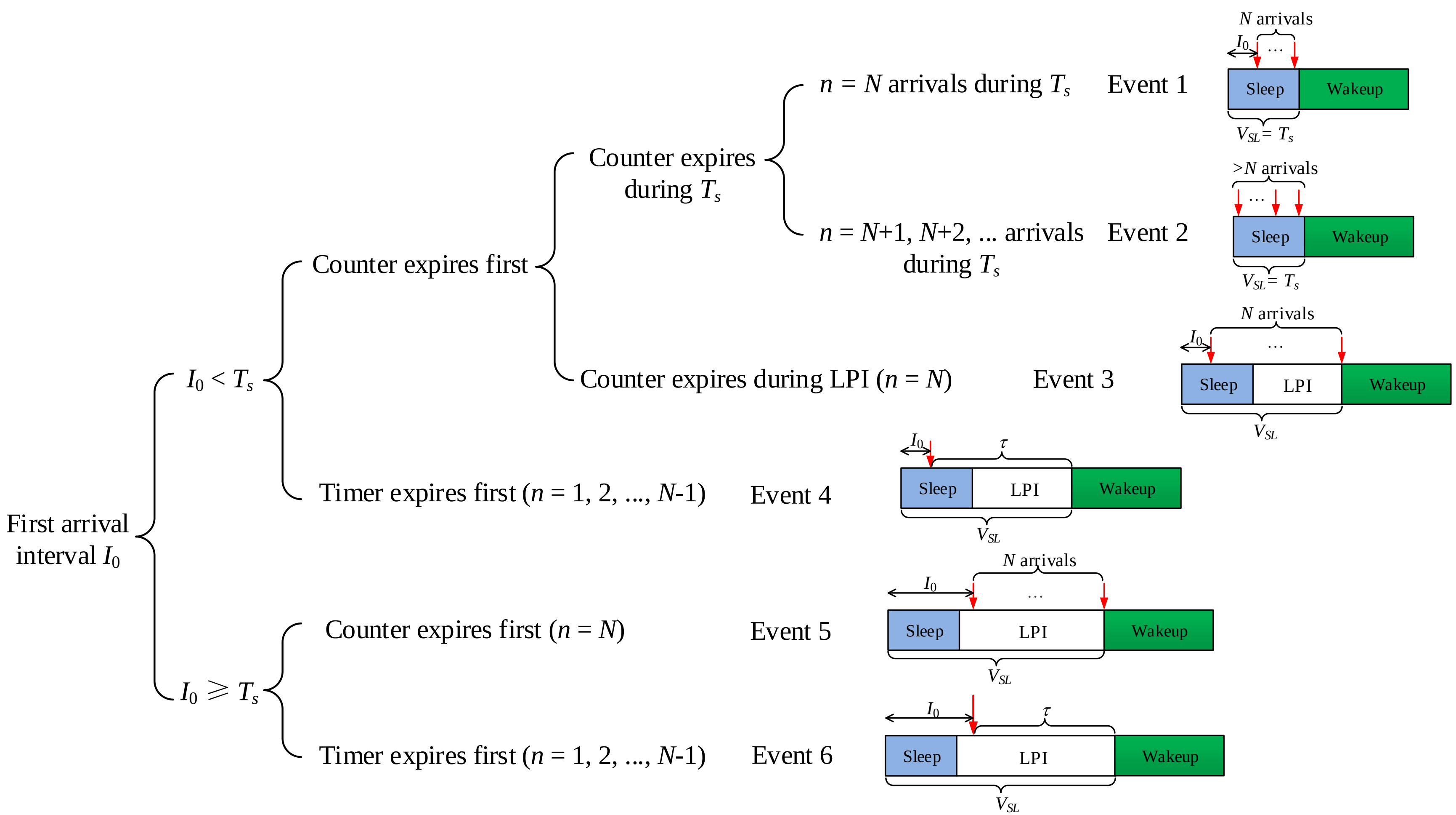
Mean Vacation Time

P-K formula of Mean Delay

Power Efficiency

Arrival Event Tree of Vacation Periods

- Six mutually-exclusive events



Distribution h_n

- $h_n = \Pr\{n \text{ arrivals during a vacation period } V\}$

$$H(z) = \sum_{n=0}^{\infty} h_n z^n$$

$$= e^{-\lambda T_w(1-z)}$$

$$\times \left[\sum_{n=0}^{N-1} e^{-\lambda T_s \frac{(\lambda T_s)^n}{n!}} (z^N - z^n) - \sum_{n=0}^{N-2} e^{-\lambda \tau \frac{(\lambda \tau)^n}{n!}} (z^N - z^{n+1}) \right.$$

