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# RADIO RESOURCE ALLOCATION: EVALUATION OF TPPSS, SPSS AND SBSS SCHEMES

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## ABSTRACT

It is a clear fact that the ingress of the current wireless multimedia networks requires optimization based on the QoS degradation it is experiencing. The classic single buffer sharing scheme (SBSS) recommended for wireless networks is limited by its delay and it is characterized by a high packet congestion. Practical wireless networks such as the GSM, GPRS and UMTS require effective radio resource sharing schemes, which meet users demand. This paper proposed two parallel buffer resource sharing mechanisms; the Static Parallel Sharing Scheme (SPSS) and the Poisson_Static Parallel Sharing Scheme (PPSS). This work developed, modeled, and simulated analytical expressions for the PPSS and SPSS, and these models were compared with the existing SBSS scheme. The simulation results demonstrated that PPSS and SPSS strategies are absolutely better than SBSS in terms of blocking probability, delay and delay variation.

**KEYWORDS:** Buffer resources, PPSS, SPSS

## INTRODUCTION

The explosive load surge experienced by the present mobile and wireless communication networks, which support a large number of users with flexible load requirements, is worrisome. The increasing demand for wireless communication resource by users is the primary source of congestion. Congestion is problematic in a wireless radio service. It is mainly caused by heterogeneous requests, which may be resolved by heterogeneous service schemes. Heterogeneity requires integration, coordination and management of the functionality of wireless radio resources (WRR) [1, 2, 3, 4, 5, 6, 7]. The WRR consists of the switches, buffer and servers. Communication experts employed several techniques for allocating scarce radio resources efficiently and optimally [7]. These techniques are focused on the radio and core access points. Radio and core access methods projected by researchers are yet to meet the demands of users [8]. The accumulation of traffic at the ingress of a node forces network operators to dramatically increase the capacity of their networks to match users' requests [9]. The implication is that users may be required to compete for resources when the request demanded exceeds the service capacity of a wireless network.

Allocating the correct service rate expected to deliver a high performance metric to both non-real time and sensitive real-time applications is a critical resource allocation problem. This is as a result of the overwhelming nature of requests. In addition, the radio service process is subject to interruptions, such as breakdown of servers, scheduled off-periods, non-optimal assignment and coordination of resources etc. [10]. Some existing methods employed to resolve the explosive traffic demands, which overwhelmed resources, include network resource scaling and optimization, and the introduction of heterogeneous micro base station and shared channel allocation [9, 11, 12, 13, 14]. Resource aggregation, sharing and reservation produce less blocking and waiting compared to when they operate individually [15, 16, 17, 18].

## DYNAMIC THRESHOLD SCHEME

Congestion, may render wireless telecommunication resources ineffective. It causes unbalanced delay, throughput degradation and resource overload. Occasionally, it leads to blocking of packets in a wireless network [19, 20, 21]. Mixed packets, such as voice and data, constitute the primary source of congestion. Thus, understanding: (a) the influence of overload on the resources; (b) the switching principles and the operational functions of the wireless links; and (c) the buffer management scheme is essential in improving the quality of service (QoS) of a wireless network [22, 23, 24, 25]. The queueing delay and the fluctuation in delay of a group buffers or servers are two paramount key quality indicators (KQIs) when considering the management of congestion in a digital system. Researchers utilize both the static threshold schemes (STSs) and the dynamic threshold schemes (DTSs) to regulate packet requests [23]. A detail study of the STS is presented in [23, 26].

Popular DTSs include the dynamic buffer sharing schemes (DBTSs). The DBTSs guarantee a full utilization of network resources and they provide a balance between isolation and efficiency [23]. Most practical DBTSs require just a queue, a counter, comparators and a shift register. A high threshold results in unfair sharing of resources, whereas a low threshold results in an excessively unused buffer waiting spaces in DBTSs [27, 28, 29, 30, 31]. The major limitation of a DBTS is the complexity of its algorithm and the complication of the packet management process [28, 31].

Pushout queuing scheme (PQS) is a DTS, which pushes out a lower priority packet from a buffer in favour of a higher priority packet when the threshold is exceeded. It minimizes packet loss and maximizes throughput. However, it is difficult to manage [32].

Dynamic Partial_Sharing/Partitioning Threshold Scheme (DP/PTS) is a combination of two STSs configured to function as a DTS mechanism. The two STSs are the Complete Sharing Scheme (CSS) and the Complete Partitioning Scheme (CPS). In the DP/PTS mechanism, a portion of the entire buffer pool is shared among inactive output while the unused part is partitioned among the active output. A port is said to be active if its queue length is larger than the ratio of the total of the total buffer size to the total number of output ports [27]. The DP/PTS is an efficient and a fair DTS scheme. Nevertheless, it has an overwhelming task of identifying and expunging the longest packets from parallel queues. DPP/PTS is also difficult to implement in a multi-space priority queueing system [27, 33]. Dynamic Queue-control Threshold Scheme (DQTS) is employed in sharing a pool of buffers between packet voice and data. The DQTS blocks data request from entering a reserved buffer space when it perceives that the entrance of such packet will cause the threshold to be exceeded. It is limited by excessive used buffer spaces [33, 34]. However, it guarantees a better buffer utilization than the DQTS. It establishes a common threshold for all the queues in the pool of buffers [30].

