MMPP+M/D/1 Traffic Model in Video-Data Integrated Service under ATM System

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Abstract**—With the advent of 3G mobile communication system, the traffic of wired and wireless networks become voice/video - data integrated service. For real time operation of voice and video signals, circuit switch traffic or Markovian traffic is the best fitted but for data traffic where small amount of delay is tolerable, the non-Markovian traffic like service time of general distribution with finite buffer is preferable. In this paper, Markov modulated Poisson process (MMPP) traffic, which is in concise form of Markovian chain, is used for multimedia traffic and M/D/1 traffic of fixed length packet is considered for asynchronous transfer mode (ATM) cell. The combined model becomes MMPP + M/D/1 traffic, which is used to get the probability density function and mean delay of a voice/video-integrated network.**

Index Terms**— ATM cell, voice-data integrated service, mean delay, moment generating function, non-Markovian traffic.**

I. Introduction

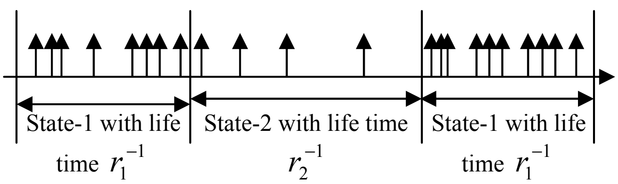
The aim of the 3G mobile network is to provide high speed packet communication for real time operation of voice/video-data integrated traffic [1]-[4]. The circuit switched network can carry the traffic at high bit rates at the expense of working with fixed bandwidths. It is suitable for real-time operation but incurs a huge waste of link capacity/bandwidth for the case of burst traffic or the traffic of variable bit rate. The packet switched network on the other hand offers bandwidth when necessary; for example, asynchronous transfer mode (ATM) offers both high and low bit rates and ensure efficient use of the available bandwidth [5]. The most widely used mathematical model of traffic analysis is the Markovian chain. One of the major drawbacks of Markov chain lies in the incorporation of large number of probability states which complicates the analysis of the traffic parameters of a network. Markov arrival process (MAP) provides an equivalent state transition chain of few probability states with some assumption as discussed in [6]. Teletraffic engineering adopts three most widely used cases of MAP which are as follows: phase-type (PH) Markov renewal process (PH-MRP), Markov modulated Poisson process (MMPP) and batch Markovian arrival process (BMAP).

The MMPP is a doubly stochastic Poisson process where arrival rate of any traffic depends on its probability state which forms a continuous-time Markov chain. In a continuous-time Markov chain, sojourn time/life time in any state i is exponentially distributed with parameter λ_i. At the end of the sojourn time in state i, a transition takes place to another state or to the same state. The transition may or may not correspond to an arrival. Let us consider the simple case of two-state MMPP, also known as MMPP(2) system, where the arrival rate, λ_i (i=1, 2) appears alternately with exponentially distributed life time, r_i^{-1} (i=1, 2). These are shown in Fig. 1 where the transition between level-1 and level-2 occurs without any arrival. The two-state MMPP is characterized by the matrix pair (Q, D), where Q is the infinitesimal generator matrix and D is the arrival matrix. Here, both Q and D are 2×2 square matrices. The generator matrix Q, is expressed as the sum of matrix D and another matrix C; all the off-diagonal elements of C and all the elements of D are nonnegative but the diagonal elements of C are negative:

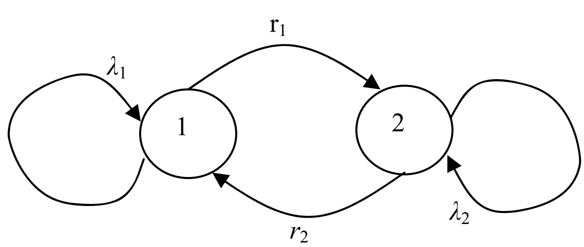
$$\mathrm{C}=\begin{bmatrix}-(r_1+\lambda_1) & r_1 \\ r_2 & -(r_2+\lambda_2)\end{bmatrix},\ \mathbf{D}=\begin{bmatrix}\lambda_1 & 0 \\ 0 & \lambda_2\end{bmatrix}$$

and

$$\mathrm{Q{=}C{+}D}=\begin{bmatrix}-r_1 & r_1 \\ r_2 & -r_2\end{bmatrix}.$$



(a) Packet arrival and sojourn time



(b) State transition chain

Fig. 1. The two-state MMPP.

