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

Sunggeun Jin, Member, IEEE
Daji Qiao, Member, IEEE
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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.
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.
Fig. 1. Exemplary snapshot of the DRX operation in 3GPP LTE Advanced wireless networks.
Analytical Model

$t_I$: 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

Fig. 2. Example for active state operation.
Analytical Model (Cont.)

- Power-Saving Factor:
  - \( \frac{E[T_D]}{(E[T_A]+E[T_D])} \)
  - \( T_D \): 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:

\[
\frac{E[T_D]}{E[T_D] + E[T_A]}
= \frac{E[T_D](1 - \rho)}{E[T_D] + \frac{1}{\lambda}(e^{\lambda C_T} - 1)}
= (1 - \rho) \times \left( \frac{1 - (e^{-\lambda C_S})^N}{1 - e^{-\lambda C_S}} C_S + \frac{(e^{-\lambda C_S})^N}{1 - e^{-\lambda C_L}} C_L \right)
\left/ \left( \frac{1 - (e^{-\lambda C_S})^N}{1 - e^{-\lambda C_S}} C_S + \frac{(e^{-\lambda C_S})^N}{1 - e^{-\lambda C_L}} C_L + \frac{1}{\lambda}(e^{\lambda C_T} - 1) \right) \right. 
\]
Analytical Model (Cont.)

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

- Transmission Delay:

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

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

\[
E[D]=(1 - P_S - P_L)E[D_I]
+ P_S \left( E[D_I] + \frac{C_S}{2(1-\rho)} \right)
+ P_L \left( E[D_I] + \frac{C_L}{2(1-\rho)} \right)
\]

\[
= \frac{\lambda E[X^2]}{2(1-\rho)}
+ \frac{1}{2} \left( \frac{1-(e^{-\lambda C_S})^N}{1-e^{-\lambda C_S}} (C_S)^2 + \frac{(e^{-\lambda C_S})^N}{1-e^{-\lambda C_L}} (C_L)^2 \right)
\]

\[
\left( \frac{1-(e^{-\lambda C_S})^N}{1-e^{-\lambda C_S}} C_S + \frac{(e^{-\lambda C_S})^N}{1-e^{-\lambda C_L}} C_L + \frac{1}{\lambda} (e^{\lambda C_T} - 1) \right).
\]

(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, $\lambda = 0.1$/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.