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Jitter Buffer Modelling and Analysis for TDM over PSN

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Abstract

Time Division Multiplexing (TDM) over Packet Switched Network (PSN) is a pseudo wire technology for emulating TDM Circuits over Packet Networks. Conceptually, the important ingredients of the above technology are to implement the following, in the PSN (i) Quality of Service (QoS) which is implemented through scheduling at the intermediate nodes that gives priority to packets containing 'TDM' payload (ii) timing and synchronization and (iii) scheduling in the jitter buffer for minimum output variance. Among these, this paper addresses (iii) as a first step assuming that the PSN provisions the "unacknowledged virtual circuit" (the main components of 'virtual circuit' are QoS and connection-oriented service). This work targets to implement a scheduling algorithm (service intervals) in jitter buffer at the receiver, such that the variance of inter-departure intervals of TDM stream is minimized. This is accomplished by the buffer modelled as M/G/1 queueing system with Auto-Regressive AR (1) correlations within service intervals. The motivation for the above correlation structure is two-fold. First, given the correlations within the service intervals, such a correlation results in reduction of variance in the inter-departure interval. The other is that the analysis of such a correlated queue is analytically tractable. The variance of the inter-departure time is presented. The analysis of the departure process, the waiting times of incoming packets of this correlated queue aids in determining the correlation parameter that are sub-optimal in the context of TDMoPSN. Our study also includes a M/G/1 queue with AR (1) cross-correlations between the inter-arrival and the service times. A G/G/1 queue in which the inter arrivals are correlated, and with AR (1) correlations of the above two types are also studied. Extensive simulations demonstrate our analytical and approximation results.

Keywords: TDMoPSN, Packet Delay Variation; Correlated queue; Clock recovery

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1. Introduction

TDM technology has been the main ingredient of carrier networks over several decades. TDM emulates the Plain Old (Analog) Telephony System (POTS) in a digital communication infrastructure, by hard partitioning the Band-Width (BW) of the communication channel, resulting in low latency (and ideally zero delay variance of voice samples) comparable to that of POTs, while, enabling multiplexing and transmission of many voice signals, in a single communication channel. Even so, with stupendous strides in the allied areas (like DSP, VLSI, PSN technologies etc.), it is possible to deliver the voice services of comparable quality as POTS, while exploiting the full capacity of the communication channel (much better than what TDM could do). Time Division Multiplexing over Packet Switched Network (TDMoPSN) has evolved for a seamless transport of TDM services over Packet Networks. For its effective functioning it is imperative that latency, packet delay variation, traffic prioritization and TDM circuit performance be taken care. A buffer placed at the receiver helps to mitigate the ill-effects of the PSN.

The rest of the paper is organized as follows. Section II briefly describes conventional and proposed model for TDM over PSN. Section III discusses the proposed queueing model in detail. Section IV gives the theoretical and simulation results for the queueing parameters. In Section V, conclusions are drawn and future work is outlined.

2. Conventional model for TDM over PSN

TDM over PSN is a technology wherein TDM circuit is emulated in a PSN to cross the PSN Island. This is implemented by tweaking the PSN to emulate a TDM network, as far as possible. This essentially means that a node in PSN has to allocate a constant bandwidth (equal to TDM bit rate) to the TDM stream. While the PSN is designed to handle a bursty traffic, it is inherently poor in handling the CBR traffic. But an attempt is made to serve the CBR traffic by provisioning QoS. Even with this, as the TEPs are stored along with the packets from other sources, TEPs experience different amount of delay at each node[3]. This leads to an inexorable effect called Packet Delay variation (PDV). These packets having the TDM payload, on arriving at the receiver are stored in a jitter buffer, which is meant to mitigate the effect of packet delay variation introduced by the PSN. PDV, if not controlled, causes a colossal damage such as overrun or underrun of the jitter buffer. This in turn, leads to receiver clock slips.