Mean Vacation Time and Mean Cycle Time

- $H'(1)$: the mean number of arrivals during vacation
- By Little's Law, mean vacation time $\bar{V}$

$$\bar{V} = \frac{H'(1)}{\lambda}$$

- Mean cycle time

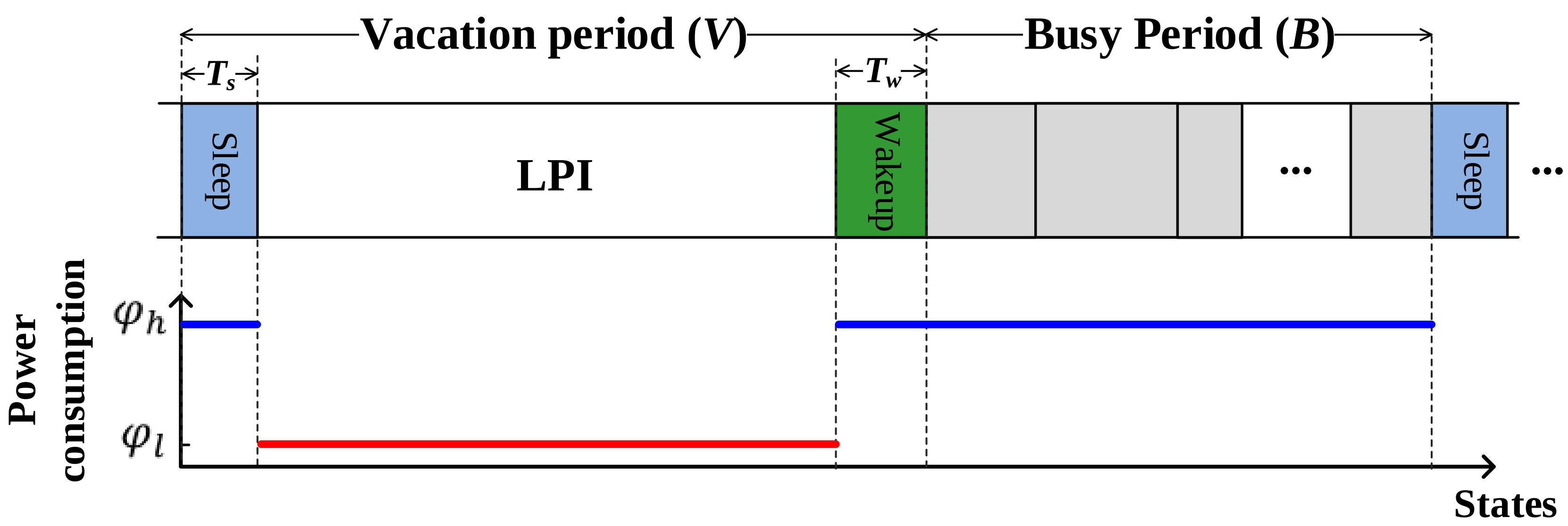
$$\bar{C} = \frac{\bar{V}}{1-\rho}$$

Power Efficiency η

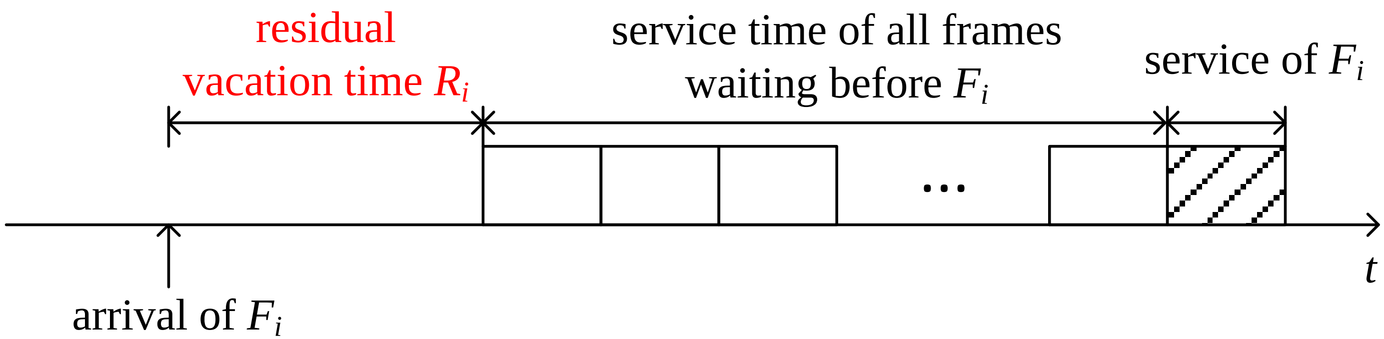
$$\eta = \frac{\text{average power saved in one cycle by an LPI}}{\text{averge power of one cycle if EEE is not used}}$$

