APPLICATION OF SPSS MECHANISM ON A GPRS RADIO RESOURCE ALLOCATION

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ABSTRACT

The first and second generation telecommunication systems such as the Total Access Communication System (TACS) and Global System for Mobile Communication (GSM) were primarily developed to carry voice services alone. The increase in the demand for multimedia services supported by Internet Protocol (IP) and General Packet Radio Service (GPRS) has led to the sharing of scarce radio resource that was available to the existing GSM. The separate allocation of static bandwidth for voice and data, projected by the Third Generation Partnership Project (3GPP), has not achieved its purpose in solving network congestion problems. Therefore, a congestion avoidance radio resource allocation scheme known as a Static parallel sharing scheme SPSS is proposed for the typical GPRS system. Further, the model was analyzed using the Microsoft Excel spreadsheet. It was observed that the SPSS reduces drastically the blocking probability, delay and fluctuation in delay. The blocking and the delay probability of the parallel queue increase with increase in the utilization factor, for specified values of parallel queues (M). However, the parallel blocking probability decreases with an increase in the utilization factor with specific queue lengths while the delay and the fluctuation in delay decreases with an increase in the number of parallel buffers. A comparison between the SPSS and the Single Buffer Sharing Scheme (SBSS) - the existing best threshold buffer scheme, was also carried out. The result of the experimental analysis shows that the SPSS performed better than the SBSS.

KEYWORDS: GPRS, Resources, SPSS

1. INTRODUCTION

The first and second generation cellular mobile telephony systems, such as the Total Access Communication System (TACS) and Global System for Mobile Communication (GSM) use dedicated circuit switch links to carry voice services [1]. These links are not supported by the Internet services. Later generation networks provided support for multimedia services and could comfortably interface to the Internet using the GPRS system. The GPRS, on the other hand, supports packet switched services, in contrast with the TAC and GSM [2, 3], and can thus be interfaced directly with the Internet. Resources are made available for the General Packet Radio Service (GPRS) system to provide mobile subscribers with performance guaranteed packet data services over the original GSM radio channels [4].

The GPRS system employs resource sharing schemes that allocate resources only when user data are actually transmitted thereby providing more efficient use of the resources. Previous work on GPRS presented Single Buffer Sharing Scheme (SBSS) as the best buffer sharing scheme from the analytical point of view [5]. However, SBSS uses a centralized buffer may result in an unintended long delay. This limitation led to the introduction of the SPSS with short parallel queues. The SPSS prevents intolerable delay during busy periods. Therefore, the Quality of Service (QoS) of the

parallel buffer which includes, blocking probability, delay, and the fluctuation in delay, is determined and compared to the SBSS. The expository sections are as follows: In section 2, the threshold scheme is exploited; the architecture of the wireless GPRS radio resource from which the model was developed, is presented in section 3. Section 4 proposes a Markov model description of the radio resources and the derivation of the transition probability, the queueing delay and the fluctuation in delay. In section 5, the methodology is discussed, whereas section 6 and 7 presents the result and analysis, and conclusion respectively.

2. THRESHOLD SCHEME

The application of a threshold scheme, in a queueing theory, is a common practice in resource allocation. It applies a cutoff value to a collection of resources in order to regulate the sharing of the resources. In order to institute a control to a burst of packet traffic admitted into a radio access point, the implementation of a threshold value is imperative. Cutoff schemes are employed, particularly, in a voice and data networks, asynchronous transfer mode (ATM), earthquake disasters, emergency in hospitals to mention but a few [6, 7]. When a threshold scheme is based on the First-Come, First-Serve service discipline, it is termed Static buffer partitioning or sharing or dynamic threshold scheme depending on the behaviour of the cutoff. In a Static-Priority discipline, the priority of a customer is an unchangeable inherent quality which determines the class the customer belongs to, and the priority disciplines of the classes differ from each other [8]. Threshold policies optimize the performance of a system [9].

A threshold scheme where two classes of packets are served with the priority queueing discipline is popularly termed Queue-Length with Prioritized Threshold (QPT), alternating priority or queue with alternating priorities [10, 6, 11, 7, 12, 13]. Under the QPT technique, a single server processes and transmits a higher priority packet only when the queue length of a lower priority queue is less than or equal to a specified threshold value. When the queue length of the lower priority packets exceeds the specified threshold, the single server switches its services to the lower priority packets. The server continues to serve the lower priority packets until the queue length is below the threshold [7, 14]. If one of the priority queues is empty, the server continues to serve the queue with packets waiting. A queueing model without threshold grants preference to a higher priority packet whereas the lower priority packets have the precedence in infinite threshold [15, 14, 16]. The QPT may be operated in the FCFS discipline as well as the priority queueing discipline [17, 18, 19, 20, 21, 22, 19].

Unlike the QPT scheme, the alternating priority scheme (APS) ensures that the single server processes and empties the packets in a queue before switching to the next [15, 10, 9]. The APS gives preference to a delay sensitive packet and it is employed in the non-preemptive, preemptive priority and postpone algorithm [23, 19, 16, 24]. A queueing mechanism known as the Queue-length-dependent priority scheme (QLPS), a multi-server system, applies the APS. During a busy period, optimal performance is guaranteed.

