The Scientific Temper (2023) Vol. 14 (2): 375-382
E-ISSN: 2231-6396, ISSN: 0976-8653
Doi: 10.58414/SCIENTIFICTEMPER.2023.14.2.21
https://scientifictemper.com/
RESEARCH ARTICLE

Analysis of multiple sleeps and N-policy on a M/G/1/K user request queue in 5g networks base station

Deena Merit C K*, **Haridass M**

Abstract

The primary purpose of green communication is to reduce energy use. The base station (BS) is a radio receiver/transmitter that acts as the wireless network's hub. It serves as a link between a wired and wireless network. To receive and transmit messages, BS uses a lot of energy. The use of effective sleep and wake-up/setup activities with an acceptable delay helps reduce base station power consumption. In this paper, the BS's service process is modeled as a finite buffer M/G/1 queue with close down, sleep, and setup. After a certain number N of user requests (URs) have accumulated in the system, to awaken the BS from multiple sleeps (MS) the N-Policy is implemented. To produce probability generating functions, the supplementary variable approach is applied. The UR's mean delay and the BS's mean power consumption are calculated using simulation. According to computational studies, multiple sleeps with N-policy consume less power than multiple sleeps without N-policy.

Keywords: Mobile Network, Wireless Network, Energy Consumption, Multiple Sleeps, N- Policy, Finite capacity.

Introduction

Cellular networks and technology have grown dramatically since the late 1970s, with succeeding generations (2G to 4G). The channel capacity was 30 kHz and the data speed was 2.4 kbps in first generation (1G) cellular networks. Only voice calls were allowed on 1G cellular networks. Then, in 1991, second-generation (2G) cellular networks with bandwidths ranging from 30 to 200 kHz were launched, allowing users to exchange text messages (SMS and MMS) at modest rates of up to 64 kbps. 3G and 4G cellular networks were developed in 2000 and 2008 to boost bandwidth and data speed, respectively. 3G and 4G cellular networks have different bandwidth requirements. The bandwidth of 3G and 4G cellular networks was 5 to 20 MHz, however 4G customers got speed maximum of 100 Mbps, whereas 3G users only get a maximum speed of 14 Mbps. This is due to the fact that the data rate of 4G is greater than that of 3G. Although 4G cellular networks have a larger capacity and data throughput, they have a higher latency. In early 2019, 5G cellular networks were deployed to minimise latency and provide faster multi-Gbps peak data rates, increased dependability, huge network capacity, and availability.

In 5G cellular networks, the power consumption with a bandwidth of 100 MHz is five times higher than that in a 4G network with a bandwidth of 20 MHz, presuming the power spectrum density is the same (I *et al.*, 2020). The optimal use of MS with the strategy would undoubtedly cut power consumption with a reasonable delay. This paper, has also used the same MS with -policy sleeping technique on a finite buffer, a single server UR queue of a BS with Poisson arrivals, generally distributed service time, close down, and setup. In Kendall's notation, it was represented as finite buffer, multiple sleep with - policy M/G/1 with closed down and setup, because the UR queue was always time sensitive, a finite capacity queueing method was used to prevent congestion delays. Finite capacity M/G/1 queue with vacation and exhaustive service discipline was initially discussed by Lee (1984).

The researchers Niu *et al.* (2015), Guo *et al.* (2016) and Yang *et al.* (2017) examined the sleeping methods in BS by treating the UR queue as a queueing system which is an infinite capacity queueing system. In fact, as the number of customers waiting for service grows, the waiting time in the

Department of Mathematics, PSG College of Technology, Coimbatore, Tamil nadu, India

***Corresponding Author:** Deena Merit C K, Department of Mathematics, PSG College of Technology, Coimbatore, Tamil nadu, India, E-Mail: ckd.maths@psgtech.ac.in

How to cite this article: Deena, Merit, C.K., Haridass, M. (2023). Analysis of multiple sleeps and N-policy on a M/G/1/K user request queue in 5g networks base station. The Scientific Temper, **14**(2):375-382.

Doi: 10.58414/SCIENTIFICTEMPER.2023.14.2.21

Source of support: Nil

Conflict of interest: None.

Received: 17/03/2023 **Accepted:** 25/04/2023 **Published** : 30/06/2023

infinite capacity queue increases without any restriction. As a result, finite buffer queueing might be utilized to restrict the customer's waiting time. The isolated technique, in which each BS switches mode based on its own load, the cooperative approach, in which traffic from sleeping BSs is allowed to overflow to neighboring active BSs, and a combination of both methods were all examined by Wu *et al.* (2017). Chen (2020) discussed the benefits of the newly proposed multi-stage sleep mode control for 5G systems and then derived an analytical model for it based on the M/M/1/K queueing system in terms of energy efficiency and system delay. Each BS was modeled by Wu, *et al.* (2020) as a finite capacity M/G/1 vacation queueing system with closed down, and setup. They examined the three sleeping schemes: isolated scheme, cooperative scheme, and hybrid system, demonstrating the tradeoff between power consumption, blocking probability, and mean delay. While performing research in queueing systems, several writers employ a combination of close-down time, setup time, and -policy. Haridass and Arumuganathan (2012) derived steady-state performance measurements for multiple vacations queueing system with setup time. Parthasarathy and Sudhesh (2001) obtained the performance measures for a -policy transient Poisson queueing system. The steady state behavior of a batch arrival, batch service queueing system along with -policy, multiple vacations, and setup times was studied by Reddy *et al.* (1998). Among this, to get the queue size distribution, Haridass and Arumuganathan (2012) and Reddy *et al.* (1998) employed the supplementary variable technique.

This study has applied the sleeping scheme MS with -policy to the UR queueing system of a BS modeled as a M/G/1/K queueing system with closed down and setup.

Model Description

The arrival process of URs to the BS is a Poisson with the rate . Each UR is individually processed in the BS. The capacity of the BS is finite, say . The service time of the UR is an independent and identically distributed random variable . URs are processed based on FIFO queue discipline in the BS. The server will close down when there is no UR in the queue to reduce power consumption. If any UR is received during close down, the server instantly resumes operation; otherwise, the server is put into sleep mode. The sleeping time is an independent and identically distributed random variable . The wake-up scheme is defined as multiple sleep with -Policy. In such case, the sleeping BS awakens only when any sleeping time has ended and or more URs have accumulated. If there are at least URs in the queue at the end of any sleep, the server begins to set up (known as warm-up), and after setup is complete, the server begins to serve user requests. The random variables for service time, for close down time, for sleep time, and for setup time follows any general distribution.