The n-state MMPP is also characterized by (**Q, D**), where now each matrix is an $n\times n$ square matrix. The MMPP traffic model is being widely used in recent times as found in the current literature. In [7] the authors deal with waiting time of MMPP(2) traffic, which is applicable to real-time ATM

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network. The paper first shows the evaluation technique of the waiting time, based on the generator matrix and Laplace transform [8]. The authors finally suggest an approximate technique following *two-term* exponential function. The results of both the techniques are found to be very close. In [9], the authors determine the performance of transmission for telemedicine using ATM network. The paper shows the profile of the probability of overflow of queue versus buffer size based on MMPP model. In [10], the authors determine packet loss rate of MMPP/M /1/ K traffic where variable length packet is considered. In [11], performance of voice over Internet (VoIP) traffic is analyzed for a cognitive radio system using a two-state MMPP model. In [12], the average queue length and packet dropping probability of VoIP traffic is analyzed based on statistical multiplexing (talk spurt and silent periods) of two-state MMPP. In [13], authors have claimed the development of an approximate method to evaluate the performance of voice and MMPP video traffic. In [14], constant and variable bit rate traffic is modeled under ATM network and the throughputs for videoconferencing are calculated.

The traffic in circuit switched telecommunications network usually follow exponential arrival and exponential service time distribution like M/M/n/K/N as complete notation. In ATM network, service time of each cell/packet is fixed; hence deterministic service time traffic like M/D/n/K/N is applicable to detect traffic parameters for that network. In case of single server case, ATM traffic can be modeled as M/D/1 of infinite queue which is a special case of M/G/1 [15].

In our present paper, the combined traffic of voice/video and data is modeled by MMPP+M/D/1 based on the concept of MMPP/D/1 and M/G/1 traffic models to determine the mean waiting time of the individual traffic.

The paper is organized as follows: Sec II deals with the traffic model of statistical multiplexing for the case of ATM packet link and its combination with exponential traffic. Section III provides the results of the system model described in Sec. II. Finally, Sec. IV concludes the entire analysis.

II. System Model

When voice or video signals are sent in packetized form, the system is modeled as of ON-OFF pattern. In case of a single source, the spurt and silence periods are assumed to be exponentially distributed with mean α^{-1} and β^{-1} respectively. If the sampling period of voice/video is T (cells / packets are formed for a fixed duration T of the analog signal), then three statistical parameters of the traffic are [16], [17]:

the packet arrival rate,

$$\lambda = \frac{\beta}{T(\alpha+\beta)}, \tag{1}$$

the SCV of inter arrival time,

$$C_a{}^2 = \frac{1-(1-\alpha T)^2}{T^2(\alpha+\beta)^2}, \tag{2}$$

the skewness of service time,

$$S_k = \frac{2\alpha T\left(\alpha^2 T^2 - 3\alpha T + 3\right)}{[\alpha T(2-\alpha T)]^{3/2}}. \tag{3}$$

The two-phase MMPP parameters are determined as [11], [17]:

$$r_i = \begin{cases} D\left(1+\dfrac{1}{\sqrt{1+n\lambda E}}\right); & i=1 \\ D\left(1-\dfrac{1}{\sqrt{1+n\lambda E}}\right); & i=2 \end{cases} \tag{4}$$

$$\lambda_i' = \begin{cases} n\lambda + F + F\sqrt{1+n\lambda E}\,; & i=1 \\ n\lambda + F - F\sqrt{1+n\lambda E}\,; & i=2 \end{cases} \tag{5}$$

where

$$D = \frac{K_H \lambda_{H_1} + (1-K_H)\lambda_{H_2} - \lambda}{C_a{}^2 - 1},$$

$$F = D.\frac{3C_a{}^4 - S_k C_a{}^3 - 3C_a{}^2 + 2}{3\left(C_a{}^2 - 1\right)},$$

and

$$E = \frac{K_H \lambda_{H_1} + (1-K_H)\lambda_{H_2} - \lambda}{F^2}.$$

Equations (1)-(5) provide parameters of the MMPP traffic model. Again the actual and virtual waiting time of MMPP/G/1 model as explained in [17] and [18] are:

$$W_v = W_M + \frac{uh}{1-\rho}, \tag{6}$$

and

$$W_a = W_M + \frac{uh}{\rho(1-\rho)}, \tag{7}$$

respectively, where W_M is the mean waiting time of M/G/1 traffic and is expressed as

$$W_M = \frac{\lambda_t h}{\rho(1-\rho)}. \tag{8}$$

The parameter λ_t and u are given below in Eqs. (9) and (16) respectively. Now for voice data integrated traffic of MMPP + M/D/1 case, let λ_p be the Poisson's arrival rate of the voice traffic. We have $\lambda_1 = \lambda_1' + \lambda_p$ and $\lambda_2 = \lambda_2' + \lambda_p$, where expressions of λ_1' and λ_2' are given by Eq. (5). To determine mean waiting time, we note that