2.1. Schematic for TDM over PSN: Network requirements

The scheme for implementation of TDM over PSN is shown in Fig. 1. Given a TDM stream, the 8 TDM frames (corresponding to 8 X 125μs) are collected to create a TDM Emulated Packet (TEP). If more than one TDM connection is handled by the IWF, then a lesser number of frames per connection is used to create a TEP. This is done to decrease the packet overhead. These TEPs are transported to their destination using unacknowledged connection oriented service. The connection oriented service solves the problem of packet ordering. The second problem encountered in packet networks is the queueing delay (which is variable for each packet), introduced by packet routers and switches. And is more dominant than other components of end-to-end delay (transmission and propagation). QoS ensures that the delay requirements are met. Third problem inherent with the packet network is most damaging: the variation of delay or packet jitter across TEPs (of the same connection). It is because of the varying delay that each packet experiences, the constant bit rate TDM stream at the transmitter does not retain its CBR nature, while on the contrary, exhibits high variability in the inter-arrival times. While the solution to the first problem is the unacknowledged connection oriented service, the solution to the second problem is the provisioning of QoS in the PSN. The solution to the third problem should jointly be handled by the PSN and the receiver NNI. This paper concentrates on the solution at the receiver NNI to the last problem, assuming the solutions to the first and second exists and are already implemented. To summarize the following are the network requirements to be satisfied: i) Connection-oriented service in order to avoid misordering of packets ii) Since voice, a real time service is to be transmitted, there is an upper bound on the queueing delay. This portrays the need for QoS iii) The QoS implementation is such that the packet delay variation is minimum and iv) Packet loss should be minimum. To emulate the TDM over PSN, one more criteria remains to be satisfied by the network: timing and synchronization, i.e. , transmitting timing information optionally by the network. With the above framework, requirements and assumptions, the problem addressed in this paper is to design an algorithm for the jitter buffer dequeueing algorithm such that the output has minimum variance.