Table 1: Notations

Description	Notation			
	Service time	Close down time	Sleep time	Setup time
Random variable	S	C	V	R
PDF	$s(x)$	$c(x)$	$v(x)$	$r(x)$
CDF	$S(x)$	$C(x)$	$V(x)$	$R(x)$
LST	$\tilde{S}(\theta)$	$\tilde{C}(\theta)$	$\tilde{V}(\theta)$	$\tilde{R}(\theta)$
Remaining time at time t	$S^0(t)$	$C^0(t)$	$V^0(t)$	$R(t)$

An M/G/1/K queue with sleep, close down and setup time are used to model the user request (UR) queue in the base station (BS) pertaining to the above-mentioned scenario. Table I lists the notations used in the proposed work's queueing model.

The system state probabilities are defined as follows:

$P_{1,n}$ (x, t) - The probability that there are exactly n URs in buffer at time t and one in service with remaining service time lying in between x and x + dx.

Q_{jn}(x, t) - The probability of exactly n URs in buffer on j sleep at time t with remaining sleeping time which lies between x and x + dx.

R_n(x, t) - The probability that there are exactly n URs in buffer at time t with the remaining setup time of BS lying between x and x + dx.

C_0 (x, t) - Probability that the BS is in close down process with remaining close-down time lying in between x and x + dx, and no URs.

The Queue size Distribution

The queue size equations are obtained using the supplementary variable technique. All possible system states are identified and corresponding equations are written for an infinitesimal Δt of the proposed model as follows:

$$P_{1,0}(x-\Delta t,t+\Delta t)=P_{1,0}(x,t)[1-\lambda\Delta t] +P_{1,1}(0,t)s(x)\Delta t + \int_0^\infty C(y,t)dys(x)[\lambda\Delta t] \quad (1)$$

$$P_{1,n}(x-\Delta t,t+\Delta t)=P_{1,n}(x,t)[1-\lambda\Delta t] +P_{1,n+1}(0,t)s(x)\Delta t +P_{1,n-1}(x,t)[\lambda\Delta t],$$

$$1\le n\le N-2 \quad (2)$$

$$P_{1,n}(x-\Delta t,t+\Delta t)=P_{1,n}(x,t)[1-\lambda\Delta t] +P_{1,n+1}(0,t)s(x)\Delta t +P_{1,n-1}(x,t)[\lambda\Delta t] +R_{n+1}(0,t)s(x)\Delta t,$$

$$N-1\le n\le K-2 \quad (3)$$

$$P_{1,K-1}(x-\Delta t,t+\Delta t)=P_{1,K-1}(x,t)[1-\lambda\Delta t] +P_{1,K-2}(x,t)[\lambda\Delta t] +R_K(0,t)s(x)\Delta t \quad (4)$$

$$Q_{j0}(x-\Delta t,t+\Delta t)=Q_{j0}(x,t)[1-\lambda\Delta t]+Q_{(j-1)0}(0,t)v(x)\Delta t,$$

$j\geq 2$ (8)

$$Q_{jn}(x-\Delta t,t+\Delta t)=Q_{jn}(x,t)[1-\lambda\Delta t]+Q_{j(n-1)}(x,t)[\lambda\Delta t]+Q_{(j-1)n}(0,t)v(x)\Delta t,$$

$j\geq 2, 1\leq n\leq N-1$ (9)

$$Q_{jn}(x-\Delta t,t+\Delta t)=Q_{jn}(x,t)[1-\lambda\Delta t]+Q_{j(n-1)}(x,t)[\lambda\Delta t],$$

$j\geq 2, N\leq n\leq K$ (10)

$$R_N(x-\Delta t,t+\Delta t)=R_N(x,t)[1-\lambda\Delta t]+\sum_{j=1}^{\infty}Q_{jN}(0,t)r(x)\Delta t \quad (11)$$

$$R_n(x-\Delta t,t+\Delta t)=R_n(x,t)[1-\lambda\Delta t]+R_{n-1}(x,t)[\lambda\Delta t]+\sum_{j=1}^{\infty}Q_{jn}(0,t)r(x)\Delta t,$$

$N+1\leq n\leq K$ (12)

Since the system does not change over time in steady state, the assumptions

$P_{1,n}(x)=lim_{t\to\infty}P_{1,n}(x,t)$, $C_0(x)=lim_{t\to\infty}C_0(x,t)$,

$Q_{jn}(x)=lim_{t\to\infty}Q_{jn}(x,t)$, $R_n(x)=lim_{t\to\infty}R_n(x,t)$ are taken to obtain the steady state probabilities. Using these assumptions in Equations from (1) to (12), the following steady state equations are obtained:

$$-\frac{d}{dx}P_{1,0}(x)=-\lambda P_{1,0}(x)+P_{1,1}(0)s(x)+\lambda s(x)\int_0^{\infty}C(y)dy \quad (13)$$

$$-\frac{d}{dx}P_{1,n}(x)=-\lambda P_{1,n}(x)+P_{1,n+1}(0)s(x)+\lambda P_{1,n-1}(x),$$

$1\leq n\leq N-2$ (14)

$$-\frac{d}{dx}P_{1,n}(x)=-\lambda P_{1,n}(x)+P_{1,n+1}(0)s(x)+\lambda P_{1,n-1}(x)+R_{n+1}(0)s(x),$$