$$\pi_1 = \frac{r_2}{r_1 + r_2}, \quad \pi_2 = \frac{r_1}{r_1 + r_2},$$

and

$$\lambda_t = \frac{\lambda_1 r_2 + \lambda_2 r_1}{r_1 + r_2}. \tag{9}$$

Let us define a function

$$W(z) = \frac{1}{2}\left(\lambda_1(1-z) + r_1 + \lambda_2(1-z) + r_2\right) + \frac{1}{2}\sqrt{\left(\lambda_1(1-z) + r_1 - \lambda_2(1-z) - r_2\right)^2 - 4r_1 r_2},$$

which can be simplified to

$$W(z)=\frac{1}{2}\{(1-z)(\lambda_1+\lambda_2)+(r_1+r_2)\} + \frac{1}{2}\sqrt{\{(1-z)(\lambda_1-\lambda_2)+(r_1-r_2)\}^2-4r_1r_2}\,. \tag{10}$$

For MMPP/ D/1 model, we have

$$z=b^*(W(z))=e^{-hW(z)}. \tag{11}$$

Solving the above equation, we get the value of z. Let us evaluate the probabilities of transitions P_{01} and P_{02}, we obtain

$$P_{01}=\frac{W(z)-R_1(z)-\gamma_2}{(\lambda_2-\lambda_1)(1-z)}(1-\rho),\ \rho=\lambda_t h; \tag{12}$$

and

$$P_{02}=1-\rho-P_{01}, \tag{13}$$

where

$$R_j(z)=\lambda_j(1-z)+r_j;\quad j=1,2.$$

The mean waiting time is

$$W_j(z)=\pi_j\left(W_v+u\frac{\lambda_j-\lambda_t}{G}\right),\ j=1,2; \tag{14}$$

where

$$G=\sum_{j=1}^{2}\pi_j(\lambda_j-\lambda_t)^2, \tag{15}$$

and

$$u=\frac{\lambda_1-\lambda_2}{(1-\rho)(r_1+r_2)^2}[r_1P_{01}(1-\lambda_2h)-r_2P_{02}(1-\lambda_1h)]. \tag{16}$$

Now the mean waiting time of the individual traffic is given by

$$W_{MMPP/D/1}=\frac{\lambda_1' W_1+\lambda_2' W_2}{\lambda_t'}, \tag{17}$$

where

$$\lambda_t'=\frac{\lambda_1' r_2+\lambda_2' r_1}{r_1+r_2} \tag{18}$$

and

$$W_{voice}=W_1+W_2. \tag{19}$$

III. Results

It is to be noted here that the steady state probability states of M/G/1 traffic are given by the following expression

$$\Pi_j^*=\frac{1}{j!}Lt_{z\to 0}\frac{d^j}{dz^j}G(z),$$

where j = 0, 1, 2, 3… and the moment generating function $G(z)$ is expressed in generalized form as

$$G(z)=(1-a)\{b^*(\lambda-\lambda z)(z-1)\}/\{z-b^*(\lambda-\lambda z)\}.$$

In M/D/1 model, $b^*(\lambda-\lambda z)=\exp\{-h\lambda((1-z)\}$. The detailed derivation of the steady state probability Π_j^* in terms of the moment generating function $G(z)$ is given in Appendix A.

Varying the traffic intensity ρ, the probability of states of the M/D/1 traffic model is plotted in Fig. 2. The tail of the probability density function (PDF) increases with increase in the offered traffic intensity, ρ.

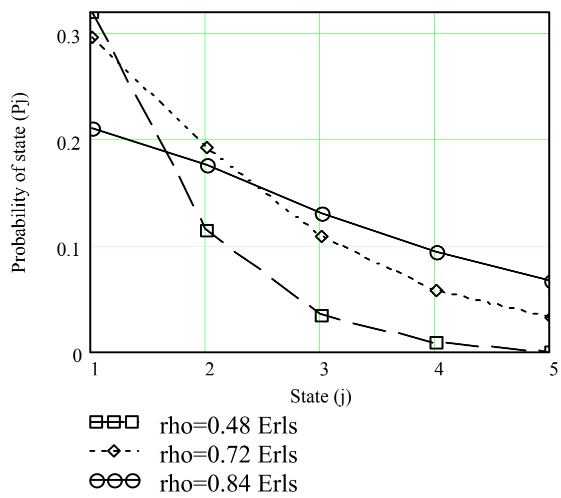

Fig. 2. The probability of state of the M/D/1 traffic.