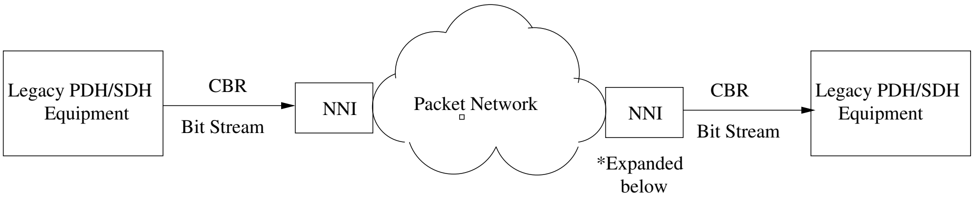

Fig. 1. Overall Block Diagram

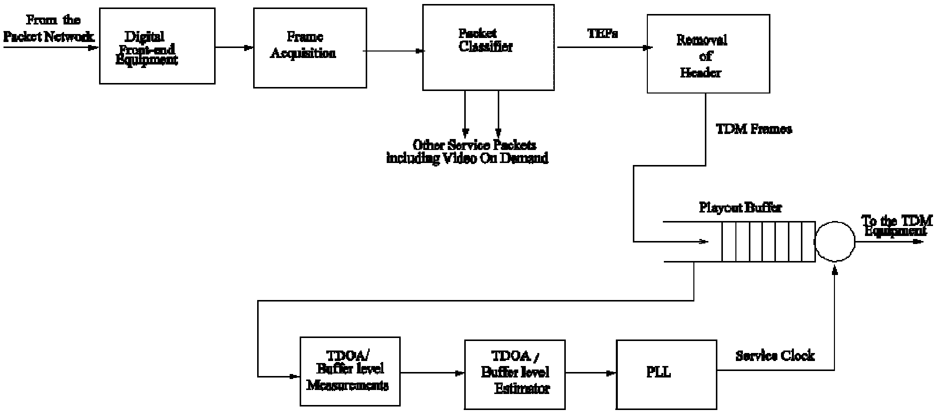

Fig. 2. Network-Network Interface Block at the Receiver

2.2. Block Diagram for Real world Jitter Buffer

Fig. 2 explains the skeleton of the Packet Network-TDM Network Interface. At the digital communication front-end equipment, equalization, detection of bits and then identification of special sequence of bits is carried out. Frame acquisition is run at the digital communication front-end to identify an arrival of a frame / packet, apart from identifying various fields within a frame / packet. And then they are buffered. A packet classifier identifies packets carrying TDM frames from the above set of packets. These packets (carrying TDM payload) are stripped of their packet headers, stored in a buffer called ’jitter buffer’ to minimize the jitter of the outgoing TDM stream. The inter-arrival time of these TDM frames are recorded as Time Difference of Arrival (TDOA), simultaneously noting down the arrival instances of these bundle of TDM frames. The TDOA measurements are fed to an algorithm [many algorithms are addressed in the literature] which estimates the TDM frame arrival rate (and thus the bit-rate, but these estimates are known ONLY at the TDM frame arrival instances). Thus, the estimates are constant over a TDM frame reception/transmission. [Thus, strictly speaking though the PLL is used in subsequent block the bit-level clock is NOT recovered and hence, these schemes belong to Layer 2 recovery methods]. The estimates of the bit-rate are fed to the Phase Locked Loop (PLL) whose output serves as the clock to the hardware which dequeues (serves) the TDM frames. The departure instances of these TDM frames are measured for benchmarking the efficacy of the dequeueing algorithms used.

2.3. Mathematical Model for Jitter Buffer

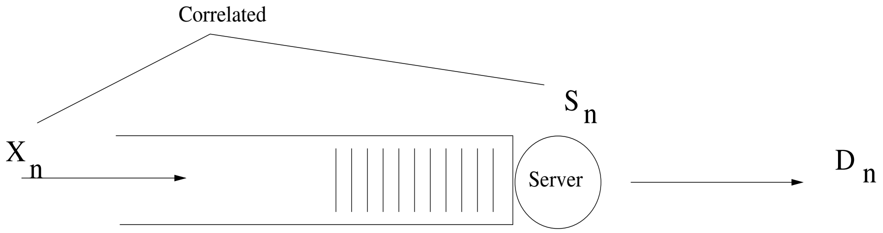

Fig. 3. FIFO, Single server queue with correlations

The receiver jitter buffer is conventionally modeled as a queueing system, in which the TDM frames that arrive in a random fashion, are accommodated in the buffer. The receiving hardware is analogous to the server, in the queueing system. Thus, the receiver jitter buffer is modeled as a single server, first in first out (FIFO) queue where X_n is the inter-arrival time process, S_n is the service time process. The inter-departure time process of this queue should have minimum variance so that the jitter in the TDM frames is controlled (as specified in the TDM standards). One way of reducing the variance of inter-departure time is to incorporate correlation either in service intervals themselves or to introduce cross-correlation between the arrival and service processes, as shown in Fig. 3 and given in[13]. Variance of the inter-departure time of a queue, especially under heavy traffic condition depends only on the first and second moments of the service time, while the mean waiting time in addition to the above depends on the asymptotic correlation within arrivals, within service intervals and cross-correlation between arrivals and service intervals. Queueing models with Exponential Auto-Regressive and Moving Average (EARMA) positive correlations within inter-arrivals, within service intervals and cross-correlations between inter-arrival and service interval are discussed in[7]. Any attempt to increase the correlation within the arrivals, the service times or decrease cross-correlation between the arrival and service time will increase the mean waiting time. A queueing model with Auto-Regressive (AR) service intervals following Gamma distribution is considered by[10]. In our model, we use Auto-Regressive AR (1) with correlations between service intervals[10]. The intuition behind using this model is that, the service time distribution converges to a deterministic distribution leading to reduction in the variance of the inter-departure intervals.