$$= \frac{(\bar{V} - T_s - T_w) \times (\varphi_h - \varphi_l)}{\bar{C} \times \varphi_h}$$

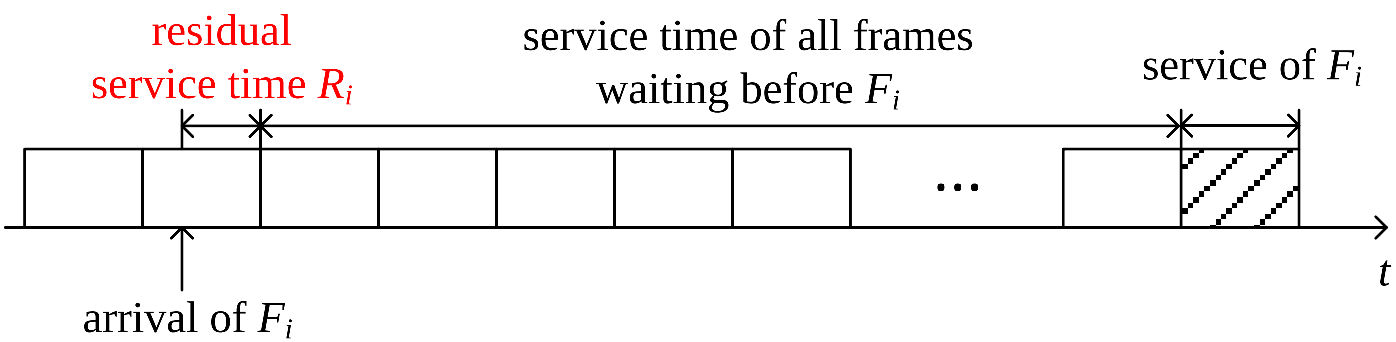
$$= \left(1 - \frac{T_w + T_s}{\bar{V}}\right) \cdot \frac{(1-\rho) \times (\varphi_h - \varphi_l)}{\varphi_h}$$



Delay Analysis



(a) Frame F_i arrives during a vacation period.



(b) Frame F_i arrives during a busy period.

$$D = \frac{R}{1-\rho} + \bar{X},\ \ R\text{: mean residual time}$$

- D. P. Bertsekas, R. G. Gallager, and P. Humblet, *Data networks*, vol. 2. Prentice-Hall International New Jersey, 1992.

Mean Residual Time

$$R = \boldsymbol{E[R_i|\xi = 0]} \times Pr\{\xi = 0\} + \boldsymbol{E[R_i|\xi = 1]} \times Pr\{\xi = 1\}$$

$$= E[R_i|\xi = 0] \times (1-\rho) + E[R_i|\xi = 1] \times \rho$$

$$\xi = \begin{cases} 0, & \text{if frame arrives during a vacation period} \\ 1, & \text{if frame arrives during a busy period} \end{cases}$$