$N-1\leq n\leq K-2$ (15)

$$-\frac{d}{dx}P_{1,K-1}(x)=-\lambda P_{1,K-1}(x)+\lambda P_{1,K-2}(x)+R_K(0)s(x) \quad (16)$$

$$-\frac{d}{dx}C_0(x)=-\lambda C_0(x)+P_{1,0}(0)c(x) \quad (17)$$

$$-\frac{d}{dx}Q_{10}(x)=-\lambda Q_{10}(x)+C_0(0)v(x) \quad (18)$$

$$-\frac{d}{dx}Q_{1n}(x)=-\lambda Q_{1n}(x)+\lambda Q_{1(n-1)}(x),$$

$1\leq n\leq K$ (19)

$$-\frac{d}{dx}Q_{j0}(x)=-\lambda Q_{j0}(x)+Q_{(j-1)0}(0)v(x),$$

$j\geq 2$ (20)

$$-\frac{d}{dx}Q_{jn}(x)=-\lambda Q_{jn}(x)+\lambda Q_{j(n-1)}(x)+Q_{(j-1)n}(0)v(x),$$

$j\geq 2,\ 1\leq n\leq N-1$ (21)

$$-\frac{d}{dx}Q_{jn}(x)=-\lambda Q_{jn}(x)+\lambda Q_{j(n-1)}(x),$$

$j\geq 2,\ N\leq n\leq K$ (22)

$$-\frac{d}{dx}R_N(x)=-\lambda R_n(x)+\sum_{j=1}^{\infty}Q_{jN}(0)r(x) \quad (23)$$

$$-\frac{d}{dx}R_n(x)=-\lambda R_n(x)+\lambda R_{n-1}(x)+\sum_{j=1}^{\infty}Q_{jn}(0)r(x),$$

$N+1\leq n\leq K$ (24)

Taking Laplace Stieltjes transform on both the sides of the equations from (13) to (24),

$$-[\theta\tilde{P}_{1,0}(\theta)-P_{1,0}(0)]=-\lambda\tilde{P}_{1,0}(\theta)+P_{1,1}(0)\tilde{S}(\theta)+\lambda\tilde{S}(\theta)\int_0^{\infty}C(y)dy \quad (25)$$

$$-[\theta\tilde{P}_{1,n}(\theta)-P_{1,n}(0)]=-\lambda\tilde{P}_{1,n}(\theta)+P_{1,n+1}(0)\tilde{S}(\theta)+\lambda\tilde{P}_{1,n-1}(\theta), 1\leq n\leq N-2 \quad (26)$$

$$-[\theta\tilde{P}_{1,n}(\theta)-P_{1,n}(0)]=-\lambda\tilde{P}_{1,n}(\theta)+P_{1,n+1}(0)\tilde{S}(\theta)+\lambda\tilde{P}_{1,n-1}(\theta)+R_{n+1}(0)\tilde{S}(\theta),$$

$N-1\leq n\leq K-2$ (27)

$$-[\theta\tilde{P}_{1,K-1}(\theta)-P_{1,K-1}(0)]=-\lambda\tilde{P}_{1,K-1}(\theta)+\lambda\tilde{P}_{1,K-2}(\theta)+R_K(0)\tilde{S}(\theta) \quad (28)$$

$$-[\theta\tilde{C}_0(\theta)-C(0)]=-\lambda\tilde{C}_0(\theta)+P_{1,0}(0)\tilde{C}(\theta) \quad (29)$$

$$-[\theta\tilde{Q}_{10}(\theta)-Q_{10}(0)]=-\lambda\tilde{Q}_{10}(\theta)+C_0(0)\tilde{V}(\theta) \quad (30)$$

$$-[\theta\tilde{Q}_{1n}(\theta)-Q_{1n}(0)]=-\lambda\tilde{Q}_{1n}(\theta)+\lambda\tilde{Q}_{1(n-1)}(\theta),$$

$1\leq n\leq K$ (31)

$$-[\theta\tilde{Q}_{j0}(\theta)-Q_{j0}(0)]=-\lambda\tilde{Q}_{j0}(\theta)+Q_{(j-1)0}(0)\tilde{V}(\theta),$$

$j\geq 2$ (32)

$$-[\theta\tilde{Q}_{jn}(\theta)-Q_{jn}(0)]=-\lambda\tilde{Q}_{jn}(\theta)+\lambda\tilde{Q}_{j(n-1)}(\theta)+Q_{(j-1)n}(0)\tilde{V}(\theta),$$

$j\geq 2,\ 1\leq n\leq N-1$ (33)

$$-[\theta\tilde{Q}_{jn}(\theta)-Q_{jn}(0)]=-\lambda\tilde{Q}_{jn}(\theta)+\lambda\tilde{Q}_{j(n-1)}(\theta),$$

$j\geq 2,\ N\leq n\leq K$ (34)

$$-[\theta\tilde{R}_N(\theta)-R_N(0)]=-\lambda\tilde{R}_N(\theta)+\tilde{R}(\theta)\sum_{j=1}^{\infty}Q_{jN}(0) \quad (35)$$

$$-[\theta\tilde{R}_n(\theta)-R_n(0)]=-\lambda\tilde{R}_n(\theta)+\lambda\tilde{R}_{n-1}(\theta)+\tilde{R}(\theta)\sum_{j=1}^{\infty}Q_{jn}(0) \quad ,N+1\leq n\leq K \quad (36)$$

The following probability generating functions are defined:

$$\tilde{P}_1(z,\theta)=\sum_{n=0}^{K-1}\tilde{P}_{1,n}(\theta)z^n \qquad ;P_1(z,0)=\sum_{n=0}^{K-1}P_{1,n}(0)z^n$$

$$\tilde{C}(z,\theta)=\tilde{C}_0(\theta) \qquad ;C(z,0)=C_0(0)$$

$$\tilde{R}(z,\theta)=\sum_{n=N}^{K}\tilde{R}_n(\theta)z^n \qquad ;R(z,0)=\sum_{n=N}^{K}R_n(0)z^n$$

$$\tilde{Q}_j(z,\theta)=\sum_{n=0}^{K}\tilde{Q}_{jn}(\theta)z^n \qquad ;\ Q_j(z,=\sum_{n=0}^{K}Q_{jn}(0)z^n$$

$$j=1,2,3,\ldots \qquad (37)$$

Multiplying equation (25) z^0, (26) by z^n (n=1,2,3...,N-2), by (27) by z^n (n=N-1,N,N+1,N+2...), taking summation from 0 to K

