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Numerical Analysis of the Power Saving in 3GPP LTE Advanced Wireless Networks

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Introduction

- Third-Generation Partnership Project (3GPP) Long-Term Evolution Advanced (LTE-A) wireless networks provide power-saving operations since lifetime extension of battery-powered mobile devices is one of the most important features for user convenience
- LTE-A wireless networks support the power-saving operation called Discontinuous Reception (DRX) operation. In this operation, the user equipment (UE) periodically wakes up to monitor new packet arrivals by receiving an indication message conveyed via a control channel.

Introduction (Cont.)

- The performance of the power-saving operation can be evaluated with two metrics: the power saving factor and the average packet transmission delay.
- In viewpoint of power consumption, we can characterize the DRX operation by two operational states: active and sleeping states.
- M/G/1 queuing system is modeled to describe the packet transmission delay.

DRX Operation in 3GPP LTE-A Wireless Networks

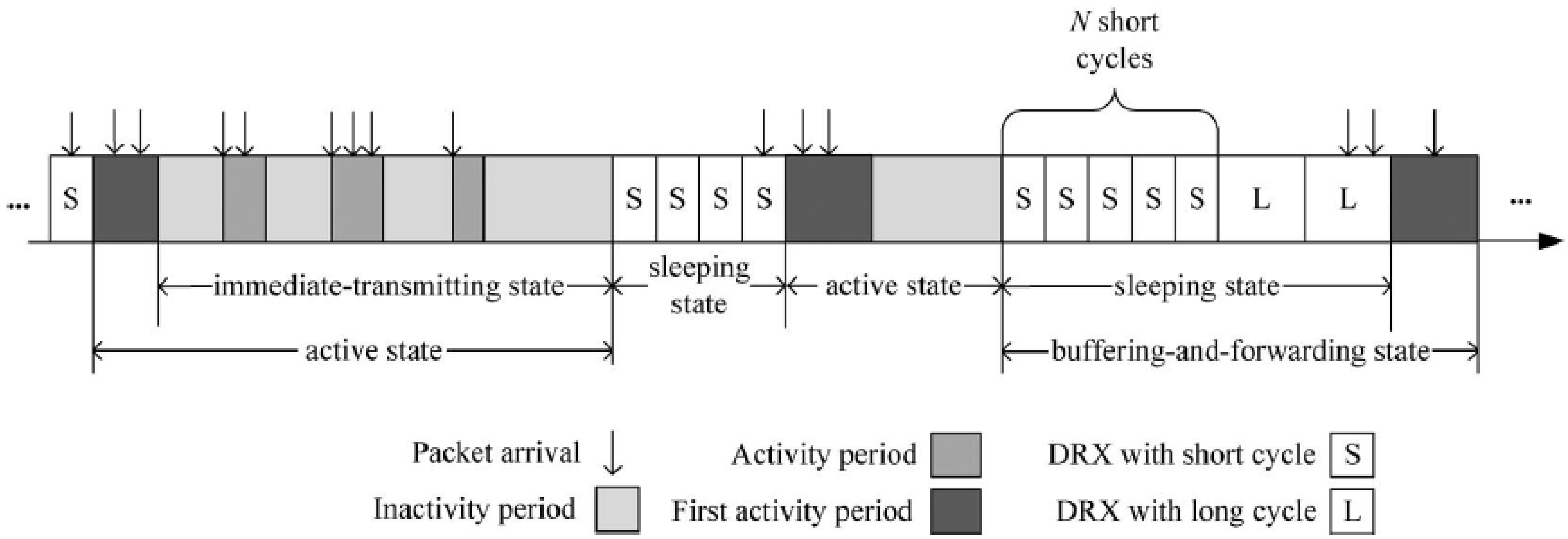

Fig. 1. Exemplary snapshot of the DRX operation in 3GPP LTE Advanced wireless networks.