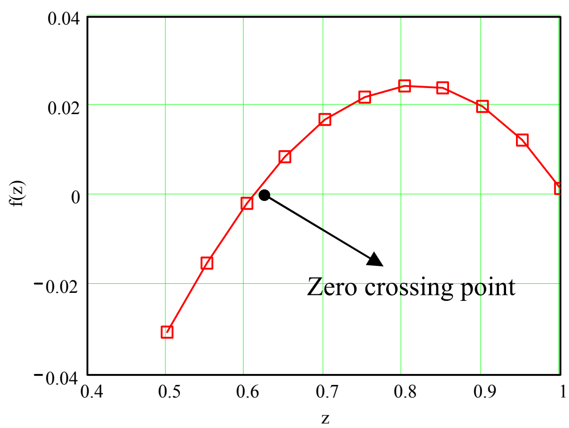

Fig. 3. Graphical solution of $f(z)=z-e^{-hW(z)}$.

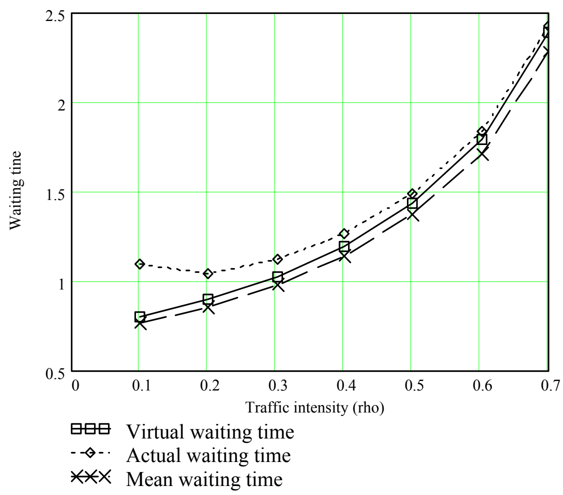

Fig. 4. The variation of virtual, actual and mean waiting time against offered traffic intensity.

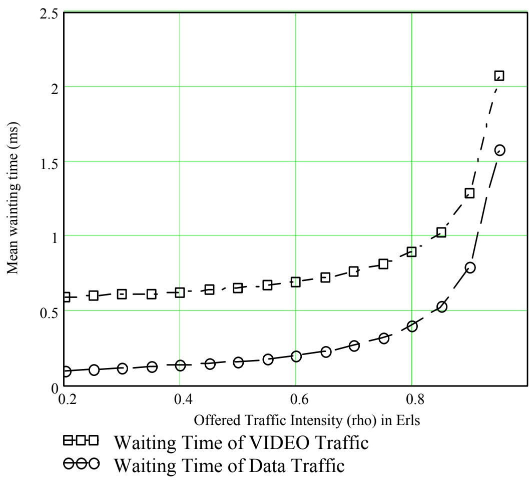

Fig. 5. Waiting time profile of video and data traffic of the combined model.

In the MMPP/D/1 traffic model, the following set of practically realizable traffic parameters are used: λ_1 = 0.36 cells/ms, λ_2 = 0.2 cells/ms, h = 2ms, r_1 = 0.015 and r_2 = 0.125. For the above physical parameters, we obtain $\lambda_t = (\lambda_1 r_2 + \lambda_2 r_1)/(r_1 + r_2)$ = 0.343 cells/ms. Now solving the relation, $f(z) = z - \exp\{-hW(z)\}$ for the case of deterministic service time, we get z = 0.62. The graphical solution of Eq. (11) is shown in Fig. 3, where z = 0.62 corresponds to the zero crossing point. The variation of virtual, actual and mean waiting time [17], [18] against the offered traffic intensity ρ is shown in Fig. 4, where each of the three parameters rises exponentially with increase in the traffic intensity, ρ .