$$\theta\sum_{n=0}^{K-1}\tilde{P}_{1,n}(\theta)z^n+\sum_{n=0}^{K-1}P_{1,n}(0)z^n=$$
$$-\lambda\sum_{n=0}^{K-1}\tilde{P}_{1,n}(\theta)z^n+\lambda\sum_{n=1}^{K-1}\tilde{P}_{1,n-1}(\theta)z^n$$
$$+\tilde{S}(\theta)(\sum_{n=0}^{K-2}P_{1,n+1}(0)z^n+\sum_{n=N-1}^{K-1}R_{n+1}(0)+\lambda\int_0^{\infty}C(y)dy)$$

$$\Rightarrow z[\theta-\lambda+\lambda z]\tilde{P}_1(z,\theta)=[z-\tilde{S}(\theta)]P_1(z,0)$$
$$-\tilde{S}(\theta)\left(-P_{1,0}(0)+R(z,0)+\lambda z\tilde{C}(z,0)\right)$$
$$+\lambda\tilde{P}_{1,K-1}(\theta)z^{K+1} \qquad (38)$$

Substituting θ=λ-λz in equation (38)

$$[z-\tilde{S}(\lambda-\lambda z)]P_1(z,0)=\tilde{S}(\lambda-\lambda z)(-P_{1,0}(0)$$
$$+R(z,0)+\lambda z\tilde{C}(z,0))-\lambda\tilde{P}_{1,K-1}(\lambda-\lambda z)z^{K+1}$$

$$P_1(z,0)=\frac{\tilde{S}(\lambda-\lambda z)(-P_{1,0}(0)+R(z,0)+\lambda z\tilde{C}(z,0))}{[z-\tilde{S}(\lambda-\lambda z)]}$$
$$-\frac{\lambda\tilde{P}_{1,K-1}(\lambda-\lambda z)z^{K+1}}{[z-\tilde{S}(\lambda-\lambda z)]}$$

$$\Rightarrow z[\theta-\lambda+\lambda z]\tilde{P}_1(z,\theta)=[z-\tilde{S}(\theta)]$$
$$X[-\frac{\lambda\tilde{P}_{1,K-1}(\lambda-\lambda z)z^{K+1}}{[z-\tilde{S}(\lambda-\lambda z)]}$$
$$\frac{\tilde{S}(\lambda-\lambda z)(-P_{1,0}(0)+R(z,0)+\lambda z\tilde{C}(z,0))}{[z-\tilde{S}(\lambda-\lambda z)]}]$$
$$-\tilde{S}(\theta)(-P_{1,0}(0)+R(z,0)+\lambda z\tilde{C}(z,0))$$
$$+\lambda\tilde{P}_{1,K-1}(\theta)z^{K+1} \qquad (39)$$

$$\tilde{P}_1(z,\theta)=\frac{[\tilde{S}(\lambda-\lambda z)-\tilde{S}(\theta)]}{[\theta-\lambda+\lambda z]}\frac{[(-P_{1,0}(0)+R(z,0)+\lambda z\tilde{C}(z,0))]}{[z-\tilde{S}(\lambda-\lambda z)]}$$
$$+\frac{[[z-\tilde{S}(\lambda-\lambda z)]\lambda\tilde{P}_{1,K-1}(\theta)z^{K+1}-[z-\tilde{S}(\theta)]\lambda\tilde{P}_{1,K-1}(\lambda-\lambda z)z^{K+1}]}{z[\theta-\lambda+\lambda z][z-\tilde{S}(\lambda-\lambda z)]} \qquad (40)$$

Using equation (37) in equation (29) the following equation is obtained

$$-\theta\tilde{C}(z,\theta)+C(z,0)=-\lambda\tilde{C}(z,\theta)+P_{1,0}(0)\tilde{C}(\theta)$$
$$\Rightarrow[\theta-\lambda]\tilde{C}(z,\theta)=C(z,0)-P_{1,0}(0)\tilde{C}(\theta) \qquad (41)$$

Substituting θ=λ in (41) we obtain the following

$$C(z,0)=\tilde{C}(\lambda)P_{1,0}(0) \qquad (42)$$

Substituting (42) in (41), the following is obtained

$$\tilde{C}(z,\theta)=\frac{\tilde{C}(\lambda)-\tilde{C}(\theta)}{[\theta-\lambda]}P_{1,0}(0) \qquad (43)$$

Multiplying equation (30) by Z^0, (31) by z^n (1≤n≤K) and taking summation from 0 to K, we get the following

$$-\theta\sum_{n=0}^{K}\tilde{Q}_{1n}(\theta)z^n+\sum_{n=0}^{K}Q_{1n}(0)z^n=-\lambda\sum_{n=0}^{K}\tilde{Q}_{1n}(\theta)z^n$$
$$+\lambda\sum_{n=1}^{K}\tilde{Q}_{1(n-1)}(\theta)z^n+C_0(0)\tilde{V}(\theta)$$
$$-\theta\sum_{n=0}^{K}\tilde{Q}_{1n}(\theta)z^n+\sum_{n=0}^{K}Q_{1n}(0)z^n=-\lambda\sum_{n=0}^{K}\tilde{Q}_{1n}(\theta)z^n$$
$$+z\lambda\sum_{n=0}^{K-1}\tilde{Q}_{1n}(\theta)z^n+C_0(0)\tilde{V}(\theta)$$

$$-\theta\sum_{n=0}^{K}\tilde{Q}_{1n}(\theta)z^n+\sum_{n=0}^{K}Q_{1n}(0)z^n=-\lambda\sum_{n=0}^{K}\tilde{Q}_{1n}(\theta)z^n$$
$$+z\lambda[\sum_{n=0}^{K}\tilde{Q}_{1n}(\theta)z^n$$

$$-\tilde{Q}_{1K}(\theta)z^K]+C_0(0)\tilde{V}(\theta)$$
$$-\theta\tilde{Q}_1(z,\theta)+Q_1(z,0)=-\lambda\tilde{Q}_1(z,\theta)+z\lambda[\tilde{Q}_1(z,\theta)$$
$$-\tilde{Q}_{1K}(\theta)z^K]+C_0(0)\tilde{V}(\theta)$$
$$\Rightarrow[\theta-\lambda+\lambda z]\tilde{Q}_1(z,\theta)=Q_1(z,0)-C(z,0)\tilde{V}(\theta)$$
$$+z\lambda\tilde{Q}_{1K}(\theta)z^K \qquad (44)$$