The Service-class Buffer Threshold Scheme (SBTS) is a DTS. It comprises the input terminal, a scheduler, a buffer and a buffer controller. The SBTS aggregates packets in a common pool of buffers and routes them dynamically to different service classes with the help of packet identifiers. It maintains and retains the link between the service class and the buffer, depending on when the packets are successfully delivered [28].

Dynamic Window-based Threshold Scheme (DWTS) transmitters send packets to receivers without waiting for acknowledgement. It consists of a window controller (WC) and a traffic controller (TC). The WC executes the Additive-Increase-Multiplicative-Decrease (AIMD) protocol among the source node. The TC scales the rate of the window and stabilizes the varying traffic pattern from the sources as well. When there is a buffer overflow, the TC calculates the duration of the multiplicative-Decrease (MD) phase and the scale parameter and sends it to the WC. The WC in response adjusts its window size [35]. This work proposes two new static Buffer threshold schemes, which could be employed as DTS schemes for voice and data packets. The main aim is to introduce schemes which can handle congestion, delay and delay variation projected for the current wireless networks. To this effect, this paper developed the following analytical QoS expressions for the PPSS and SPSS mechanism. The QoS expressions are the: (a) blocking probability (PB); (b) expectation of packet length (E[LQ]); (c) delay (E[D]); (d) variance (V[n]) and (d) delay variation (E[DV]). The QoS is evaluated graphically and analytically. At the end the results of both the PPSS and the SPSS are compared with the SBSS.

## MATHEMATICAL METHOD

Figure 1 is the Markov transition rate Probability model of the PPSS implemented on a GPRS radio. It was adopted from the previous work of the researchers in [26]. A detailed transition rate probability chain of the SPSS is also in [26]. The states of the parallel storage facility are formulated from Poisson assumptions which state that:

- Only one packet is selected at a small interval of time by the PPSS.
- Activities in each of the queues are independent
- Parallel servers and storage facilities are independently and identically distributed
- The length of the queues and the capacity of the service facilities are finite
- The setup (switching) time between queues are negligible
- Selection of two or more queues by the PPSS scheme, at a small interval, is prohibited
- The queue lengths of the queues are equal.