2.4. Literature survey

TDM over PSN enables transmitting the continuous data stream generated by TDM equipment as a stream of discrete packets. The data stream consists of individual time slots retrieved from the E1 frame structure, from a bundle of frames. These are then encapsulated in packets and sent across the network. As the packet network use statistical multiplexing, the average rate is measured over a long interval (difference between the maximum and minimum transmission delays expected in the network). In order to recover the payload clock of a bundle, several clock recovery schemes are used.

In TDMoPSN, when there is no common clock between the transmitter and the receiver, Adaptive Clock Recovery (ACR) is used for deriving a synchronous clock from an asynchronous packet stream. ACR essentially uses packet arrival rate[1, 2, 3] and/or buffer level[5, 4, 6] as means to recover the transmitter clock frequency. However, under heavy network utilization, it does not meet phase and time requirements, as specified by the standards. For achieving better synchronization, we use a correlated queueing model[13], with a different correlation structure at the data link layer of the ISO stack.

Heavy traffic results for the waiting time distribution of a correlated queue having all the three types of correlations, among inter-arrivals, among service times and between inter-arrival and service times is given in[7]. A general sufficient condition for a heavy-traffic limit theorem for the waiting time in a general G/G/1 model with inter-arrival time and service time sequence is established in[9]. These are used in our mean waiting time analysis. A queueing model with Auto-Regressive (AR) service intervals is considered in[10]. We use this model with exponential distribution (which is our contribution), for modelling the jitter buffer and study its mean waiting time and inter-departure process. We look at departure process, its statistics and use the same in a jitter buffer model. We include here in our studies a queue with non-Poissonian arrival process, to cater to the real world scenario, where the arrival process is self-similar.

For achieving synchronization at the data link layer of the ISO stack, [13] a queueing model with EARMA cross-correlations is used and its departure process is studied. This queueing model allows for the comparison of the queue to a M/M/1 queue with the same marginal distribution. The parameters of interest are ratio of mean waiting time of the queue to that of a M/M/1 queue and ratio of the variance of the inter-departure intervals to that of the inter-arrival intervals. Here, the payloads extracted from the TDM encapsulated packets arriving from the transmitter, are queued in the jitter buffer. They are served such that the variance of the inter-departure process of the outgoing packet stream is minimum. This is achieved only under light-medium traffic conditions, but at the cost of mean waiting time. Under heavy traffic conditions, the queue resembles a M/M/1 queue in terms of the departure process. Meaning that, the variance of the inter-departure intervals is same as the variance of the inter-arrival times. Their[13] work includes a G/G/1 queue model with inter-arrival correlations and EARMA cross-correlations. This queue under heavy traffic limit conditions mimics a M/M/1 queue. The objective of minimum variance is achieved under light-medium traffic condition, a variance ratio of only 0.8 is obtained. But, in this paper we look at a queue which could be approximated by a M/D/1 queue and gain much better in terms of variance a well as mean waiting time.

3. Our queue model

We basically adopt the above general framework, focusing on the jitter buffer dequeueing algorithms (scheduling the departure instants by fixing the service intervals), such that the corresponding TDM slip-rate is minimized. As mentioned before, we model the jitter buffer as a FIFO queueing system in which the arrivals are Poisson, with infinite capacity (buffer memory is large enough to hold large number of TEPs), and the transmission time by the line card (hardware) is the service intervals. To achieve the optimal performance (of yielding minimum TDM slip rate), we need to design the service intervals such that the IDT variance is minimized. [Note that, one way to minimize the TDM slip rate is to design the queue which yields minimum IDT variance]. One important assumption, which we make here is that the queueing model operates at high utilization/traffic intensity. This is to justify the average arrival rate of TDM frames at the input of the jitter buffer is equal to the capacity of the outgoing (physical) communication channel (TDM line). We thus consider the following queues: The service process is an AR (1) process, Poisson/General arrivals, single server, having an infinite buffer space.

Table 1. below gives the definition of the common symbols used

Table 1. Common symbols.