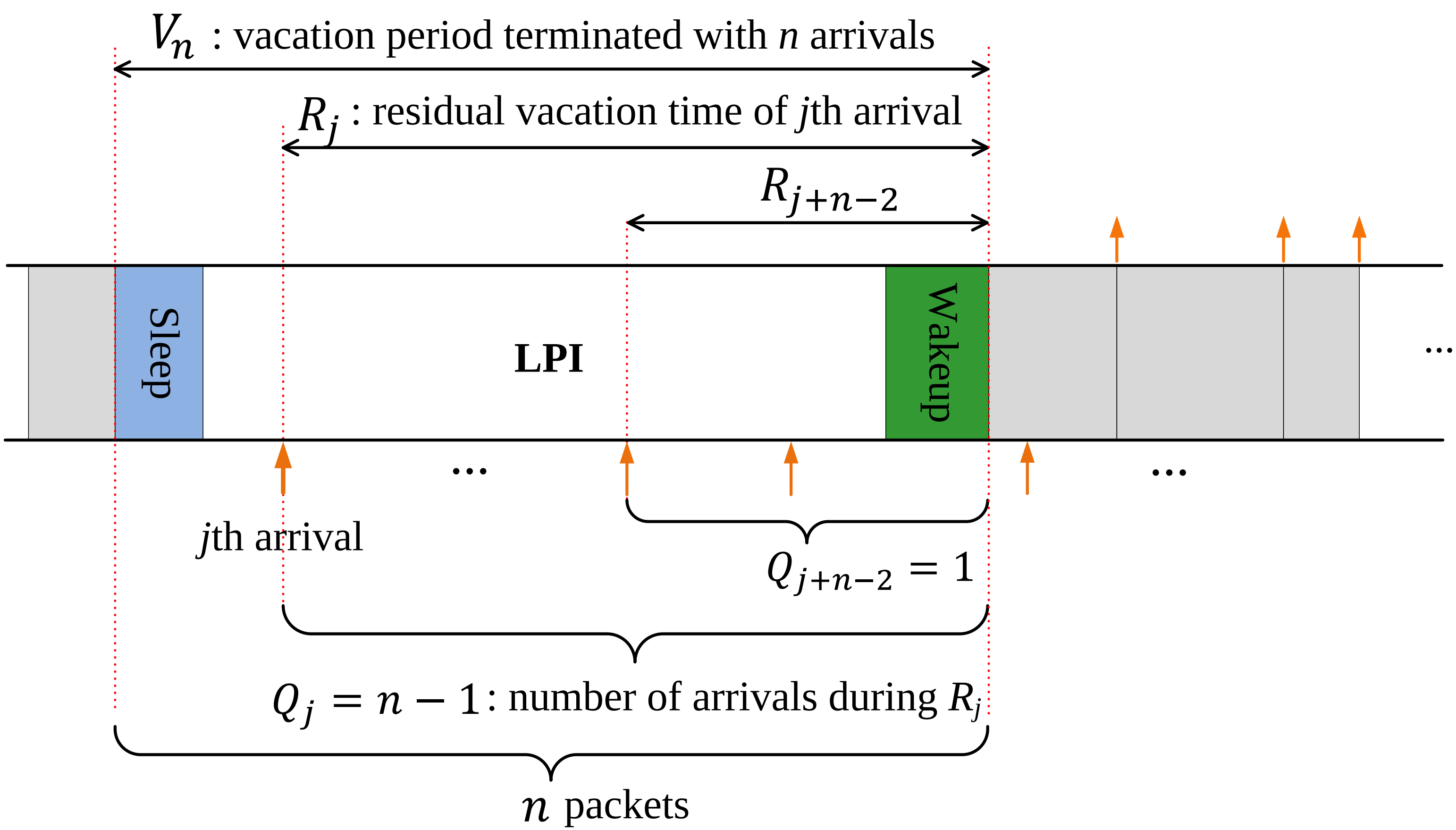
$E[R_i|\xi = 1] = \frac{1}{2\rho}\lambda\overline{X^2}$: independent of arrival process

$E[R_i|\xi = 0] = ?$: dependent on arrival process

- D. P. Bertsekas, R. G. Gallager, and P. Humblet, *Data networks*, vol. 2. Prentice-Hall International New Jersey, 1992.

Residual Vacation Time of Each Arrival

- Given V_n, number of arrivals during residual vacation time seen by a frame is determined



Mean Residual Vacation Time

$$E[R_i|\xi = 0] = \sum_{n=1}^{\infty} E[R_i|\xi = 0, \text{frame } i \text{ arrives in a } V_n] \cdot P_n$$

- P_n: conditional probability that a frame arrives in a V_n.