Alternating Sharing Discipline (ASD) serves two parallel queues like the APS. However, ASD serves a single packet in one queue and then switch to the next queue. In theory, its performance is excellent, but it is difficult to apply in practice [6, 25]. Static and dynamic threshold schemes are currently being implemented in lossy and lossless communications systems such as the Public Switched Telephone network (PSTN) and Public Switched Data Network (PSDN). Wireless networks, including 2G, 3G, and 4G have immensely benefited from the threshold schemes.

Radio resource reservation and radio management, channel and buffer management, transportation, emergency in the hospital, earthquake disaster, etc. are some of the areas where the threshold is still currently applied [26, 27, 28, 29].

3. THE ARCHITECTURE OF A WIRELESS GPRS RADIO RESOURCE

Figure 1 illustrates the architecture of a typical GPRS radio resource in the Basic Service (BSS) node. The node comprises the sources, packet admitter, classifier and shaper, multiplexer, scheduler, parallel transmission buffers and channels. Active packet bursts admitted into the access are delayed by the shaper for a small interval, and are later transferred to the multiplexer (MUX). The MUX forwards the packets to the scheduler for onward delivery to the channels [30, 31, 32, 33]. The SPSS embedded in the PCU orchestrates the admission of packets into the GPRS radio access and out of the channels. Each of the parallel buffer queues is occupied by a single packet request. However, a lengthy packet occupies one or more parallel queue. SPSS has the advantage of reducing the blocking probability and the delay of the queues. Figure 1 is converted into the transition rate Markov chain model shown in Figure 2. Figure 2 is used for deriving the key QoS parameters.
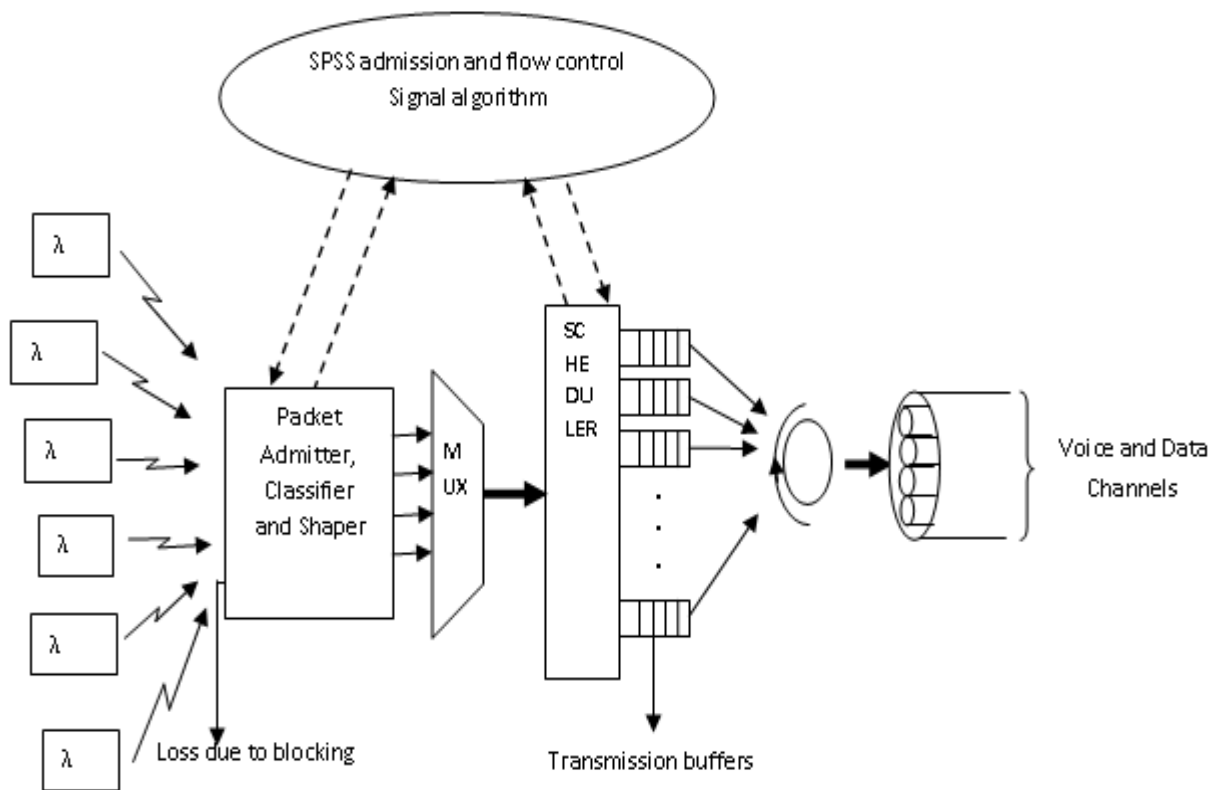