Analytical Model

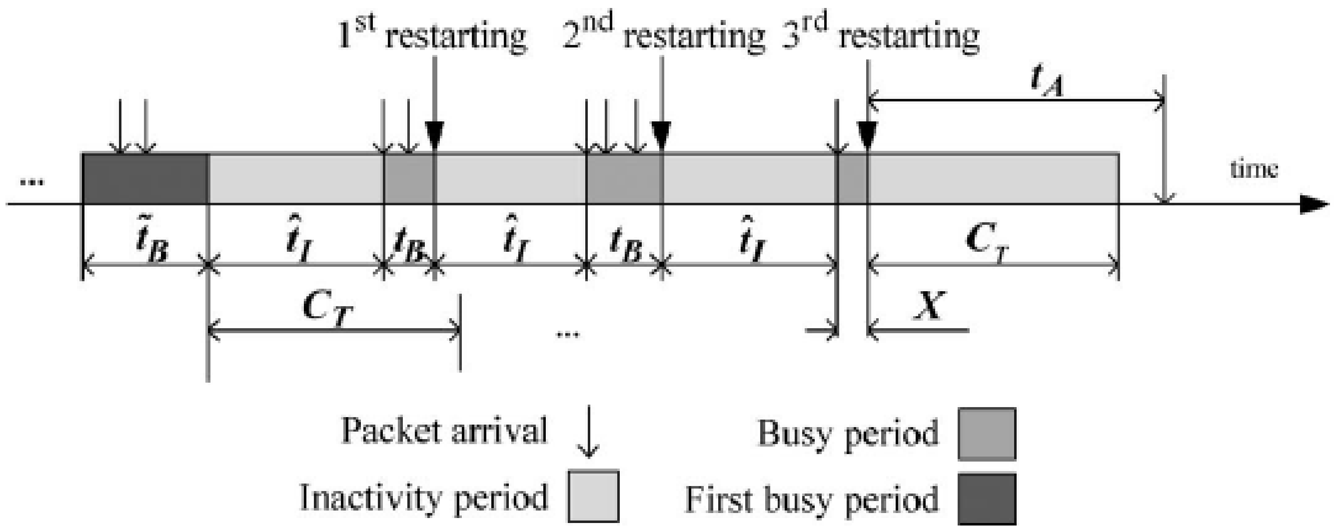

Fig. 2. Example for active state operation.

t_I :Time between the start of an inactivity timer and the time that new packet arrives.
t_B : Activity period
C_T : Inactivity Timer
X : Transmission time for a single packet

Analytical Model (Cont.)

- Power-Saving Factor:
  - $\mathrm{E}[T_D]/(E[T_A]+\mathrm{E}[T_D])$
  - T_D: Overall time that the UE spends in sleeping state.
  - T_A: Overall time that the UE spends in active state.

Analytical Model (Cont.)

- Power-Saving Factor:

$$
\begin{aligned}
&\frac{E[T_D]}{E[T_D]+E[T_A]} \\
&= \frac{E[T_D](1-\rho)}{E[T_D]+\frac{1}{\lambda}(e^{\lambda C_T}-1)} \\
&= (1-\rho)\times\left(\frac{1-(e^{-\lambda C_S})^N}{1-e^{-\lambda C_S}}C_S+\frac{(e^{-\lambda C_S})^N}{1-e^{-\lambda C_L}}C_L\right) \\
&\Big/\left(\frac{1-(e^{-\lambda C_S})^N}{1-e^{-\lambda C_S}}C_S+\frac{(e^{-\lambda C_S})^N}{1-e^{-\lambda C_L}}C_L+\frac{1}{\lambda}(e^{\lambda C_T}-1)\right).
\end{aligned}
$$

Analytical Model (Cont.)

- Transmission Delay:
  - Derive the average transmission delay for M/G/1 queuing system.
  - Using the Pollaczek-Khinchine formula.
  - $\mathrm{E}[D_I] = \frac{\lambda E[X^2]}{2(1-\rho)}$

Analytical Model (Cont.)