- Applying Little's Law

$$\lambda E[R_i|\xi = 0] = \sum_{n=1}^{\infty} \lambda E[R_i|\xi = 0, \text{frame } i \text{ arrives in a } V_n] \cdot P_n$$

$$= \sum_{n=1}^{\infty} E[Q_i|\xi = 0, \text{frame } i \text{ arrives in a } V_n] \cdot P_n$$

$$= \sum_{n=1}^{\infty} \left[\frac{(n-1)+(n-2)+\cdots+1+0}{n}\right] \cdot \frac{n \cdot h_n}{H'(1)}$$

$$= \frac{H''(1)}{2H'(1)}.$$

P-K Formula of Mean Delay

- **Theorem 1:** The mean delay of EEE systems is given by:

$$D = \frac{\lambda \overline{X^2}}{2(1-\rho)} + \frac{H''(1)}{2\lambda H'(1)} + \bar{X}$$

if $H(z) = V^*(\lambda - \lambda z)$

- Classical P-K Formula

$$D = \frac{\lambda \overline{X^2}}{2(1-\rho)} + \frac{\overline{V^2}}{2\bar{V}} + \bar{X}$$

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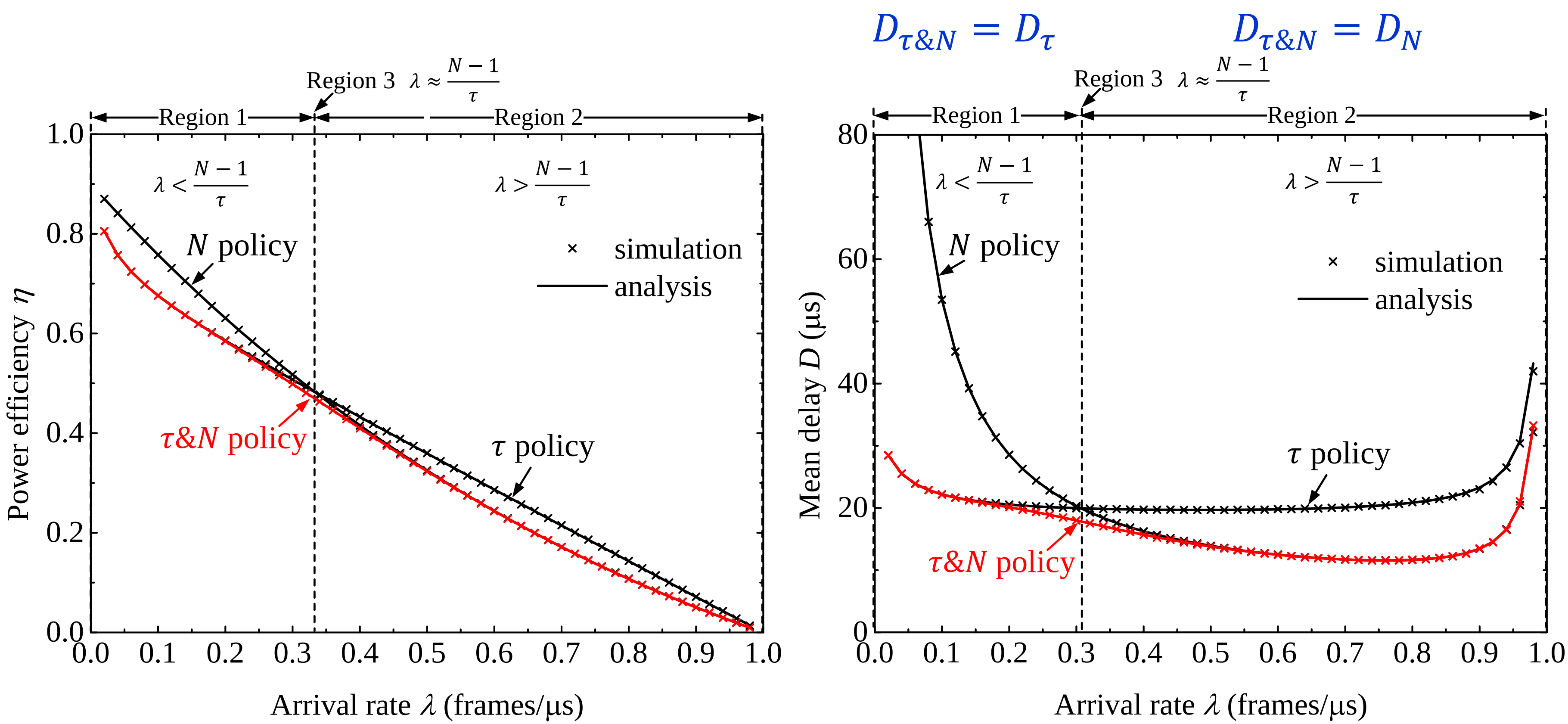
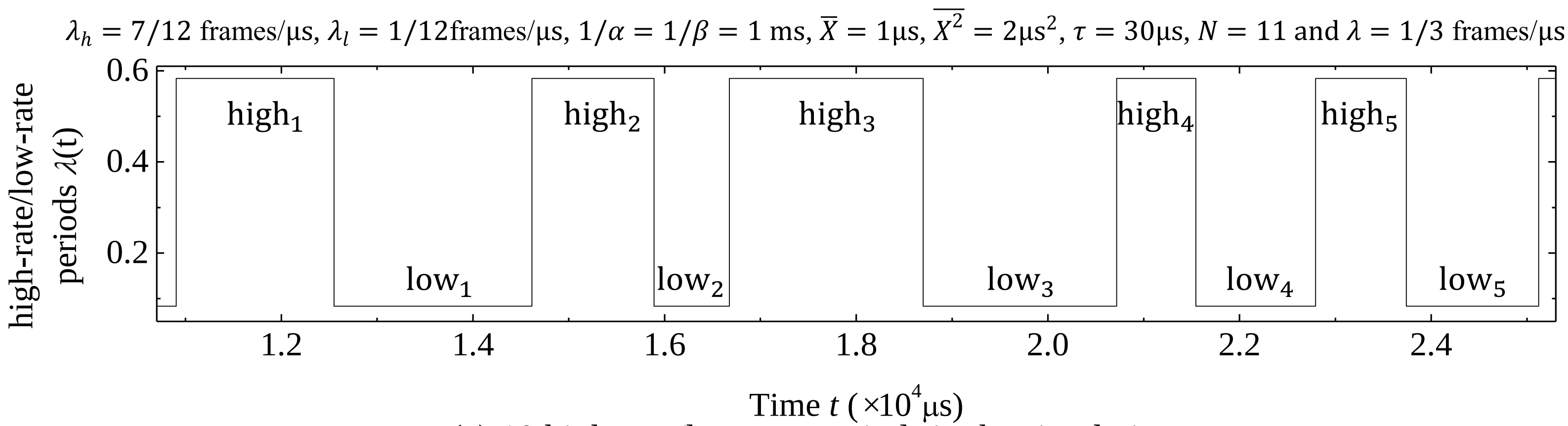
Timer vs. Counter