Figure 1: Architecture of a Wireless GPRS Radio Node

4. MARKOV MODEL DESCRIPTION OF THE GPRS RADIO RESOURCES

The transition rate Markov chain shown in Figure 2 is employed in developing the QoS expressions for the GPRS node. Figure 2 consists of C parallel servers and K parallel buffers. The capacities of the queues are K_1, K_2,… K_M. The transition probability of the states is determined by employing the fluid flow principle governing equilibrium state. The fluid flow equations of states 1, 2, C are expressed by equations (1-4).
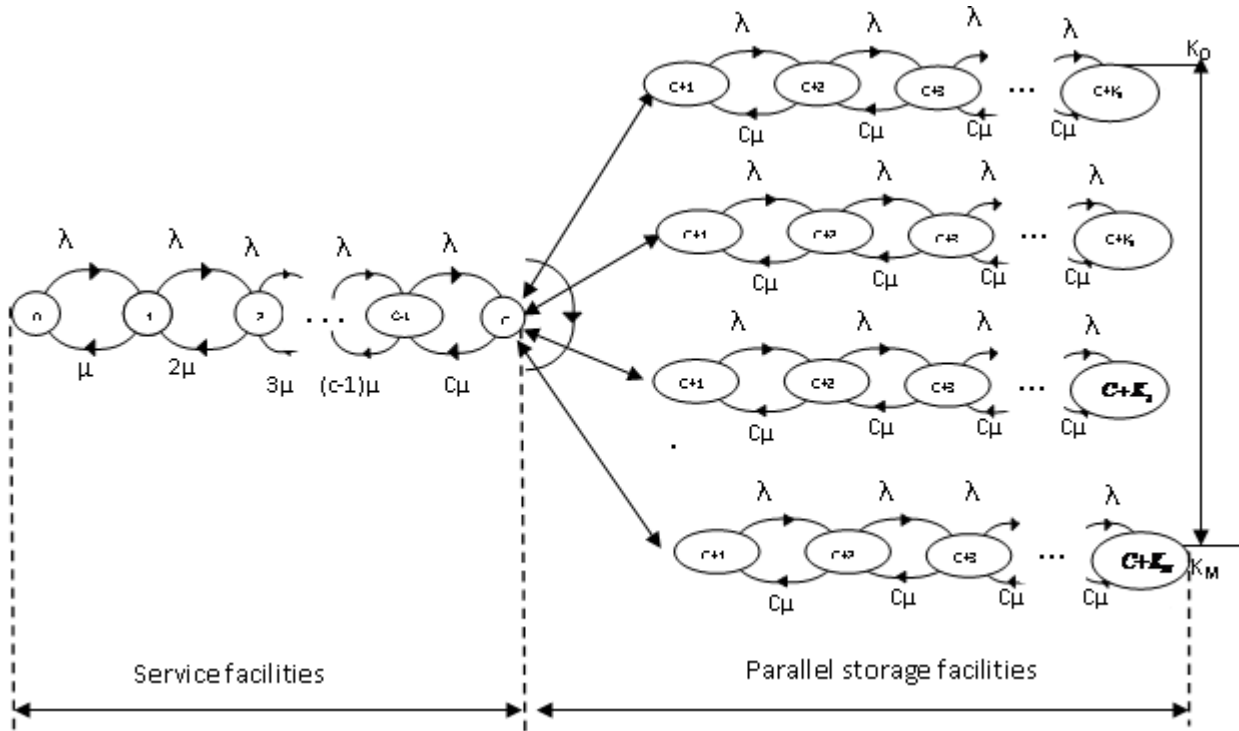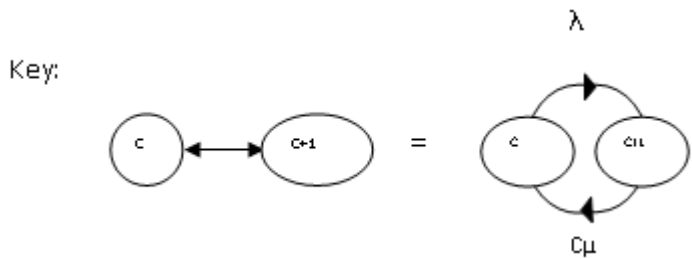
Figure 2: Markov Transition Rate Probability Chain of a GPRS Radio Model

K – the queue size of the individual queue K_1 – the capacity of 1 [st] parallel buffer K_M – the capacity of Mth parallel buffer λ – average arrival rate

μ – average service rate C- the Cth service facility

i= the number of the parallel buffer i= 1, 2, 3, … M.

State: Transition rate Probability

[0]:　　　　　　　$\lambda P_0 = \mu P_1$;　　　　　　　　　　　　　　　　　　　　　　　　(1)

[1]:　　　　　　　$\lambda P_0 + 2\mu P_2 = \lambda P_1 + \mu P_1$　　　　　　　　　　　　　　　　　(2)

[C-1]:　　　　　　$\lambda P_{C-2} + C\mu P_C = \lambda P_{C-1} + (C-1)\mu P_{C-1}$　　　　　　　　(3)

[C]:　　　　　　　$\lambda P_{C-1} + C\mu P_{C+1} = \lambda P_C + C\mu P_{C-1}$　　　　　　　　　　(4)

By substituting P_1 in equation (1) into equation (2) the result of the transition probability of state two produces equation (5).

$$P_2 = \left[\frac{\lambda}{\mu}\right]^2 \frac{P_0}{2!} \tag{5}$$

Solving equations (1-4) recursively yields the transition probability of the nth state of the service facility in equation (6).