Substituting θ=λ-λz in equation (44)

$$Q_1(z,0)=C(z,0)\tilde{V}(\lambda-\lambda z)-z\lambda\tilde{Q}_{1K}(\lambda-\lambda z)z^K \qquad (45)$$

Using (45) in (44)

$$[\theta-\lambda+\lambda z]\tilde{Q}_1(z,\theta)=C(z,0)[\tilde{V}(\lambda-\lambda z)-\tilde{V}(\theta)]$$
$$-\lambda[\tilde{Q}_{1K}(\lambda-\lambda z)-\tilde{Q}_{1K}(\theta)]z^{K+1}$$

$$\tilde{Q}_1(z,\theta)=\frac{\begin{bmatrix} C(z,0)[\tilde{V}(\lambda-\lambda z)-\tilde{V}(\theta)] \\ -\lambda z^{K+1}[\tilde{Q}_{1K}(\lambda-\lambda z)-\tilde{Q}_{1K}(\theta)]\end{bmatrix}}{[\theta-\lambda+\lambda z]} \quad (46)$$

Multiplying equation (32) by z^0, (33) by z^n (n=1,2,…,N-1), (34) by z^n (n=N,N+1,…,K) taking summation from 0 to K

$$-\theta\sum_{n=0}^{K}\tilde{Q}_{jn}(\theta)z^n+\sum_{n=0}^{K}Q_{jn}(0)z^n=-\lambda\sum_{n=0}^{K}\tilde{Q}_{jn}(\theta)$$
$$+\lambda\sum_{n=1}^{K}\tilde{Q}_{j(n-1)}(\theta)z^n+\tilde{V}(\theta)\sum_{n=0}^{N-1}\tilde{Q}_{(j-1)n}(0)z^n$$
$$-\theta\sum_{n=0}^{K}\tilde{Q}_{jn}(\theta)z^n+\sum_{n=0}^{K}Q_{jn}(0)z^n=-\lambda\sum_{n=0}^{K}\tilde{Q}_{jn}(\theta)z^n$$
$$+z\lambda\sum_{n=1}^{K}\tilde{Q}_{j(n-1)}(\theta)z^{n-1}$$
$$+\tilde{V}(\theta)\sum_{n=0}^{N-1}\tilde{Q}_{(j-1)n}(0)z^n$$

$$-\theta\sum_{n=0}^{K}\tilde{Q}_{jn}(\theta)z^n+\sum_{n=0}^{K}Q_{jn}(0)z^n=-\lambda\sum_{n=0}^{K}\tilde{Q}_{jn}(\theta)z^n$$
$$+z\lambda\sum_{n=0}^{K-1}\tilde{Q}_{jn}(\theta)z^n+\tilde{V}(\theta)\sum_{n=0}^{N-1}\tilde{Q}_{(j-1)n}(0)z^n$$
$$-\theta\tilde{Q}_j(z,\theta)+Q_j(z,0)=-\lambda\tilde{Q}_j(z,\theta)$$
$$+z\lambda[\tilde{Q}_j(z,\theta)-\tilde{Q}_{jK}(\theta)z^K]$$
$$+\tilde{V}(\theta)\sum_{n=0}^{N-1}\tilde{Q}_{(j-1)n}(0)z^n$$
$$\Rightarrow[\theta-\lambda+\lambda z]\tilde{Q}_j(z,\theta)=Q_j(z,0)$$
$$-\tilde{V}(\theta)\sum_{n=0}^{N-1}Q_{(j-1)n}(0)z^n$$
$$+\lambda z^{K+1}\tilde{Q}_{jK}(\theta) \quad (47)$$

Substituting θ = λ - λz in equation (47)

$$0=Q_j(z,0)-\tilde{V}(\lambda-\lambda z)\sum_{n=0}^{N-1}Q_{(j-1)n}(0)z^n$$
$$+\lambda z^{K+1}\tilde{Q}_{jK}(\lambda-\lambda z)$$
$$Q_j(z,0)=\tilde{V}(\lambda-\lambda z)\sum_{n=0}^{N-1}Q_{(j-1)n}(0)z^n$$
$$-\lambda z^{K+1}\tilde{Q}_{jK}(\lambda-\lambda z) \quad (48)$$

Using the equation (48) in (47), the following is obtained

$$\tilde{Q}_j(z,\theta)=\frac{\begin{bmatrix}[\tilde{V}(\lambda-\lambda z)-\tilde{V}(\theta)]\sum_{n=0}^{N-1}Q_{(j-1)n}(0)z^n \\ -\lambda z^{K+1}[\tilde{Q}_{jK}(\lambda-\lambda z)-\tilde{Q}_{jK}(\theta)]\end{bmatrix}}{[\theta-\lambda+\lambda z]} \quad (49)$$

Multiplying equation (35) by z^n, (36) by z^n (n=N+1,N+2,…,K) and taking summation from N to K

$$-\theta\sum_{n=N}^{K}\tilde{R}_n(\theta)z^n+\sum_{n=N}^{K}R_n(0)z^n=-\lambda\sum_{n=N}^{K}\tilde{R}_n(\theta)z^n$$
$$+z\lambda\sum_{n=N+1}^{K}\tilde{R}_{n-1}(\theta)z^{n-1}$$
$$+\tilde{R}(\theta)\sum_{n=N}^{K}\sum_{j=1}^{\infty}Q_{jn}(0)z^n$$
$$-\theta\sum_{n=N}^{K}\tilde{R}_n(\theta)z^n+\sum_{n=N}^{K}R_n(0)z^n=-\lambda\sum_{n=N}^{K}\tilde{R}_n(\theta)z^n$$
$$+z\lambda[\sum_{n=N}^{K}\tilde{R}_n(\theta)z^n-\tilde{R}_K(\theta)z^K]$$

$$+\tilde{R}(\theta)\sum_{n=N}^{K}\sum_{j=1}^{\infty}Q_{jn}(0)z^n$$
$$-\theta\tilde{R}(z,\theta)+R(z,0)=-\lambda\tilde{R}(z,\theta)$$
$$+z\lambda[\tilde{R}(z,\theta)-\tilde{R}_K(\theta)z^K]$$
$$+\tilde{R}(\theta)\sum_{n=N}^{K}\sum_{j=1}^{\infty}Q_{jn}(0)z^n$$
$$\Rightarrow[\theta-\lambda+\lambda z]\tilde{R}(z,\theta)=R(z,0)$$
$$-\tilde{R}(\theta)\sum_{j=1}^{\infty}[Q_j(z,0)$$
$$-\sum_{n=0}^{N-1}Q_{jn}(0)z^n]$$
$$+\lambda\tilde{R}_K(\theta)z^{K+1} \quad (50)$$