- Transmission Delay:

$$P_S = \frac{\lambda E[t_S]}{\lambda\left(E[T_A]+E[T_D]\right)}$$

$$P_L = \frac{\lambda E[t_L]}{\lambda\left(E[T_A]+E[T_D]\right)}.$$

$$\begin{aligned}E[D] =& (1-P_S-P_L)E[D_I] \\ &+P_S\left(E[D_I]+\frac{C_S}{2(1-\rho)}\right)+P_L\left(E[D_I]+\frac{C_L}{2(1-\rho)}\right) \\ =& \frac{\lambda E[X^2]}{2(1-\rho)} \\ &+\frac{1}{2}\left(\frac{1-(e^{-\lambda C_S})^N}{1-e^{-\lambda C_S}}(C_S)^2+\frac{(e^{-\lambda C_S})^N}{1-e^{-\lambda C_L}}(C_L)^2\right)\Big/ \\ &\left(\frac{1-(e^{-\lambda C_S})^N}{1-e^{-\lambda C_S}}C_S+\frac{(e^{-\lambda C_S})^N}{1-e^{-\lambda C_L}}C_L+\frac{1}{\lambda}(e^{\lambda C_T}-1)\right).\end{aligned} \tag{16}$$

Results

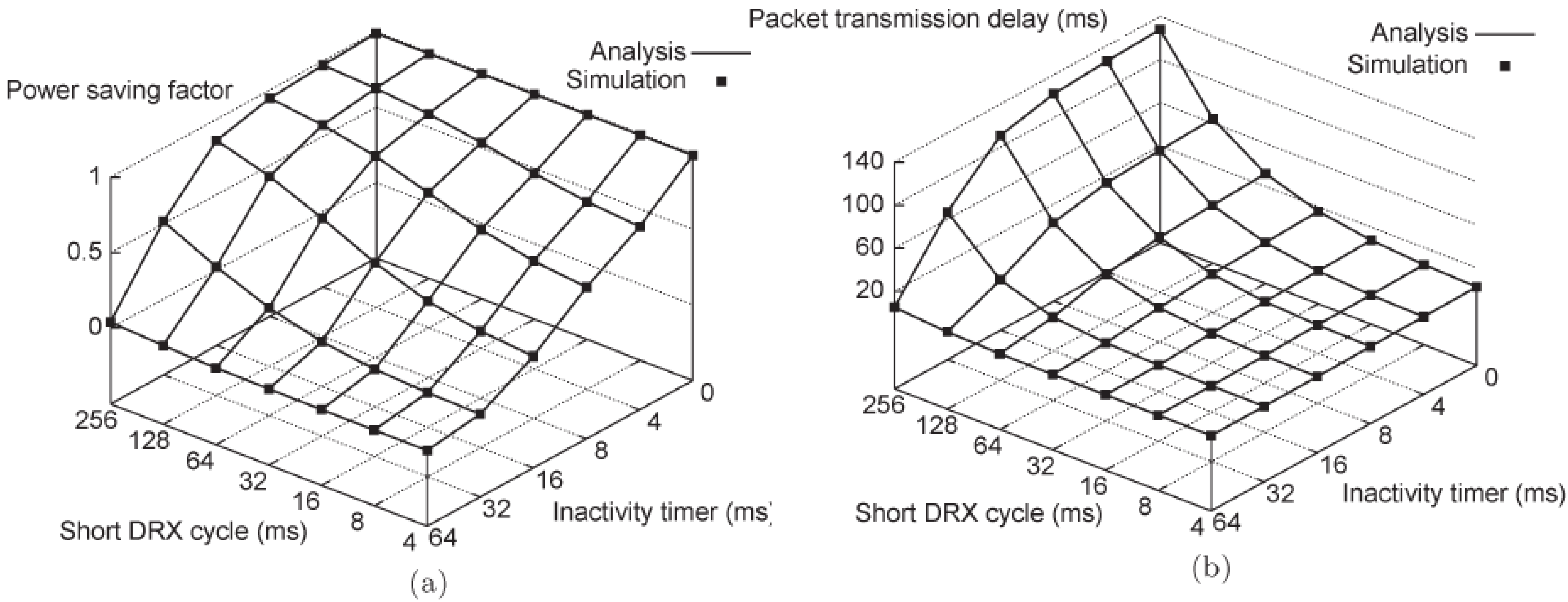

Fig. 3. Power-saving factor and average packet transmission delay when $N = 2, \tau = 0.1, \lambda = 0.1$, and $C_L = 2C_S$. (a) Power-saving factor. (b) Average packet transmission delay.