[n]:
$$P_n = \left(\frac{\lambda}{\mu}\right)^n P_0 \tag{6}$$

Also, employing the fluid flow principle to states $C, \ldots C+k_1$ and $C, \ldots C+k_M$, the transition probability of states $C+k_1, \ldots C+k_M$ are produced as shown in equations (7-9).

[C+k$_1$]:
$$P_{C+K_1} = \frac{(C\rho)^{C+K_1}}{C^{K_1} * C!} P_0 \tag{7}$$

[C+k$_2$]:
$$P_{C+K_2} = \frac{(C\rho)^{C+K_2}}{C^{K_2} * C!} P_0 \tag{8}$$

[C+k$_M$]:
$$P_{C+K_M} = \frac{(C\rho)^{C+K_M}}{C^{K_M} * C!} P_0 \tag{9}$$

The probability that requests are delayed in the nth state of the parallel buffer queueing spaces is presented in equation (10)

$$P_{n_i} = \frac{(C\rho)^n}{C^{n-c} * C!} P_0 \tag{10}$$

Where,

P_0 = the idle probability- probability that the entire resource is empty

P_n = the transition probability the of nth state

K_i = the queue capacity of the ith parallel queue, i = 1, 2, …M

n = C+k$_i$

The characteristics of packets in the parallel queues $K_1, K_2, \ldots, K_M$ in Figure 2 are partially related by the function stated in equations (11 & 12).

$$f(k_{1,M}) = \frac{1}{\phi_{K_1}} + \frac{1}{\phi_{K_2}} + \ldots + \frac{1}{\phi_{K_M}} = \frac{\phi_{K_2}..\phi_{K_M} + \phi_{K_1}..\phi_{K_M} + \ldots + \phi_{K_2}..\phi_{K_{M-1}}}{\phi_{K_1}\phi_{K_2}..\phi_{K_M}} \tag{11}$$

Applying $\sum_{n=1}^{\infty} P_n = 1$, therefore

$$\sum_{n=0}^{c-1} \frac{(c\rho)^n}{n!} P_0 + \sum_{n_i=c}^{k_i} Q_{K_i} P_0 = \sum_{n=0}^{c-1} \frac{(c\rho)^n}{n!} P_0 + \sum_{n=c}^{k_i} \frac{\prod_{i=1}^{M} \phi_{K_i}}{\sum_{\substack{j=1 \\ j=i}}^{M} \prod_{i=1}^{M} \phi_{K_i}} P_0 = 1 \text{ , and}$$

$$P_0 = \left(\sum_{n=0}^{c-1} \frac{(c\rho)^n}{n!} + \sum_{n_i=c}^{k_i} \frac{\prod_{i=1}^{M} \phi_{K_i}}{\sum_{\substack{j=1 \\ j=i}}^{M} \prod_{i=1}^{M} \phi_{K_i}} \right)^{-1} \tag{12}$$

Where,

$$\phi_{K_i} = \frac{(c\rho)^n}{c^{n-c} c!}$$

The expression of the expected queue size of the Mth parallel buffer is presented in equation (13). Little's law of expected queue is related by the queue delay and the arrival rate. The parallel queueing delay is shown to be the expression in equation (14)

$$E[L_Q] = \sum_{n=c}^{k_i} (n-c) Q_{K_i} = \sum_{n=c}^{k_i} (n-c) \frac{\prod_{i=1}^{M} \phi_{K_i}}{\sum_{\substack{j=1 \\ j \neq i}}^{M} \prod_{i=1}^{M} \phi_{K_i}} \tag{13}$$

$$E[D_Q] = \lambda^{-1} * \left[\sum_{n=c}^{k_i} (n-c) \frac{\prod_{i=1}^{M} \phi_{K_i}}{\sum_{\substack{j=1 \\ j \neq i}}^{M} \prod_{i=1}^{M} \phi_{K_i}} \right] \tag{14}$$

Also, with equal queue capacity, the expected parallel queue delay E[D] after manipulation can further be expressed as

$$E[D] = \frac{(c\rho)^c \rho}{M\lambda c!} P_0 * \left(\frac{(1-\rho^{k-c+1}) - (1-\rho)((k-c+1)\rho^{k-c})}{(1-\rho)^2} \right) \tag{15}$$

Fluctuation in the queueing occupancy can best be described by the variance in the queue. The variance of the parallel buffer queue is computed by equation (16-18).

$$V[L_Q] = V[n] = E[n^2] - (E[n])^2 \tag{16}$$

but

$$E\left[n^2\right] = E\left[n(n-c)\right] + cE\left[n\right] = \sum_{n=c}^{k_M} n(n-c)P_n + cE\left[L_Q\right] \tag{17}$$