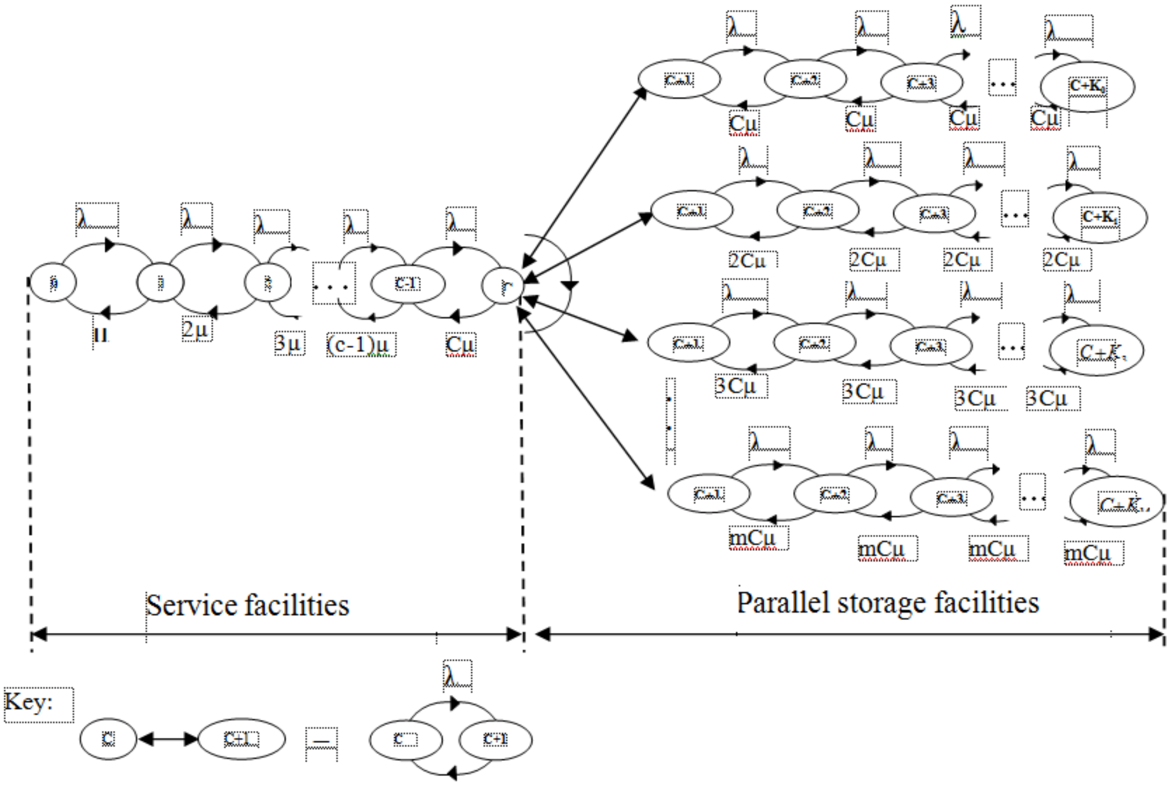


**Figure 1: Markov Transition rate Probability Chain of a GPRS Radio Model**

The QoS expression of the GPRS radio resource is developed based the assumptions stated above. The principle of network traffic equilibrium, asserting that the sum of inflow rate is equal to the sum of outflow rate is also applied to the Markov chain. From it, the state transition probability of the service facility is derived. Equations (1-5) are the mathematical expressions of the state of the service facilities.

State: Transition Rate Probability

[0]: $\lambda P_0 = \mu P_1$; $P_1 = \frac{\lambda}{\mu} P_0$ - - - - - - - - (1)

[1]: $\lambda P_0 + 2\mu P_2 = \lambda P_1 + \mu P_1$; $P_2 = \left(\frac{\lambda}{\mu}\right)^2 \frac{P_0}{2!}$ - - - - - - (2)

[2] $\lambda P_1 + 3\mu P_3 = \lambda P_2 + 2\mu P_2$; $P_3 = \left(\frac{\lambda}{\mu}\right)^3 \frac{P_0}{3!}$ - - - - - - (3)

[C-2]: $\lambda P_{C-3} + (C-1)\mu P_{c-1} = \lambda P_{C-2} + (C-2)\mu P_{C-2}$ - - - - - - (4)

[C-1]: $\lambda P_{C-2} + C\mu P_C = \lambda P_{C-1} + (C-1)\mu P_{C-1}$ - - - - - (5)

By solving the equations recursively, the transition probability of the state (C-1) can be expressed as

$$P_{C-1} = \left(\frac{\lambda}{\mu}\right)^{C-1} * \frac{P_0}{(C-1)!} \qquad (6)$$

This work labels the transition states of the parallel queues by the notations [C-1], 2[C-1], 3[C-1], M[C-1].

Similarly, the transition probability of the m<sup>th</sup> parallel queues is written as $P_{m(C+k)}$. The solution of the parallel queue is influenced by states C-1 and C, respectively, and a number of queues occupied by the packets. Therefore, the solution of each queue is performed recursively beginning from state [C-1]. For the first parallel queue, the blocking probability of the first queue is formulated from the chain by equations (7-16).

State: Transition Rate probability

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

from which $P_C = \frac{\lambda}{C\mu} P_{C-1}$ - - - - - - - - (7)

By substituting equation (6) into equation (7),

$P_C = \frac{\lambda}{C\mu} * \left(\frac{\lambda}{\mu}\right)^{C-1} * \frac{P_0}{(C-1)!} = \left(\frac{\lambda}{\mu}\right)^{C} * \frac{P_0}{C!}$ - - - - - (8)

Similarly, the state transition probabilities of states [C] – [C+2] are given by equations (9) – (11).

[C]: $P_{C+1} = \frac{\lambda}{C\mu} P_C = \left(\frac{\lambda}{\mu}\right)^{C+1} \frac{P_0}{C * C!}$ - - - - - - - (9)

[C+1]: $P_{C+2} = \frac{\lambda}{C\mu} P_{C+1} = \left(\frac{\lambda}{\mu}\right)^{C+2} \frac{P_0}{C^2 * C!}$ - - - - - - (10)

[C+2] $P_{C+3} = \frac{\lambda}{C\mu} P_{C+} = \left(\frac{\lambda}{\mu}\right)^{C+3} \frac{P_0}{C^3 * C!}$ - - - - - - (11)

By applying the principle of mathematical induction, the transition probability of state [C+k-1] is resolved computationally and the result is shownin equation (12).