Substituting θ = λ - λz in equation (50)

$$0=R(z,0)-\tilde{R}(\lambda-\lambda z)\sum_{j=1}^{\infty}[Q_j(z,0)-\sum_{n=0}^{N-1}Q_{jn}(0)z^n]$$
$$+\lambda\tilde{R}_K(\lambda-\lambda z)z^{K+1}$$
$$\Rightarrow R(z,0)=\tilde{R}(\lambda-\lambda z)\sum_{j=1}^{\infty}[Q_j(z,0)-\sum_{n=0}^{N-1}Q_{jn}(0)z^n]$$
$$-\lambda\tilde{R}_K(\lambda-\lambda z)z^{K+1} \quad (51)$$

Substituting (51) in (50)

$$[\theta-\lambda+\lambda z]\tilde{R}(z,\theta)=[\tilde{R}(\lambda-\lambda z)-\tilde{R}(\theta)]\sum_{j=1}^{\infty}[Q_j(z,0)-\sum_{n=0}^{N-1}Q_{jn}(0)z^n]-\lambda z^{K+1}[\tilde{R}_K(\lambda-\lambda z)-\tilde{R}_K(\theta)]$$

$$\tilde{R}(z,\theta)=\frac{\left[\begin{array}{c}[\tilde{R}(\lambda-\lambda z)-\tilde{R}(\theta)]\sum_{j=1}^{\infty}[Q_j(z,0)-\sum_{n=0}^{N-1}Q_{jn}(0)z^n]\\-\lambda z^{K+1}[\tilde{R}_K(\lambda-\lambda z)-\tilde{R}_K(\theta)]\end{array}\right]}{[\theta-\lambda+\lambda z]} \quad (52)$$

Using the equations (40), (43), (46), (49) and (52), the probability generating function of the queue size P(z) is obtained as

$$P(z)=\tilde{P}_1(z,0)+\tilde{C}(z,0)+\tilde{Q}_1(z,0)+\sum_{j=2}^{\infty}Q_j(z,0)+\tilde{R}(z,0)$$

$$=\frac{[\tilde{S}(\lambda-\lambda z)-1]}{[-\lambda+\lambda z]}\frac{[(-P_{1,0}(0)+R(z,0)+\lambda z\tilde{C}(z,0))]}{[z-\tilde{S}(\lambda-\lambda z)]}$$

$$+\frac{[[z-\tilde{S}(\lambda-\lambda z)]\lambda z^{K+1}-[z-1]\lambda\tilde{P}_{1,K-1}(\lambda-\lambda z)z^{K+1}]}{z[-\lambda+\lambda z][z-\tilde{S}(\lambda-\lambda z)]}$$

$$+\frac{\tilde{C}(\lambda)-1}{[-\lambda]}P_{1,0}(0)$$

$$+\frac{[\tilde{C}(\lambda)P_{1,0}(0)[\tilde{V}(\lambda-\lambda z)-1]-\lambda z^{K+1}[\tilde{Q}_{1K}(\lambda-\lambda z)-1]]}{[-\lambda+\lambda z]}$$

$$+\sum_{j=2}^{\infty}\frac{\left[\begin{array}{c}[\tilde{V}(\lambda-\lambda z)-1]\sum_{n=0}^{N-1}Q_{(j-1)n}(0)z^n\\-\lambda z^{K+1}[\tilde{Q}_{jK}(\lambda-\lambda z)-1]\end{array}\right]}{[-\lambda+\lambda z]}$$

$$+\frac{\left[\begin{array}{c}[\tilde{R}(\lambda-\lambda z)-1]\sum_{j=1}^{\infty}[Q_j(z,0)-\sum_{n=0}^{N-1}Q_{jn}(0)z^n]\\-\lambda z^{K+1}[\tilde{R}_K(\lambda-\lambda z)-1]\end{array}\right]}{[-\lambda+\lambda z]}$$

$$=\frac{1-z}{[-\lambda+\lambda z][z-\tilde{S}(\lambda-\lambda z)]}[(1-z(1-\tilde{C}(\lambda))$$

$$+\tilde{C}(\lambda)\tilde{R}(\lambda-\lambda z)\tilde{V}(\lambda-\lambda z))P_{1,0}(0)$$

$$+\tilde{R}(\lambda-\lambda z)[1-\tilde{V}(\lambda-\lambda z)]\sum_{j=1}^{\infty}\sum_{n=0}^{N-1}Q_{jn}(0)z^n]$$

$$+\frac{[[z-\tilde{S}(\lambda-\lambda z)]\lambda z^{K+1}-[z-1]\lambda\tilde{P}_{1,K-1}(\lambda-\lambda z)z^{K+1}]}{z[-\lambda+\lambda z][z-\tilde{S}(\lambda-\lambda z)]}$$

$$+\sum_{j=1}^{\infty}\frac{-\lambda z^{K+1}[\tilde{Q}_{jK}(\lambda-\lambda z)-1]}{[-\lambda+\lambda z]}$$

$$+\frac{-\lambda z^{K+1}[\tilde{R}_K(\lambda-\lambda z)-1]}{[-\lambda+\lambda z]} \quad (53)$$

Simulation Model

The performance of the queueing system is analyzed using analytical, approximation, or simulation methods. An analytical method is more appropriate for simple queueing systems whereas the simulation approach will provide the best approximation solution for complex queueing systems. In a queueing system, each specification is associated with a distribution. Further extension is tedious and time-consuming in the analytical approach, but is simple to do with the simulation approach. The proposed fnite buffer queue with sleep, close down and setup time was simulated for 4,32,000 seconds(5 days) using simulation software ARENA. Its model document is given in Figure 1.