Thus

$$D_f = \frac{V\left[n\right]}{\lambda} = \frac{E\left[n(n-c)\right] + cE\left[n\right] - \left(E\left[n\right]\right)^2}{\lambda} \tag{18}$$

and the fluctuation in delay (D_f) is expressed by Little' law as a function of the arrival rate (λ), service rate (μ), utilization factor (ρ), and the quantity of the parallel queues (M) shown in equation (19). However, when k=c, D_f reduces to equation (20).

$$D_f = \frac{k(c\rho)^c \rho}{M\lambda c!} P_0 * \left(\frac{\left(1-\rho^{k-c+1}\right) - (1-\rho)\left((k-c+1)\rho^{k-c}\right)}{(1-\rho)^2} \right) +$$
$$c * \frac{(c\rho)^c \rho}{M\lambda c!} P_0 * \left(\frac{\left(1-\rho^{k-c+1}\right) - (1-\rho)\left((k-c+1)\rho^{k-c}\right)}{(1-\rho)^2} \right) -$$
$$\left(\frac{(c\rho)^c \rho}{M\lambda c!} P_0 * \left(\frac{\left(1-\rho^{k-c+1}\right) - (1-\rho)\left((k-c+1)\rho^{k-c}\right)}{(1-\rho)^2} \right) \right)^2 \tag{19}$$

5. METHODOLOGY

To determine the QoS parameters of the model in Figure 2, equations (10, 12, 15 & 19), which represent the blocking and the idle probability, the delay, and the fluctuation in delay, respectively, are simulated with the Microsoft Excel 2007 spreadsheet. The results of the simulation are collected after each run to determine the QoS parameters. Parameters used in the mathematical model are: arrival rate = $5*10^{-4}$, number of servers (c) =3, specified utilization factors (ρ) = 0.1- 0.9, specified queue length (k) = 1-25 in steps of five, the number of parallel queues (M) = 50. The QoS of the GPRS is determined for varying M and ρ. In order to validate or verify the QoS, the results of the simulation are plotted, analyzed and compared with the standards of the Third Generation Partnership Project (3GPP).

6. RESULTS AND ANALYSIS

The data collected at the end of the simulation using the Microsoft Excel 2007 spreadsheet were analyzed and compared with the standard results projected by the Third Generation Partnership Project (3GPP) and the Universal Mobile Telecommunications Standard (UMTS). The parameterized details of the template developed for the blocking probability of the SBSS and the SPSS schemes shown in Figure 1 are: number of servers (c) =3, individual buffer queue length k_i =5 bits, where i=1, 2,… M; note that the queue lengths of the parallel buffers are equal in the experimentation. Utilization factor (ρ) = 0.1-0.9, varying number of parallel buffers (M) = 1, 3, 5, 7, 9, 11 and 13. The blocking probability (P_B) of the SBSS and the SPSS are compared against the adopted $P_B = 10^{-4}$-10^{-5} given by the 3GPP standard for GPRS and UMTS.

The P_B of the SBSS was increased from $3.25*10^{-12}$ and $2.35*10^{-5}$ when the utilization factor changes from 0.1 to 0.4. The P_B value at ρ = 0.5 is $2.62*10^{-4}$ while beyond ρ = 0.7, the P_B of SBSS exceeds the value of the standards

exponentially. Between the range $\rho = 0.1$-0.5, the P_{Bs} of the SPSS at M= 3, 5, 7, 9, 11, and 13 are 1.08^{-12}- $8.5*10^{-5}$, $6.50*10^{-13}$- $5.25*10^{-5}$, $4.6*10^{-13}$- $3.75*10^{-5}$, $3.61*10^{-13}$-$2.92*10^{-5}$, $2.95*10^{-13}$- $2.39*10^{-5}$, and $2.50*10^{-13}$- $2.2*10^{-5}$ respectively. The P_{Bs} of SPSS exceeds the standard values beyond $\rho = 0.6$. The graph in Figure 3 shows that the P_{Bs} of all the SPSS are smaller than the SBSS mechanism.

Figure 4 illustrates the P_B of the SPSS parallel buffer queues against the increment of the number of parallel buffer queues. The P_B reduces exponentially with an increase in the amount of parallel buffers. The P_B of the parallel buffers increases from $7.7*10^{-6}$- $1.54*10^{-7}$ and $3.28*10^{-5}$- $6.56*10^{-7}$ as increases from M from 1-50 at a specified value of ρ as 0.45 and 0.5 respectively. At $\rho = 0.5$, the P_B of the parallel buffer queues ranges from $2.4*10^{-5}$-$2.46*10^{-6}$ with the increase in M from 5-50. The P_B of the parallel buffer queues decreases from $7.85*10^{-5}$-$7.85*10^{-6}$ at the same range of M. At $\rho = 0.6$, the P_B of the parallel buffer queues slightly exceeds the value of the standard, whereas beyond it, the P_{BS} do not meet the requirement of the standard $P_B=10^{-4}$.