[C+k-1]: $P_{C+k} = \left(\frac{\lambda}{\mu}\right)^{C+k} \frac{P_0}{C^k * C!}$ - - - - - - - - (12)

Also, the blocking probability of the second (row 2) to the m<sup>th</sup> parallel queue (row m) are expressed in equations (13)–(16) as:

2[C+k-1]: $P_{C+k} = \left(\frac{\lambda}{\mu}\right)^{C+k} \frac{P_0}{(2C)^k * 2C!}$ - -- - - - - - (13)

3[C+k-1]: $P_{C+k} = \frac{\rho^{C+k}}{(3C)^k * 3C!} P_0$ - - - - - - - (14)

m[C+k-1]: $P_{C+k} = \frac{\rho^{C+k}}{(mC)^k * mC!} P_0$ - - - - - - (15)

By substituting n=C+k and $\frac{\lambda}{\mu} = C\rho$ into equation (15)

$$P_{C+k} = \left(\frac{\lambda}{\mu}\right)^n \frac{P_0}{(mC)^{n-c} * mC!} \qquad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad (16)$$

Packets in the m^th^ parallel queue are selected for service, by the switch, when any of the n^th^ service facility is idle. The quantity of the m^th^ queue selected is represented by the expression in equation (17). It should be noted that equation (17) is multiplied and divided through by $(C\rho)^c$ to simplify the it.

$$\sum_{n=c}^{k} \frac{(C\rho)^n}{(mC)^{n-c} * mC!} P_0 = \frac{(C\rho)^c}{(C\rho)^c mC!} \sum_{n=c}^{k} \frac{(C\rho)^n}{(mC)^{n-c}} P_0 = \frac{(C\rho)^c}{mC!} \sum_{n=c}^{k} \frac{(C\rho)^{n-c}}{(mC)^{n-c}} P_0 \qquad - \quad - \quad - \qquad (17)$$

The function is further simplified by subtracting C from both the upper limit and the lower limit, respectively, as illustrated in equation (18)

$$\frac{(C\rho)^c}{mC!} \sum_{n-c=0}^{k-c} \frac{(C\rho)^{n-c}}{(mC)^{n-c}} P_0 = \frac{(C\rho)^c}{mC!} \sum_{n-c=0}^{k-c} \left(\frac{C\rho}{mC}\right)^{n-c} P_0 = \frac{(C\rho)^c}{mC!} \sum_{i=0}^{k-c} \left(\frac{\rho}{m}\right)^i P_0 \qquad - \quad - \qquad (18)$$

Thus, from geometric series [ 36, 37, 38, 39, 40 ], $\sum_{i=0}^{k-c} \left(\frac{\rho}{m}\right)^i P_0 = \frac{1 - \left(\frac{\rho}{m}\right)^{k-c+1}}{1 - \left(\frac{\rho}{m}\right)} P_0 = \frac{1 - (m^{-1}\rho)^{k-c+1}}{1 - (m^{-1}\rho)} P_0$ (19)

and by substituting equation (19) into equation (18), the expression becomes

$$\frac{(C\rho)^c}{mC!} \frac{1 - (m^{-1}\rho)^{k-c+1}}{1 - (m^{-1}\rho)} P_0 \qquad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad (20)$$

Packet request longer than a single queueing space occupies two or more queues. The cumulative transition probability of the number of parallel queues filled by the request is given as

$$\sum_{n=c}^{k} \frac{(C\rho)^n}{(C)^{n-c} * C!} P_0 \sum_{j=1}^{m} \frac{1}{j^{n-c+1}} \qquad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad (21)$$

The principle of stochastic normalization asserts that $\sum_{n=0}^{k} P_n = 1$, from this the idle probability ($P_0$) is determine as shown in equation (22).

$$P_0 = \left[\sum_{n=0}^{C-1} \frac{(C\rho)^n}{n!} + \sum_{j=1}^{m} \frac{1}{j^{n-c+1}} * \sum_{n=c}^{k} \frac{(C\rho)^n}{C^{n-c} * C!}\right]^{-1} \qquad - \quad - \quad - \quad - \quad - \quad -- \qquad (22)$$

Where, j=1, 2, 3, m, n=k+c

By multiplying and dividing through the expression $\sum_{n=c}^{k} \frac{(C\rho)^n}{C^{n-c} * C!}$ by $(C\rho)^c$ and further application of the geometric series to equation (22), the idle probability becomes

$$P_0 = \left[ \sum_{n=0}^{C-1} \frac{(C\rho)^n}{n!} + \frac{(C\rho)^c}{C!} \left( \frac{1-\rho^{k-c+1}}{1-\rho} \right) \sum_{j=1}^{m} \frac{1}{j^{n-c+1}} \right]^{-1} \quad - \quad - \quad - \quad - \quad - \quad - \quad - \tag{23}$$

Where, g=n-c

The blocking probability of the parallel queues ($P_{mB}$) is illustrated as

$$P_{mB} = \frac{(C\rho)^{C+k}}{(jC)^k * jC!} \left[ \sum_{n=0}^{C-1} \frac{(C\rho)^n}{n!} + \frac{(C\rho)^c}{C!} \left( \frac{1-\rho^{k-c+1}}{1-\rho} \right) \sum_{j=1}^{m} \frac{1}{j^{n-c+1}} \right]^{-1} \quad - \quad - \quad - \quad - \tag{24}$$