Numerical Illustration

Using simulation software ARENA, the finite buffer M/G/1 queue with sleep, close down, and setup time was simulated for 4,32,000 seconds (5 days). The obtained results are tabulated in Tables 3 and 4, graphs are plotted based on these results.

It was assumed that the service time S, sleep time V, close down time C and setup time R random variables followed deterministic distribution its parametric values are listed in table 2. The arrival rate was taken as λ = 1/sec. The assumptions on power consumption also were given in Table 2 based on (Woon, *et al.*, 2021; Niu *et al.*, 2015).

Impact of the Capacity of the System K on Mean Delay, Mean Power Consumption and Blocking Probability

Figure 2 shows that, as the system's capacity K grew, the mean delay also increased because the number of customers waiting for service kept growing. As a result, Figure 3 shows that the expected power usage increased as well. As the system's capacity grew, the number of customers who left without receiving service and the probability of blocking reduced, as shown in Figure 4.

Impact of the Arrival Rate λ on Mean Delay, Mean Power Consumption and Blocking Probability

Figure 5 shows the impact of arrival rate λ on mean delay and mean power consumption. When arrival rate increased, the frequency of BS entering into sleep decreased. Thus, the mean delay decreased. On the other hand, the power

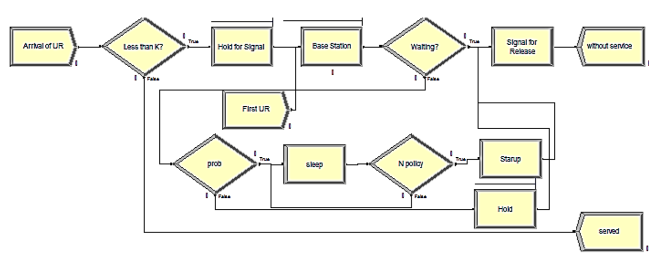

Figure 1: ARENA model document

consumption increased (see Figure 6) for increasing λ because the BS was less often went to sleep. As λ increased, 7 proves that due to the congestion the blocking probability increased.

Table 2: Assumptions

Random variable	*Mean*	*Server state*	*Power consumption*
S	2	busy	11577J/s
c	5	close down	10419.3J/s
v	6	vacation	2315.4J/s
R	5	setup	10419.3J/s

Table 3: Performance measures Vs. K for different N

N	*K*	*Expected power*	*Expected delay*	*Blocking probability*
1	10	8596.4114	5.5642	0.0691
	15	8802.7598	6.0816	0.0067
	20	8825.1492	6.1470	0.0003
	25	8825.4459	6.1579	0.0000
	30	8825.4552	6.1598	0.0000
	35	8825.4552	6.1598	0.0000
3	10	8519.4860	5.6591	0.0734
	15	8735.0030	6.2200	0.0080
	20	8768.1334	6.2827	0.0004
	25	8769.7275	6.2899	0.0000
	30	8769.8629	6.2909	0.0000
	35	8769.8629	6.2909	0.0000
5	10	8210.1870	6.0295	0.1040
	15	8524.0799	6.7592	0.0143
	20	8568.4150	6.9225	0.0009
	25	8572.2553	6.9375	0.0000
	30	8572.2713	6.937	0.0000
	35	8572.2713	6.937	0.0000
7	10	7726.9523	6.5569	0.1635
	15	8200.9923	7.6049	0.0340
	20	8319.6123	7.9516	0.0032
	25	8334.7753	7.9905	0.0001
	30	8334.6186	7.9956	0.0000
	35	8334.6186	7.9956	0.0000

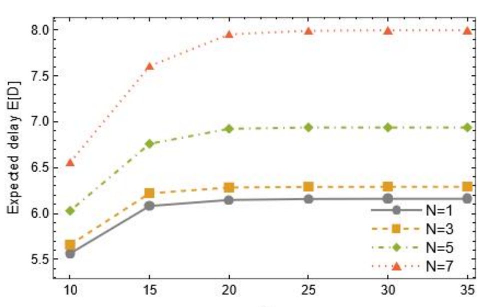

Figure 2: Mean delay vs. *K* for different *N* values

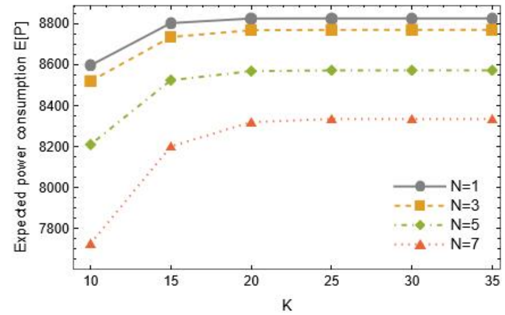

Figure 3: Mean power vs. K for different N

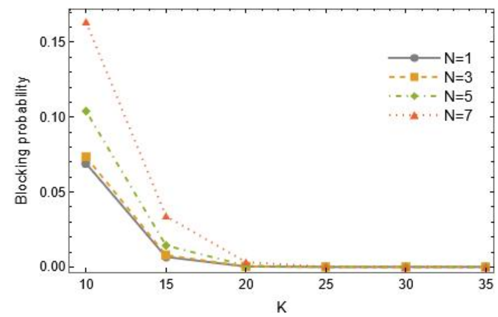

Figure 4: Blocking probability vs. K for different N

Table 4: Performance measures vs. λ for different N values

N	*λ*	*Expected power*	*Expected Delay*	*Blocking Probability*
1	0.4	7023.2654	7.5906	0.0005
	0.6	7669.9482	6.6630	0.0075
	0.8	8181.3531	6.0922	0.0312
	1.0	8596.4114	5.5642	0.0691
	1.2	8949.8054	6.0228	0.1078
	1.4	9312.9108	4.5114	0.1344
3	0.4	6317.0141	9.1694	0.0021
	0.6	7303.5826	7.3478	0.0130
	0.8	8006.5007	6.3679	0.0382
	1.0	8519.4860	5.6591	0.0734
	1.2	8914.9875	5.0535	0.1109
	1.4	9299.4185	4.5210	0.1356
5	0.4	5774.2697	11.4868	0.0099
	0.6	6795.0399	8.7357	0.0375
	0.8	7570.0827	7.1462	0.0735
	1	8210.1871	6.0295	0.1040
	1.2	8719.7896	5.2240	0.1315
	1.4	9205.1389	4.5842	0.1453
7	0.4	5407.4947	13.7492	0.0360
	0.6	6356.6987	10.0481	0.0871
	0.8	7088.1192	7.9572	0.1348
	1.0	7726.9524	6.5569	0.1636
	1.2	8324.4119	5.5196	0.1787
	1.4	8925.6573	4.7454	0.1775