Figure 5 is the result of the graph obtained when five parallel buffer queues are permanently attached to three service facility, and the utilization factor of the facility is increased from $\rho = 0.1$- 0.9 for a specified queue length (k). It was observed that the probability that packets are rejected by the parallel queues when k = 30 is the least for specific values of ρ. However, the probability of packet rejected when at k=5 for the same value of ρ is very high compared to when k=30. The P_B of the parallel buffer increases with increase in ρ.

 The Delay of the parallel queue increases with an increase in the utilization factor for a specified value of M as shown in Figure 6. Specifically, Figure 6 shows delay is highest with the SBSS and smallest with the SPSS at M=1. It can thus be said that SBSS is very sensitive to delay compared to SPSS when ρ is varied from 0.4-0.9.

In Figure 7, the fluctuation in delay reduces with the increase in the number of parallel buffers. Delay fluctuation at the specified value: $\rho = 0.45$, 0.5, 0.55, 0.6 and 0.65 lies between $2.17*10^{-6}$ – $6.51*10^{-7}$, $3.84*10^{-6}$ – $1.04*10^{-6}$, $5.35*10^{-6}$ – $1.61*10^{-6}$, $7.94*10^{-6}$ – $2.38*10^{-6}$ and $1.14*10^{-5}$ – $3.43*10^{-6}$, respectively, when M varies from 15-50. The value of M is fixed at 5 and the fluctuation in delay is measured for varying value of ρ at a specified values of k. The figure shows the result of the fluctuation in delay increases with increase in the utilization factor (ρ), and it attained its least and highest value when k = 5 and 25, respectively, as shown in Figure 8.
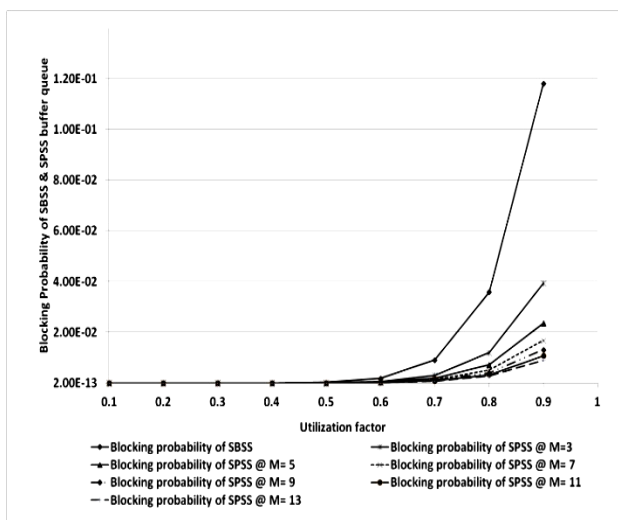

Figure 3: Graph of Blocking Probability of SBSS/SPSS vs. Utilization factor
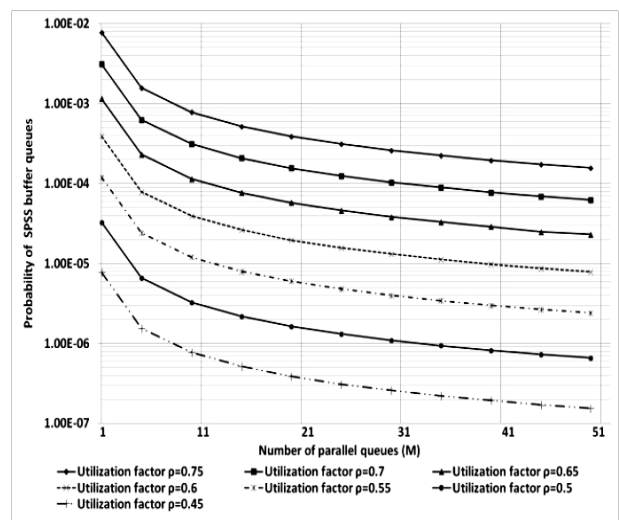

Figure 4: Graph of Blocking Probability of SPSS vs. Number of Parallel Queues (M)
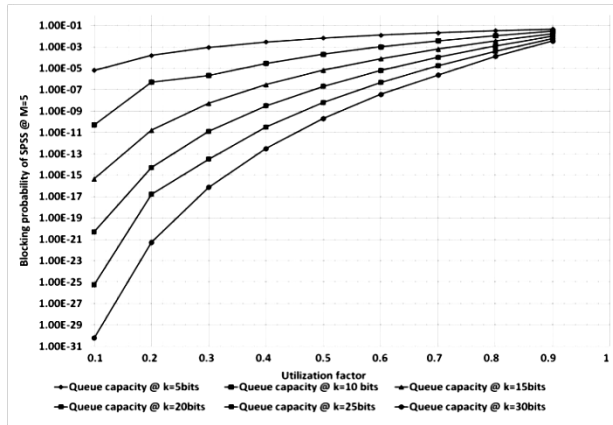
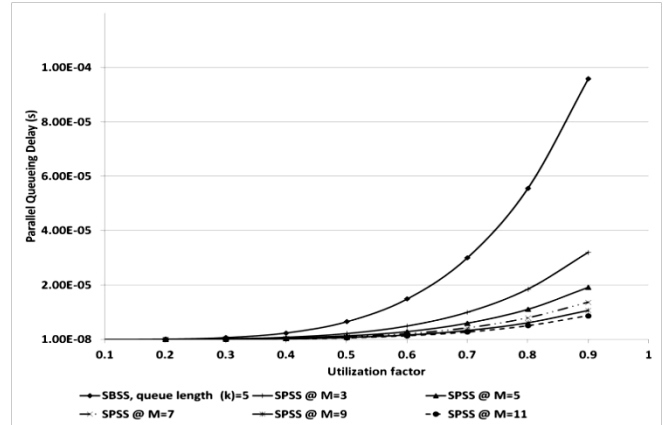**Figure 5: Blocking Probability of @ M=5 vs. Utilization Factor**