- $\eta_{\tau\&N} \approx \eta_{\tau} \approx \eta_{N}$
- $D_{\tau\&N} = \min\{D_{\tau}, D_{N}\}$

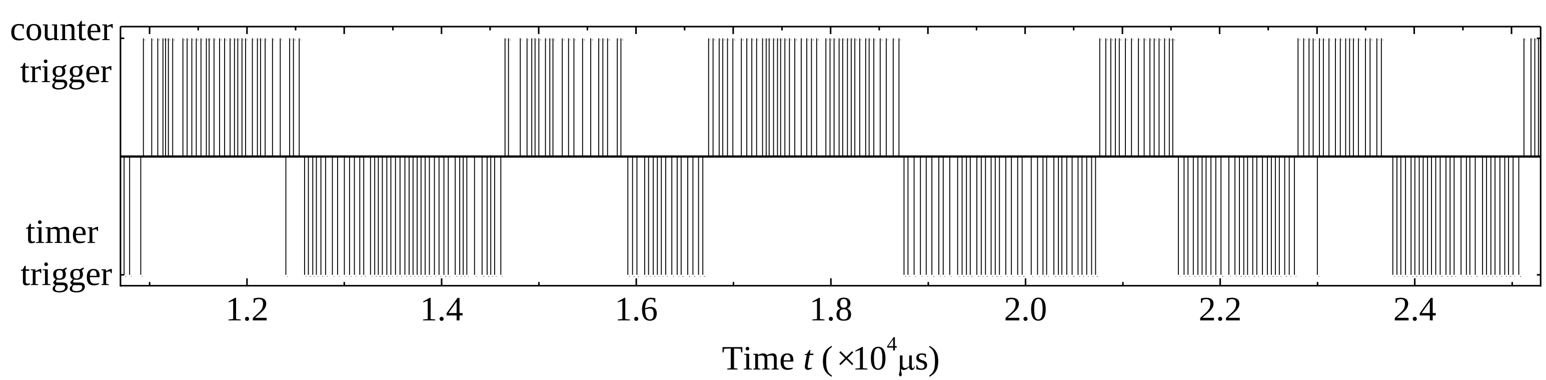


Explanation: Wakeup Triggers of $\tau\&N$ policy

- $\tau\&N$ policy can adaptively use τ and N to wake up according to instantaneous arrival rate if $\tau = \frac{N-1}{\lambda}$