The expected queue length and the mean delay of the m^th parallel buffer of PPSS scheme are given by equation (25 & 26) respectively [26].

$$E[L_Q] = E[n] = \sum_{n=c}^{k} (n-c) Pn = \sum_{n=c}^{k} (n-c) \frac{(c\rho)^n}{(mc)^{n-c} mc!} P_0 \quad - \quad - \quad - \quad - \tag{25}$$

$$E[D] = \frac{E[L_Q]}{\lambda} = \frac{\rho (c\rho)^c}{m^{n-c+1} * c!} * \left( \frac{1 - \{\rho^{k-c} (\rho + (1-\rho)[(k-c+1)])\}}{(1-\rho)^2} \right) : \rho < 1 \quad - \quad - \quad - \tag{26}$$

The variation in queueing delay of the PPSS scheme is best described by statistical variance. The expressions for variance expectation (V[n]) and the delay variation expectation ($E[D_v]$) are illustrated in equations (27)–(32).

$$E[n^2] = E[n(n-c)] + cE[n] = \sum_{n=c}^{k_M} n(n-c) P_n + cE[L_Q] \quad - \quad - \quad - \quad - \quad - \tag{27}$$

$$V[n] = E[n^2] - (E[n])^2 = E[n(n-c)] + cE[n] - (E(n))^2 \quad - \quad - \quad - \quad - \quad - \tag{28}$$

$$V[n] = \frac{k(c\rho)^c \rho}{M^{n-c+1} c!} P_0 * \left( \frac{(1-\rho^{k-c+1}) - (1-\rho)((k-c+1)\rho^{k-c})}{(1-\rho)^2} \right) + c * \frac{(c\rho)^c \rho}{M^{n-c+1} c!} P_0 * \left( \frac{(1-\rho^{k-c+1}) - (1-\rho)((k-c+1)\rho^{k-c})}{(1-\rho)^2} \right) - \left( \frac{(c\rho)^c \rho}{M^{n-c+1} c!} P_0 * \left( \frac{(1-\rho^{k-c+1}) - (1-\rho)((k-c+1)\rho^{k-c})}{(1-\rho)^2} \right) \right)^2 \tag{29}$$

$$E[D_v] = \frac{k(c\rho)^c \rho}{M\lambda c!} P_0 * \left( \frac{(1-\rho^{k-c+1}) - (1-\rho)((k-c+1)\rho^{k-c})}{(1-\rho)^2} \right) + c * \frac{(c\rho)^c \rho}{M\lambda c!} P_0 * \left( \frac{(1-\rho^{k-c+1}) - (1-\rho)((k-c+1)\rho^{k-c})}{(1-\rho)^2} \right) - \left( \frac{(c\rho)^c \rho}{M\lambda c!} P_0 * \left( \frac{(1-\rho^{k-c+1}) - (1-\rho)((k-c+1)\rho^{k-c})}{(1-\rho)^2} \right) \right)^2 \tag{30}$$

Similarly, the delay and delay variation of SPSS are given in equations (31) and (32) [26]:

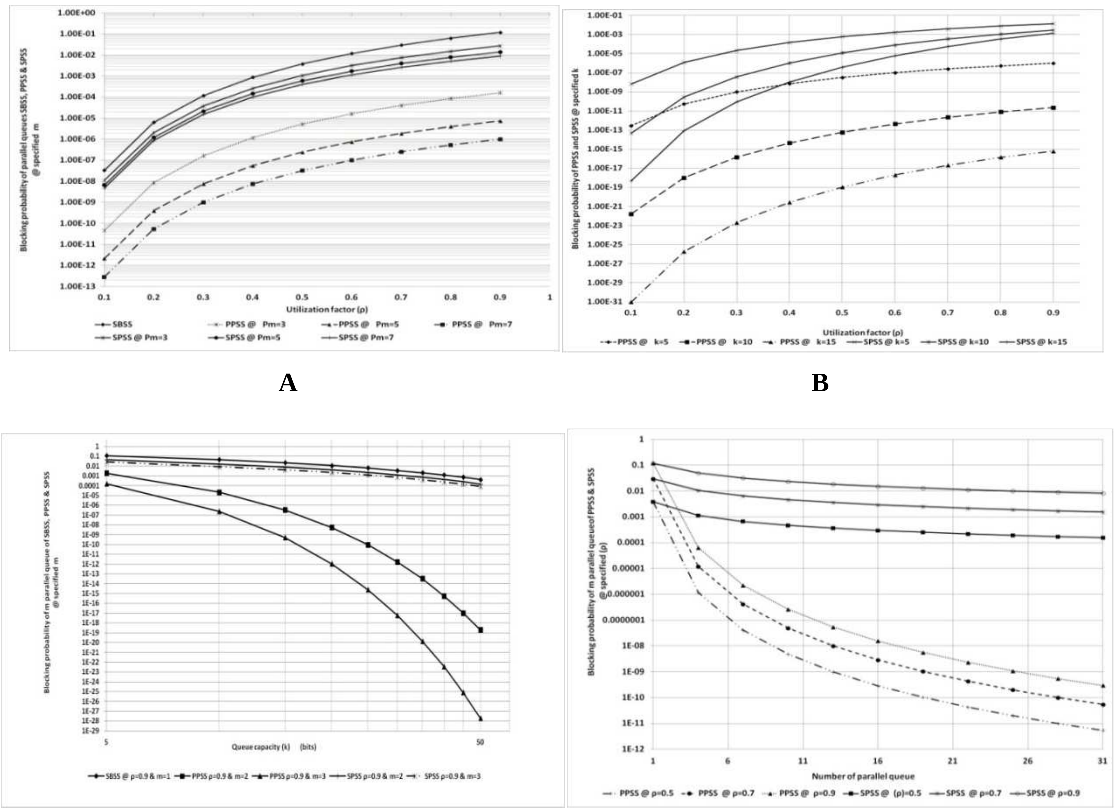
$$E[D] = \frac{(c\rho)^c \rho}{M\lambda c!} P_0 * \left( \frac{(1-\rho^{k-c+1}) - (1-\rho)((k-c+1)\rho^{k-c})}{(1-\rho)^2} \right) \quad - \quad - \quad - \quad - \tag{31}$$

$$D_f = \frac{k(c\rho)^c \rho}{M\lambda c!} P_0 * \left( \frac{\left(1-\rho^{k-c+1}\right) - (1-\rho)\left((k-c+1)\rho^{k-c}\right)}{(1-\rho)^2} \right) + c * \frac{(c\rho)^c \rho}{M\lambda c!} P_0 * \left( \frac{\left(1-\rho^{k-c+1}\right) - (1-\rho)\left((k-c+1)\rho^{k-c}\right)}{(1-\rho)^2} \right) - \left( \frac{(c\rho)^c \rho}{M\lambda c!} P_0 * \left( \frac{\left(1-\rho^{k-c+1}\right) - (1-\rho)\left((k-c+1)\rho^{k-c}\right)}{(1-\rho)^2} \right) \right)^2 \tag{32}$$

## COMPUTER SIMULATION OF THE MODEL

The mathematical models of the blocking probability ($P_B$), the delay E[D], and the delay variation ($D_f$) of the PPSS in equations (24), (29), and (30) are simulated. Expressions of SPSS and the SBSS models [23, 26] in earlier works of the researchers are simulated along side with the PPSS schemes. The Microsoft Excel 2007 computer package is used for the simulation. The parameters used for simulating the blocking probabilities ($P_B$s) of the PPSS, SPSS, and SBSS for varying utilization from 1-9 and are (i) the number of requests (n) = 8, (ii) queue capacity (k) = 5 (iii) the service rate (c), and (iv) the number of parallel queues (m) = 1-7. The $P_B$s are also simulated for specified values of queue length (k) = 5- 15, and m = 1-3. The delay and the delay variation of the queues are also simulated for the number of parallel queues. Parameters for the simulation of delay E[D] and the delay variation $D_f$ against the number of parallel buffers, are: C = 3, m = 1-31, k = 5, $\lambda = 0.05$, $\rho$=0.4 - 0.8 and $P_0 = 0.23211$. For the E[D] and $D_f$ against utilization factor ($\rho$), the parameters are: c=3, n=13, $P_0 = 0.023211$, $\lambda = 0.05$, $\rho$=0.1 - 0.9.