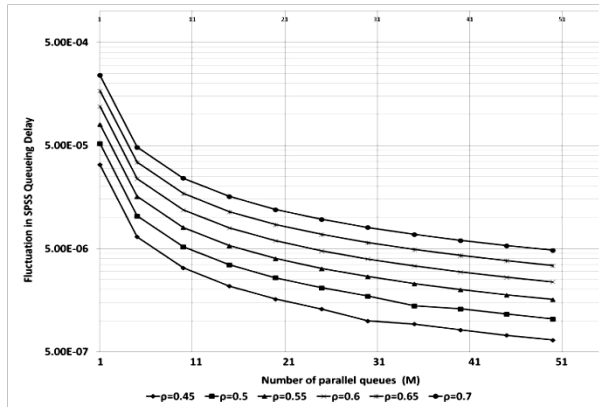**Figure 6: Delay of Parallel Queues vs. Utilization Factor**

Figure 7: Fluctuation in Delay vs. Number of Parallel Queues
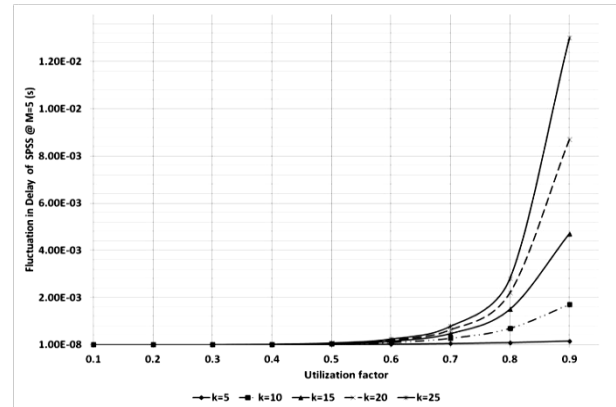

Figure 8: Fluctuation in Delay at M = 5 vs. Utilization factor

7. CONCLUSIONS

The blocking and the delay probability of the parallel queue increases with the increase in the utilization factor for specified values of parallel queues (M). However, the parallel blocking probability decreases with an increase in the utilization factor with specific queue lengths while the delay and the fluctuation in delay decrease with an increase in the number of parallel buffers. A comparison between the SPSS and the SBSS (the existing best threshold buffer scheme) was also carried out. The result of the analysis shows that the SPSS performed better than the SBSS. The application of the SPSS algorithm, in terms of delay and fluctuation in delay, is recommended for prioritizing mixed packets in a GSM, GPRS and UMTS wireless system.

REFERENCES

1. F. Xiaoyang, and G Dipak, "Performance Modeling and QoS Evaluation of MAC/RLC Layer in GSM/GPRS Networks," Proc. *38th IEEE Conf. on ICC*, Anchorage, Alaska, 2003, 271-275.

2. D.C.M Kuan, and B. S. Yeo, "A Non-Linear Binary Integer Programming Model for Location Management Design of GPRS," Proc. *IEEE Conf. on International Conf. on ICC*, 2005 3100-3106.

3. A. Farshid, and C.M.L. Victor, "QoS Support in the UMTS/GPRS Backbone Network Using DiffServ," *Proc. IEEE Conf. on GLOBCOM*, Taipei, Taiwan, 2002, 1449-14453.

4. Bettstetter C, Vogel H and Ebercpacher J, "GSM Phase 2+ General Packet Radio Service GPRS: Architecture, Protocols, and Air Interface," *IEEE Commus. Surveys*, vol. 2, no. 3, 1999, pp. 1- 13.

5. Otavboruo E, Ani C and Onyishi D, "Implementation of Static Threshold Schemes in a GPRS Resource Template, *IJECE*, vol. 2. Issue 1, Feb 2013, 105-114.

6. Sykes J. S., "Simplified Analysis of an Alternating-Priority Queuing Model with Setup Times," *Opns. Res.*, vol. 18, no. 3, Nov.-Dec. 1970, pp. 1182-1192.

7. Gong Q and Batta R, "A Queue-Length Cutoff for a Preemptive Two-Priority M/M/1 System," *SIAM*, vol. 67, no. 1, 2006, pp. 99-115.

8. Netterman A and Adris I, "A Dynamic Priority Queue with General Concave Priority Functions", *Opns. Res.*, vol. 27, no. 6, Nov.-Dec. 1979, pp. 1088-1100.