Symbols	Description
X_n	The exponential inter-arrival time between the n^{th} and the $n+1^{th}$ arrival of TEP at the receiver jitter buffer, with mean arrival rate, λ.
S_n	The service time of the n^{th} TEP, $\lim_{n\to\infty} E(S_n) = 1/\mu$.
U_n	$(S_n\text{-}X_n)$
W_n	The waiting time of the n^{th} packet in the queue.
D_n	The inter-departure time between the n^{th} and the $n+1^{th}$ departure of TEP at the Jitter buffer.

Before proceeding further, we present here an important result and a familiar terminology entrenched in the literature, which we keep referring to many times later.

3.0.1. Positive Correlations:

Karl Pearson's correlation coefficient between the two random variables X and Y, $r_{XY} = \frac{Cov(X,Y)}{\sqrt{Var(X)Var(Y)}}$.

If it is between 0 and 1, then X and Y are positively correlated or 0, then X and Y are uncorrelated.

3.0.2. Mean Waiting Time in a Correlated Queue:

Queues with all three types of correlations are studied by[7, 9]. The approximate mean waiting time of queue with all three correlations: correlations within arrivals (between current and previous arrivals), within service intervals (between current and previous service intervals), cross-correlations between arrivals and service (between current, previous inter-arrival and current service interval), under heavy traffic limit condition has been studied by[7, 9].

$$E[W] = 0.5\frac{\mu\lambda}{\mu - \lambda}\sigma_a^2 \tag{1}$$

where the asymptotic variance of U_n is given by[7] :

$$\sigma_a^2 = Var[U_1] + 2\sum_{n=1}^{\infty} Cov(U_1, U_{1+n}) \tag{2}$$

where, $U_n = S_n - X_n$, λ is the mean arrival rate and μ is the mean service rate.

3.0.3. Variance of Inter-Departure Time:

The variance of the inter departure time for a GI/G/1 queue with all three types of correlations mentioned above, from[8, 14] is presented below:

$$Var(D_n) = Var(X_n) + 2Var(S_n) - 2Cov(X_n, S_n) - \sigma_{SI}^2 \tag{3}$$

where the stationary interval variance of U_n is given by[14] :

$$\sigma_{SI}^2 = Var[U_1] \tag{4}$$

Under heavy traffic condition, the variance of the inter-departure intervals of this queue, having traffic intensity, ρ is approximated as:

$$Var(D_n) \approx (1 - \rho^2)Var(X_n) + Var(S_n) \tag{5}$$

General observations from above equations are:

A. It is evident that positive cross-correlation between inter-arrivals and service times will tend to decrease the mean waiting time, whilst, positive correlation within inter-arrivals or service time will tend to increase the mean waiting time.

B. It can be deduced that, under heavy traffic condition, the factor that renders the variance of the inter-departure time less is: decrease in the variance of the service intervals.

3.1. Proposed Models for Scheduling the TDM Frames

Model 1: AR (1) positive correlation within service times; arrivals Poisson

Table 2. gives the definition of the random variables used in the queueing model with AR (1) positive correlations within service times.

Table 2. Queue with AR (1) positive correlations within service times.

Symbol	Description
$\{E_n\}$	IID sequence with exponential distribution with positive finite mean 1/ μ
$\{S_0\}$	IID sequence with exponential distribution with positive finite mean 1/μ

Queue with AR (1) positive correlation within service intervals is considered. This is obtained from[10] where autoregressive service times of order 1 is used. But here, an exponential distribution is considered. The service intervals are defined as:

$$S_n = \alpha S_{n-1} + (1-\alpha)E_n \tag{6}$$

where α is some fixed value such that $0 \leq \alpha < 1$. The distribution of S_n is a weighted sum of exponentials. But there exists correlation between the service intervals and it amounts to the ρ-mixing of the sequences. From[15] , application 5.2, we can deduce the variance of S_n. The asymptotic variance of $U_n = S_n - X_n$, in this case is:

$$\sigma_a^2 = \lambda^{-2} + \frac{1-\alpha}{1+\alpha}\mu^{-2} + 2\frac{\alpha}{1+\alpha}\mu^{-2} \tag{7}$$