## SUMMARY OF RESULTS AND DISCUSSION



A B

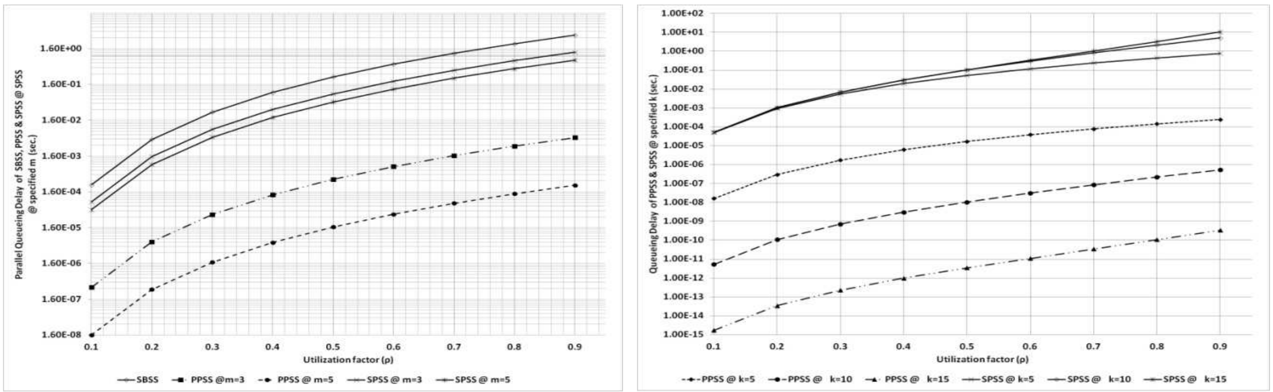
C D

Figure 2: (a)-(b) Blocking Probability vs. Utilization Factor (ρ); (c) Blocking Probability vs. Queue Length (k); (d) Blocking Probability vs. Parallel Queue (m)

Figure 2(a) illustrates the behaviour of the blocking probabilities ($P_B$s) of the PPSS, SPSS and SBSS against the utilization factors of the resources at specified quantities of parallel queues (m). The $P_B$ increases with the increase in the utilization factor. The SPSS mechanism emerges the best with the lowest $P_B$ while SBSS emerged as the worst scheme of all the models. The Pbs of the PPSS, SPSS and SBSS increase from $2.83*10^{-13}$-$1.0*10^{-6}$, $4.73*10^{-9}$-$9.10*10^{-3}$ and $3.33*10^{-8}$-1, $19*10^{-1}$ respectively.

The $P_B$s of the PPSS and the SPSS models, at specified queue length (k), are described in Figure 2(b). Generally, the $P_B$s increase with increase in the utilization factor. At k=5, 10, 15 bytes, the $P_B$s of the PPSS are $1.00*10^{-31}$-$6.39*10^{-16}$, $1.69*10^{-22}$-$2.22*10^{-11}$ and $2.83*10^{-13}$-$1.00*10^{-6}$, respectively. The $P_B$ of the SPSS is $6.64*10^{-9}$-$1.40*10^{-2}$, $4.73*10^{-14}$-$1.36*10^{-3}$, and $4.73*10^{-19}$-$1.36*10^{-3}$ at the same range of k.

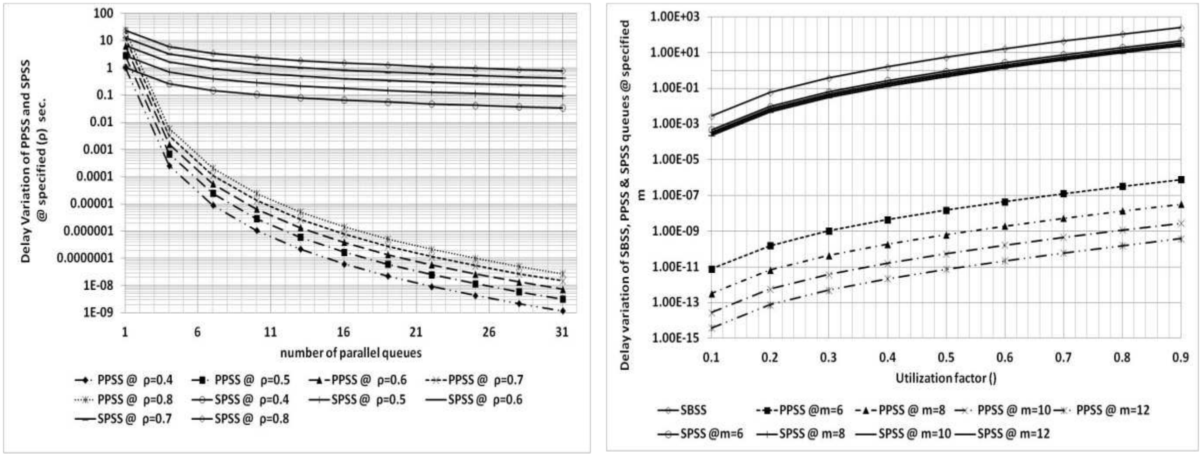
A drop in $P_B$ is experienced by PPSS, SPSS and SBSS models with separate increases in k and m, respectively. This is illustrated in Figure 2(c)-2(d). The drop is very small in the case of SPSS, whereas it is very steep with PPSS at a specified value of the utilization factor (ρ) in the Figures. In Figure 2 (c), the drop is from $1.62*10^{-4}$-$1.92*10^{-28}$ and $1.85*10^{-3}$-$1.88*10^{-19}$ for PPSS when k varies from 5-50 bits, at m=2 and 3, ρ=0. 9, respectively. The corresponding drops are: $4.68*10^{-2}$-$1.50*10^{-4}$, $2.73*10^{-2}$-$8.45*10^{-5}$ in SPSS for the range of m and ρ. At m=1, ρ=0.9 and k=5-50, PPSS, SPSS and SBSS are equal with $P_B$= 0.12-$4.23*10^{-4}$. In Figure 2(d), the $P_B$ in PPSS decreases from $3.81*10^{-3}$-$5.46*10^{-12}$, $2.99*10^{-2}$-$5.11*10^{-11}$, 0.12-$2.97*10^{-7}$, and in SPSS the drop is from $3.81*10^{-3}$-$1.55*10^{-4}$, $2.99*10^{-2}$-$1.55*10^{-3}$, 0.12-$8.19*10^{-3}$ at m=1-31.