9. Don T and Nelson R, "Approximating the Mean Time in System in a Multiple-Server Queue That Uses Threshold Scheduling," *Opns Res.*, vol. 33 no. 3, May – Jun. 1987, pp. 419-427.

10. Avi-Itzhak, B, Maxwell W. L and Miller L. W, "Queueing with Alternating Priorities," *Opns. Res.,* vol. 13, no. 2, Mar. -Apr., 1965, pp. 306-318.

11. Stidham S., "Regenerative Processes in the Theory of Queues, with Application to the Alternating-Priority Queue," *Advances in Applied Probability*, vol. 4, no. 3, Dec. 1972, pp. 542-577.

12. Stanford D. A, "Waiting and Interdeparture Times in Priority Queues with Poisson-and General-Arrival Streams," *Opns. Res.*, vol. 45, no. 5 Sep.-Oct. 1997, pp. 725-735.

13. Patrick J and Puterman M. L, "Improve Resource Utilization for Diagnostic Services through Flexible Inpatient Scheduling: A Method for Improving Resource Utilization," *The Journal of the Operational Res*, vol. 58, no. 2, Feb 2007, pp. 253-245.

14. Deng Y and Tan J, "Priority Queueing Model with Changeover Times and Switching Threshold," *Journal of Applied Probability*, vol. 38, 2001, pp. 263-273.

15. Knessl C, Choi D and Tier C, "A Dynamic Queue Model for Simultaneous Service of Two Traffic Types," *SIAM*, vol. 63, no. 2, Nov. 2002-Jan. 2003, pp. 398-422.

16. Nain Philippe, "On a Generalization of the Preemptive Resume Priority," *Advances in Applied Probability*, vol. 18, no. 1, Mar. 1986, pp. 255-273.

17. Prabhu N. U and Reeser P. K., "A Random Family of Queueing Systems with a Dynamic Priority Discipline," *Mathematics of Opn.s Res.*, vol. 10, no. 1, Feb. 1985, pp. 24-32.

18. Reiman I. M and Wein M. L, "Dynamic Scheduling of a Two-Class Queue with Setups," *Opns. Res.*, vol. 46, no. 4, Jul. Aug. 1998, pp. 532-547.

19. Schassberger R, "A Broad Analysis of Single Server Priority Queue with Independent Input Streams, One of Them Poisson," *Advances in Applied Probability*, vol. 6, no. 4, Dec. 1974, pp. 666-688.

20. Bell S. L and Williams R. J, "Dynamic Scheduling of a System with Two Parallel Servers in Heavy Traffic with Resource Pooling: Asymptotic Optimality of a Threshold Policy," *The Annals of Applied Probability*, vol. 11, no. 3, Aug. 2001, pp. 608-649.

21. Hassin R and Haviv M, "Equilibrium Threshold Strategies: The case of Queues with Priorities," *Operations Research*, vol. 45, no. 6, Nov. – Dec. 1997, pp. 966-973.

22. Lee D, "Analysis of a Two-Queue Model with Bernoulli Schedules," *Journal of Applied Probability*, vol. 34, no. 1, Mar. 1997, pp. 176-191.

23. Ward R. A and Bambos N, "On Stability of Queueing Networks with Job deadlines," *Journal of Applied Probability*, vol. 40, no. 2, June 2003, pp. 293-304.

24. Harrison J. M, "A Limit Theorem for Priority Queues in Heavy Traffic", *Journal of Applied Probability* vol. 10, no. 4 Dec 1973, pp. 907-912.

25. Eisenberg M, "Two Queues with Alternating Service," *(SIAM)*, Vol. 36, no. 2 Apr., 1976, pp. 287-303.

26. Taylor I. D. S. and Templeton J. G. C, "Waiting Time in a Multi-sever Cutoff Queue, and its Application to urban Ambulance Service," *Opns Res.*, vol. 28, no. 5 Sep. 1980, pp. 1168-1188.

27. Jaiswal N. K, "Priority Queues", Academic Press, New York, 1968, pp. 1-240.

28. Schaack C and Larson R. C, "A N-Server Cutoff Queue," *Opns Res.*, vol. 34, no. 2, Mar.-Apr. 1986, pp. 256-266.

29. Schaack C and Larson R. C, "An N Server Cutoff Priority Queue where Arriving Customers Request a Random Number of Servers," *Management Science*, vol. 35, no. 5, May 1989, pp. 614-634.

30. Krishnan S, Choudhury A. K, and Chiussi F. M, "Dynamic Partitioning: A Mechanism for a Memory Management," *INFOCOM*, 1999, pp. 144-153.

31. Kumar A, Manjunath D and Kuri Joy, "Communication Networking: An Analytical Approach," Elsevier, Oxford, 2004, (5th ed.), pp. 1-929.

32. Starlings W, "Data and Computer Communications," 1997, Prentice hall, pp. 1-799.

33. Forrouzan B. A and Fegan S. C, "Data Communications and Networking," (4th ed.), Tata McGraw-Hill, New Delhi, 2007, pp. 1-1133.