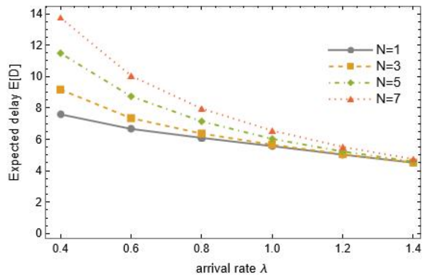

Figure 5: Mean delay Vs. arrival rate λ for different N values

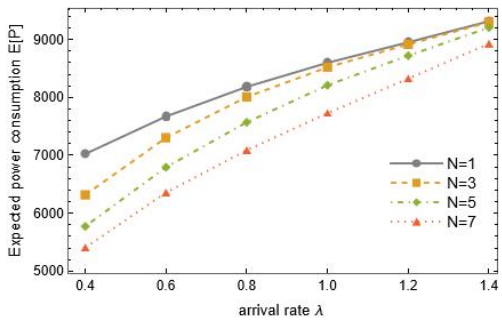

Figure 6: Mean power Vs. arrival rate λ for different N values

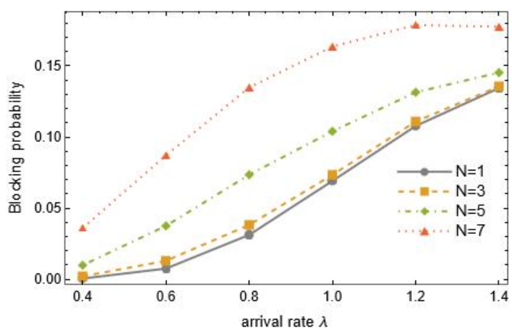

Figure 7: Blocking probability Vs. arrival rate λ for different N values

Impact of N on Mean Delay, Mean Power Consumption and Blocking Probability

The BS wait for N number of URs to awaken before proceeding, the bigger N values, caused the BS to sleep many times. Figures 2 and 5 show that when N increases, the mean delay increases. Figures 3 and 6 proved that the mean power consumption decreased as N increased. Further, figures 4 and 7 illustrates that the blocking probability increased as N increased. It is to be noted that N = 1 in the proposed model is the same as the MS model or MS without N-policy.

Summary

In this paper, the UR queue in a BS (macro cell or small cell BS) is modeled as a finite buffer M/G/1 queueing system with multiple sleeps, close down and setup. The proposed model is analyzed numerically through simulation. It is shown that the energy consumption of a BS can be reduced by introducing MS with an N-limited scheme in a finite buffer queueing system. Furthermore, one may evaluate the tradeoff between power consumption and delay by considering the sleeping method with an N-limited scheme in 5G cellular networks to optimize power consumption and latency.The optimization technique may be used to determine the best value for N and the average close down period. A randomized N-policy can also be used to broaden the task because network traffic is not always constant.

References

Chen, J. (2020). A Bounded Multi-Vacation Queue Model for Multi-stage Sleep Control 5G Base station. arXiv preprint arXiv:2011.09951.

Guo, X., Niu, Z., Zhou, S., & Kumar, P. R. (2016). Delay-Constrained Energy-Optimal Base Station Sleeping Control. *IEEE Journal on Selected Areas in Communications*. **34**(5),1073-1085.

Haridass, M., & Arumuganathan, R. (2012a). A batch service queueing system with multiple vacations, setup time and server's choice of admitting reservice, International Journal of Operational Research. **14**(2), 156-186.

I, CL., Han, S. & Bian, S. (2020). Energy-efficient 5G for a greener future. *Nat Electron*. **3**, 182–184. https://doi.org/10.1038/s41928-020-0404-1

Lee, T. T. (1984). Queue with Vacation Time and Exhaustive Service Discipline. *Operations Research*. **32**(4), 774–784.

Niu, Z., Guo, X., Zhou, S., & Kumar, P. R. (2015). Characterizing energy–delay tradeoff in hyper-cellular networks with base station sleeping control. *IEEE Journal on Selected Areas in Communications*, **33**(4), 641-650.

Parthasarathy, P. & Dharmaraja, S. (2001). Transient solution of a link with finite capacity supporting multiple streams. *Perform. Eval.* **43**, 1-14.

Reddy, G. K., Nadarajan, R., & Arumuganathan, R. (1998). Analysis of a bulk queue with N-policy multiple vacations and setup times. *Computers and operations research*. **25**(11), 957-967.

Woon, L. J., Ramasamy, G., & Thiagarajah, S. P. (2021). Peak power shaving in hybrid power supplied 5G base station. *Bulletin of Electrical Engineering and Informatics*. **10**(1), 62-69.

Wu, J., Wong, E. W., Chan, Y. C., & Zukerman, M. (2017, December). Energy efficiency-QoS tradeoff in cellular networks with base-station sleeping. In GLOBECOM 2017-2017 IEEE Global Communications Conference (pp. 1-7). IEEE.

Wu, J., Wong, E. W., Chan, Y. C., & Zukerman, M. (2020). Power consumption and GoS tradeoff in cellular mobile networks with base station sleeping and related performance studies. IEEE Transactions on Green Communications and Networking, 4(4), 1024-1036.

Yang, J., Wang, W., & Zhang, X. (2017, June). Hysteretic base station sleeping control for energy saving in 5G cellular network. In 2017 IEEE 85th Vehicular Technology Conference (VTC Spring) (pp. 1-5). IEEE.