**A** **B**

**Figure 3: (a)-(b) Queueing Delay vs Utilization Factor (ρ)**

The delay of PPSS, SPSS and SBSS models against utilization factor (ρ) for specified values of the number of parallel queues (m) and queue lengths (k), respectively, are compared in Figure 3. The delay of the models increases with an increase in ρ. In figure 3 (b), the delay tends to converge from ρ=0.1-0.3 and diverges when ρ is varied from 0.4-0.9. The delay as illustrated in Figure 3(a) at m=3, 5 and ρ =0.1-0.9 are: $3.44*10^{-7}$-$5.26*10^{-3}$, $1.60*10^{-8}$-$2.46*10^{-4}$ sec. for the PPSS model; and $8.36*10^{-5}$-1.28, $5.10*10^{-5}$-077 sec. for the SPSS model, respectively. At m=1, ρ =0.1-0.9, the delay of the SBSS model ranges from $2.54*10^{-4}$-3.84 secs. The queueing delay as shown in Figure 3(b) at k=5-15 and ρ =0.1-0.9 is: $1.60*10^{-8}$-$2.46*10^{-4}$, $5.28*10^{-12}$-$5.25*10^{-7}$, $1.69*10^{-15}$-$3.40*10^{-10}$ secs. for the PPSS model; $5.01*10^{-5}$-0.77, $5.16*10^{-5}$-5.12, 5.16-10.4 secs. for the SPSS model, respectively.



A B

**Figure 4: (a) Delay Variation vs. the Quantity of Parallel Queue (m); (b) Delay Variation vs. Utilization (ρ)**

Figure 4 (a) shows that the delay variations of the PPSS and the SPSS decrease with the increase in the number of parallel queues at specified utilization factors (ρ). The delay variations of the PPSS decrease steeply, whereas they decease gradually with the SPSS scheme. This implies that PPSS has a better performance than the SPSS. At ρ= 0.4-0.8 and m=1-30, the expected delay variations of each of the PPSS curves decrease with the following specified values: 1.06-1.19*$10^{-9}$, 2.87-3.24*$10^{-9}$, 6.35-7.38*$10^{-9}$, 13.2-1.49*$10^{-8}$, and 24.1-2.76*$10^{-8}$ secs., respectively. The decrease in the delay variations of SPSS curves in Figure (4a) are: 1.06- 34.2*$10^{-2}$, 2.87-9.27*$10^{-2}$, 6.35-2.11*$10^{-2}$, 13.2-4.27*$10^{-1}$, and 24.1-7.88*$10^{-1}$ sec., respectively. In Figure (4b), the delay variations increase with the increase in utilization factors for the PPSS, the SPSS and the SBSS schemes at specified values of number of parallel queues (m). At m = 1, the PPSS, the SPSS, and the SBSS, have the same delay variation. The implication is that their performances are identical. The delay variations of the PPSS with parameters c=3, k=10, n=13, $P_0$=0.23211, and m=6-12, are: 7.82*$10^{-12}$-7.77*$10^{7}$, 3.3*$10^{-13}$-3.28*$10^{-8}$, 2.84*$10^{-14}$-2.82*$10^{-9}$, 3.82*$10^{-15}$-3.79*$10^{-10}$ secs., whereas that of SPSS are: 4.73*$10^{-4}$-4.61*$10^{1}$, 3.55*$10^{-4}$-3.47*$10^{1}$, 2.84*$10^{-4}$-2.78*$10^{1}$, 2.36*10-2.33*$10^{1}$ secs., respectively.

## CONCLUSIONS

The analyses of the PPSS, SPSS and SBSS presents PPSS as the best scheme and SBSS as the least in terms of blocking probability, delay and delay variation in Figure 2-4. The performance of the PPSS scheme is the same as the SPSS scheme in when n=c. Thus, when buffer prioritization and partitioning is considered for voice and data, the PPSS is the most suitable mechanism to apply. In that case, voice packets should be given a lower priority because it is delay sensitive. However, the data packet is insensitive to queueing delay, therefore more parallel queues can be reserved for data packets only. Also, a lengthy queue can be reserved for data packets.

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