Lemma 1: The variance of the inter-departure time of a M/G/1 queue with AR (1) positive correlation within service intervals, under heavy traffic limit condition is given by:

$$Var(D_n) \approx (1-\rho^2)\lambda^{-2} + \frac{1-\alpha}{1+\alpha}\mu^{-2} \tag{8}$$

Model 2: AR (1) positive cross-correlations between inter-arrivals and service times; arrivals Poisson

We adopt a M/G/1 queue as our jitter buffer model, with the service intervals being correlated with inter-arrivals in the following way, with Auto-Regressive positive cross-correlations between the inter-arrival times and the service times. The current service time is related to the current inter-arrival time and previous service time as:

$$S_n = \beta S_{n-1} + (1-\beta)\lambda\mu^{-1}X_n \tag{9}$$

where β is the correlation parameter, λ is the mean arrival rate and μ is the mean service rate.

Lemma 2: The variance of the inter-departure time of a M/G/1 queue with AR (1) positive cross-correlation between inter-arrival and service intervals, under heavy traffic limit condition is given by:

$$Var(D_n) \approx (1-\rho^2)\lambda^{-2} + \frac{1-\beta}{1+\beta}\mu^{-2} \tag{10}$$

3.2. Correlated inter-arrivals

The queue is also studied with inter-arrival times being correlated within themselves, as in[11], as it was found in[12] , that the inter-arrivals in packet networks exhibit self-similarity. The jitter buffer is modeled as a G/G/1 queue, with all three types of correlations. Table 3 gives the variables related to the correlated arrival process.

Table 3. Correlated inter-arrival times.

Symbol	Description
$\{G_n\}$	IID sequence with exponential distribution with positive mean $1/\lambda$
$\{H_n\}$	IID sequence with Bernoulli distribution with $P(H_n=1)=1-\gamma$; $0 \le \gamma < 1$

The inter-arrival time between the n th and the n+1 th arrival, X_n is given by:

$$X_n = \gamma X_{n-1} + G_n H_n \tag{11}$$

Positive correlations within the inter-arrivals would increase the mean waiting time and therefore, reduce the variance of the inter-departure time, under heavy traffic limit condition. So, the above used models would perform better in terms of the variance of the inter-departure time under real-time traffic.

4. Simulation Results:

M/G/1 queue with service intervals defined as AR (1) positive correlation was simulated, for different correlation parameter, α values and traffic intensity, ρ in MATLAB. The graph of the ratio of mean waiting time of this correlated queue to the mean waiting time of the independence (M/M/1) case is plotted. Also, the ratio of the variance of the inter-departure time to the inter-arrival time is plotted, in the same graph.