Results (Cont.)

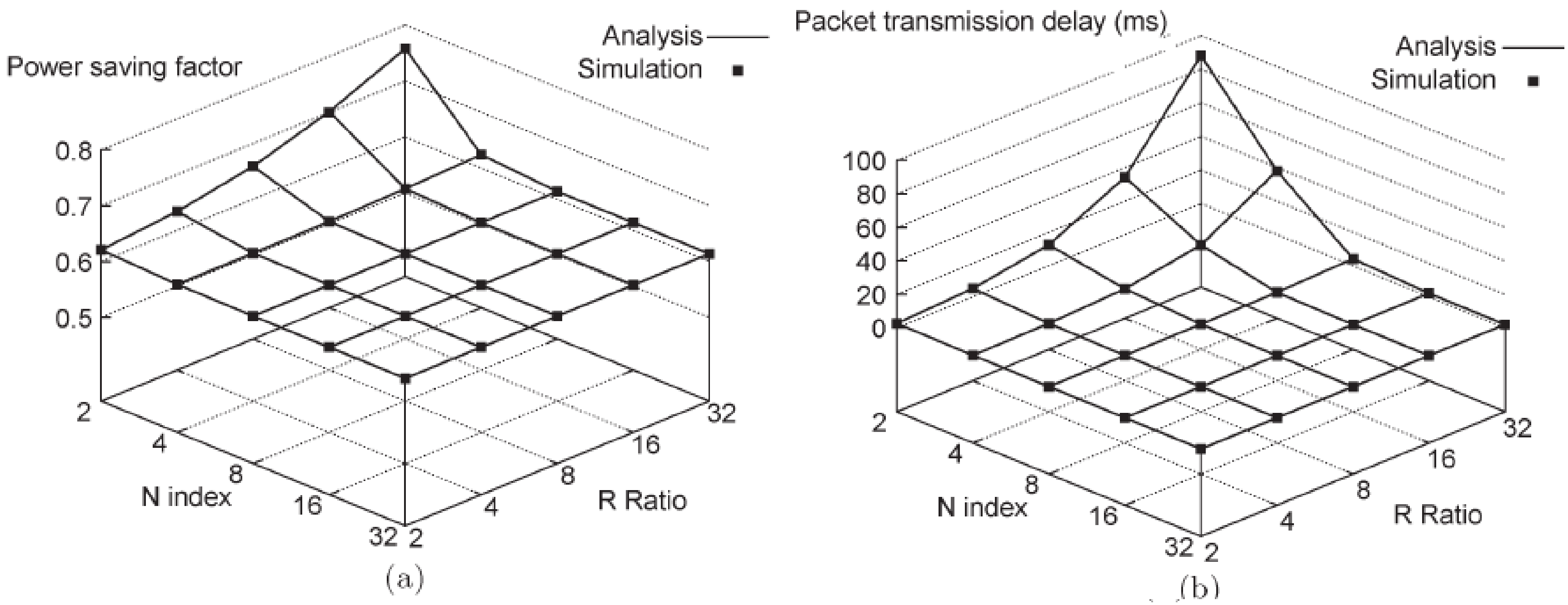

Fig. 4. Power-saving factor and average packet transmission delay when $\tau = 0.1$ ms, $\lambda = 0.1/\text{ms}$, $C_S = 8$ ms, and $C_T = 8$ ms. (a) Power-saving factor. (b) Average packet transmission delay.

Conclusion

- This paper provide an easy way to reach the accurate analytical model for the performance evaluation of the DRX operation in 3GPP LTE Advanced wireless networks

- They develop a new approach by dividing the DRX operation into several independent parts and then combine the result obtained in each part.

- They obtain accurate power-saving factor and packet transmission delay without sophisticated mathematical techniques.