(a) 10 high-rate/low-rate periods in the simulation



(b) trigger records of the process

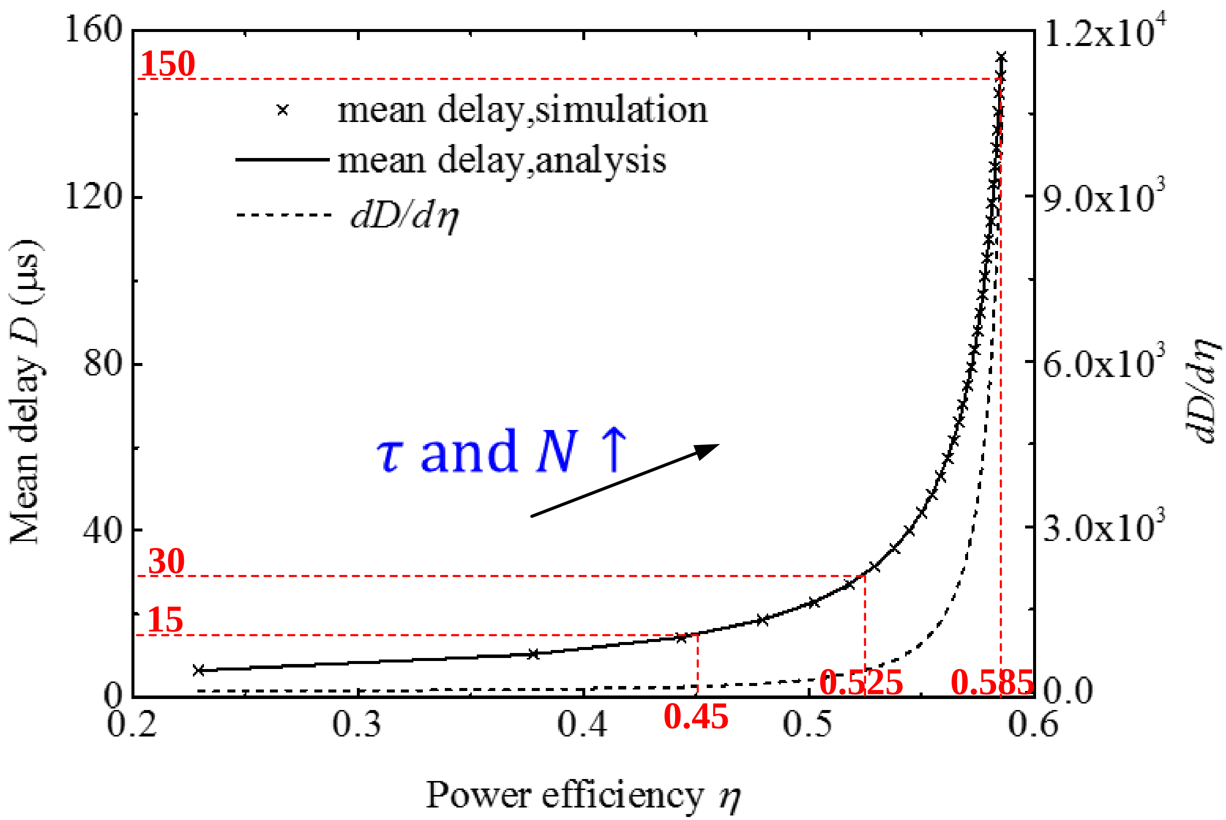
Rule EEE 1

For a given steady state traffic rate λ, the selection of parameters τ and N should comply with the following condition:

$$\frac{N-1}{\tau} = \lambda.$$

Power Efficiency versus Mean Delay

- Excessively large τ and N degrade delay performance while marginally enhancing the power efficiency



Rule EEE 2

Based on EEE 1, parameter N can be selected according to a given average delay requirement D from the expression of D_N

$$D_N \approx \frac{\lambda \overline{X^2}}{2(1-\rho)} + \frac{(N+\lambda T_w)^2 - N}{2\lambda(N+\lambda T_w)} + \bar{X}$$

Conclusions

- Develop a new approach to analyze the $M/G/1$ queue with vacations governed by the arrival process
- Derive a generalized P-K formula of mean delay
- Provide two rules to select appropriate τ and N

Thank You!