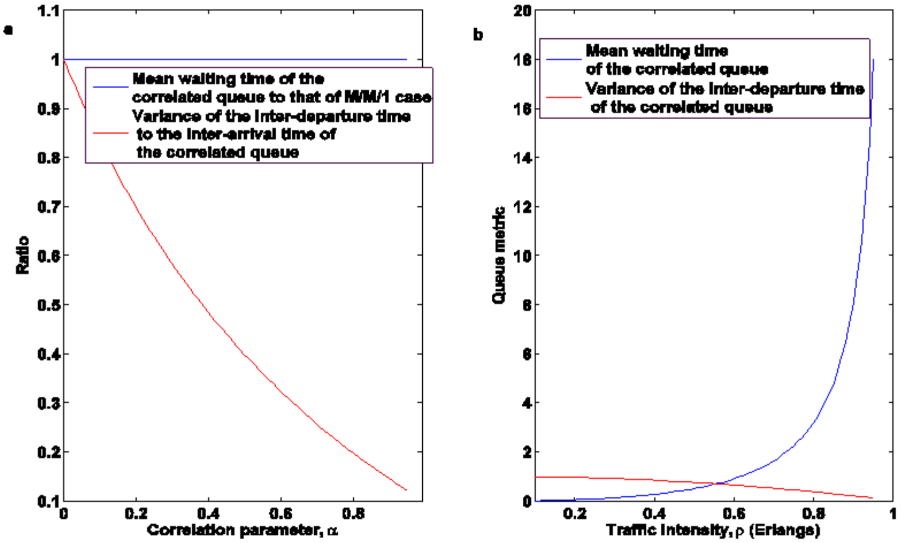

Fig. 4. (a) Ratio of the mean waiting time of the correlated M/G/1 to the M/M/1 queue and the variance of the inter-departure time to the inter-arrival time, for various correlation parameter values, α; traffic intensity, ρ=0.95 Erlangs.; (b) Mean waiting time and variance of inter-departure time of the queue for different traffic intensity values, ρ; correlation parameter α=0.95.

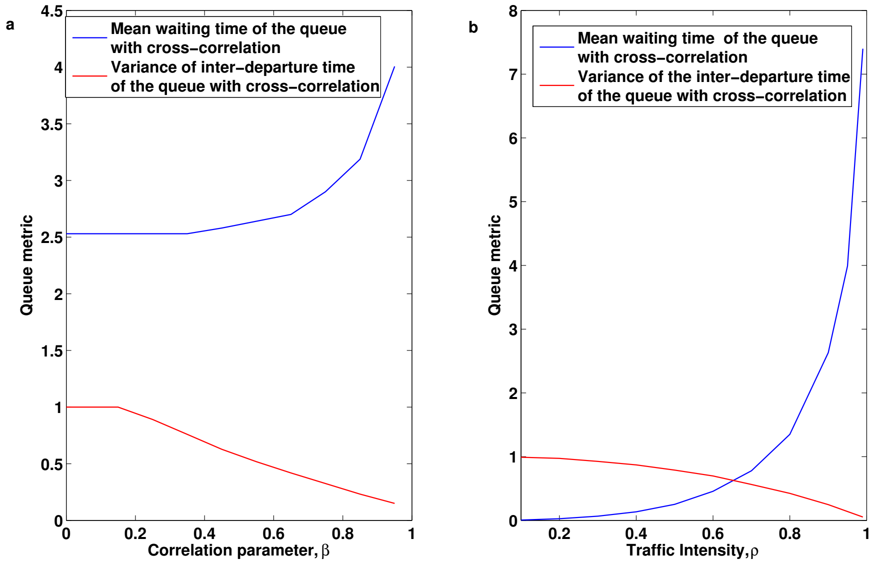

Fig. 5. (a) Mean waiting time of the M/G/1 queue with cross-correlations and the variance of the inter-departure time, for various correlation parameter values, β; traffic intensity, ρ=0.95 Erlangs.; (b) Mean waiting time and variance of inter-departure time of the queue for different traffic intensity values, ρ; correlation parameter β=0.95.

Models described in section 3 were simulated and its parameters were studied. In model 1, as is seen from Fig. 4.(a), AR (1) positive correlation within service intervals yields a better performance in terms of the variance of the inter-departure time, under heavy traffic conditions. Value of correlation parameter, α can be selected such that the variance of the inter-departure time is relatively less. When the correlation parameter approaches unity, the queue behaves as a M/D/1 queue in the context of departure process. But the mean waiting time is more than that of a M/D/1 queue with its constant service time equal to the mean of the service time considered in the correlated queue. At heavy traffic limit conditions, this queue has the same mean waiting time as that of a M/M/1 queue having the same mean service time. The variance of the inter-departure time decreases at higher values of the correlation parameter. Fig. 4. (b) gives the plot of the queue parameters such as mean waiting time and variance of the inter-departure time as a function of traffic intensity, ρ with high correlation parameter value. It is evident that the queue mimics a M/M/1 queue in terms of its mean waiting time. At heavy traffic, it approaches a M/D/1 queue in terms of the inter-departure time variance.

In model 2, where there is AR(1) cross-correlation between the inter-arrivals and the service intervals, as is seen from Fig. 5.(a), the variance of the inter-departure time almost approaches a M/D/1 queue case, with the cross-correlation parameter, β approaching unity, under heavy traffic condition. The mean waiting time mimics a M/D/1 queue case. So, if there is cross-correlation between inter-arrival and service interval, a M/D/1 queuing performance could be achieved, at higher correlation parameter value. Fig. 5. (b) gives the plot of the queue parameters as a function of traffic intensity, at high correlation parameter, β. At high utilization the queue resembles a M/D/1 queue. Therefore, queue of this model under heavy traffic condition and with high cross-correlation parameter value helps us meet our objective.

Even, when the inter-arrivals are correlated as in (12), the scheme performs well in terms of the variance of the inter-departure time. The mean waiting time is also within the permissible limit.

5. Conclusion and Future work

A correlated M/G/1 with AR(1) correlations within service intervals and cross-correlation between inter arrivals and service intervals are used for modelling the jitter buffer in TDMoPSN and value of correlation parameters of the queue is identified to achieve our objective of minimum variance of the inter-departure time. This work is also extended to arrivals being correlated, as inter-arrival times exhibit self-similarity in packet networks and their simulation results are presented. A theoretical study of the queue with all three types of correlations will provide a better insight. A study of the correlation structure in the inter-departure times is aimed at. An approximation for the first two moments of the queue length distribution of such a correlated queue can be arrived at and used for analysis in the method of buffer level based clock recovery.

References

1. Ahmed HM. Adaptive Terminal Synchronization in Packet Data Network. *IEEE Globecom* 1989. p. 728-732.
2 Aweya J, Montuno DY, Ouellette M, Felske K. Clock recovery based on packet inter-arrival time averaging. *Comp Comm* 2006;**29**:1696-1709.
3. Stein YJ. TDM Timing. *RAD Data Communications* 2006.
4. Lau RC, Fleischer PE. Synchronous Techniques for Timing Recovery in BISDN. *IEEE Trans. Comm.* 1995;**43**:1810-1813.
5. Singh RP, Lee SH. Adaptive Clock Synchronization Schemes for real-time traffic in broadband packet networks. *EUROCON 88*. p. 84-88.
6. Zhu S, Xu Y. The Study and Analysis of Joint Adaptive Clock Recovery Mechanism for TDMoIP. *ICNSC* 2008. p. 533-538.
7. Jacobs PA. Heavy traffic results for single-server queues with dependent (EARMA) service and inter-arrival times. *Adv. Appl. Prob*, 1980; **12**:517-529.
8. Kramer W, Lagenbach-Belz M. Approximate Formulae for the Delay in the Queueing System GI/G/1. *ITC8.* **235**:1-8.
9. Whitt W, Dependence in packet Queues, *IEEE Comm.* 1989.
10. Fiems D, Prabhu B, Turck KD. Analytic approximations of queues with lightly- and heavily- correlated auto-regressive service times. *Annals of operations Research* 2013.
11. Manivasakan R, Desai UB, Karandikar A. Broadband Teletraffic Characterization using Correlated Interarrival time Poisson Process (CIPP). *J. Ind. Inst. Sci.* 1999;**79**-3:233-249.
12. Leland WE, Taqqu MS, Willinger W, Wilson DV. On the self-similar nature of Ethernet Traffic. *ACM SIGCOMM Comp. Comm. Rev.* 1995;**25**:202-213.
13. Usha Rani S, Manivasakan R. Correlated M/G/1 modelling of Jitter buffer in Time Division Multiplexing over Internet Protocol. *AICT* 2012.
14. Whitt W. *An Introduction to Stochastic-Process Limits and their applications to Queues.* Springer-Verlag, 2002.
15. Vervaat W. On a Stochastic Difference Equation and a Representation of Non-Negative Infinitely Divisible Random Variables. *Adv. Appl. Prob.*1979;**11:**750-783, 1979.