Let us now go for the combining scheme of M/D/1 and MMPP/D/1, known as MMPP+M/D/1, applicable to voice-data integrated service through ATM network. Let, h = 2.718×10^{-6}s, $T = 3.397\times10^{-6}$ s and n = 3, we get the MMPP traffic parameters in per ms as: $r_1 = 0.414$, $r_2 = 0.071$, $\lambda_{b1} = 3.657\times10^2$ cells/ms and λ_{b2} = 6.239cells/ms. Therefore, we get, $\lambda_b = (\lambda_{b1}r_2+\lambda_{b2}r_1)/(r_1+r_2)$ = 58.499cells/ms. Taking λ_p = 100 cells/ms we can evaluate: $\lambda_1 = \lambda_{b1} + \lambda_p$ = 465.652 cells/ms, $\lambda_2 = \lambda_{b2} + \lambda_p$ = 106.239 cells/ms, $\lambda_t = (\lambda_1 r_2 + \lambda_2 r_1)/(r_1 + r_2)$ =158.499 cells/ms and $\rho = \lambda_t h$ = 0.431 Erls. From the graphical solution of $f(z) = z - e^{-hW(z)}$, shown in Fig. 3, we get z = 0.62. From the expressions of the transition probabilities, given by Eqs. (12) and (13), we obtain

$$P_{01} = \{W(z) - R_1(z) - r_2\}(1-\rho)/\{(\lambda_2 - \lambda_1)(1-z)\}$$
$$= 2.93\times10^{-4}$$

and

$$P_{02} = 1 - \rho - P_{01} = 0.569,$$

where

$$u = (\lambda_1 - \lambda_2)\frac{[r_1 P_{01}(1-\lambda_2 h) - r_2 P_{02}(1-\lambda_1 h)]}{(1-\rho)(r_1+r_2)^2} = 28.842.$$

Now the mean, virtual and actual waiting time of Eqs. (6) and (7) are $W_M = \lambda_t h^2/2(1-\rho)$ = 1.029E-3 ms, $W_a = W_M + uh/\rho(1-\rho)$ = 0.321ms, $W_v = W_M + uh/(1-\rho)$ = 0.139ms. The mean waiting times, W_j (j=1,2), of Eq. (14) are: $W_1 = P_1\{W_v + u(\lambda_1\lambda_t)/G\}$ = 0.1ms and $W_2 = P_2\{W_v + u(\lambda_2\lambda_t)/G\}$ = 0.038ms. The individual waiting times are: for video, $W_b = (W_1\lambda_{b1} + W_2\lambda_{b2})/\lambda_b$ = 0.632 ms and for data $W_p = W_1 + W_2$ = 0.139 ms.

The variation of the mean waiting time of the video and data traffic is shown in Fig. 5 against the offered traffic. Initially, the waiting time of each of the traffic rises slowly, and after 0.8 Erls, they rise rapidly since packet traffic starts to rise asymptotically there, after ρ = 0.88Erls [16]. When offered traffic tends to be in saturation, i.e., above 0.95 Erls, we find the waiting time to approach infinity since the rate of service falls below the arrival of packets, hence queue will increase continuously.

IV. Conclusion

The paper shows the profile of mean waiting time, virtual and actual waiting times of MMPP/D/1 against offered traffic, where all of them are found to be very close to each other and exponentially distributed as is visualized from Fig. 4. Finally, combined model of MMPP+M/D/1 is applied for video-data integrated traffic and waiting time of individual traffic is also evaluated. Both video and data traffic can tolerate the offered traffic below 0.88 Erls/trunk; which satisfies the asymptote of packet traffic. Similar analysis can also be applied in other MAP, like batch arrival process, phase type renewal process along with M/G/1 model to support traffic of variable packet length.

Appendix A

In queuing system, moment generating function or z-transformation is used to derive statistical parameters of a network traffic. The moment generating function is defined as [19]:

$$G(z) = \sum_{n=0}^{\infty} P_n z^n ,$$

which is used in a system of infinite number of probability states. Some properties of the function $G(z)$ are:

$$G(1) = \sum_{n=0}^{\infty} P_n = 1 ,$$

$$\frac{dG(z)}{dz} = \sum_{n=0}^{\infty} nP_n z^{n-1} = 1 ,$$

$$\left.\frac{dG(z)}{dz}\right|_{z=1} = \sum_{n=0}^{\infty} nP_n = E[n] ,$$

$$\left.\frac{d^2G(z)}{dz^2}\right|_{z=1} = \sum_{n=0}^{\infty} nP_n = E[n^2] - E[n] ,$$

$$zG(z) = \sum_{n=0}^{\infty} P_{n-1} z^n ,$$

$$\sum_{n=0}^{\infty} P_{n+1} z^n = z^{-1}[G(z) - P_0] .$$

If k calls exist in a M/G/1 system just after a call departure, the call at the front of the queue (FIFO case) enters service and j calls arrive during its service time, then the number of calls present at its departure is $k+j-1$.

Let Π_j^* is the probability that j calls exist just after departure of a call in M/G/1 system and p_j is the probability that j calls arrive during the service time [17].

Therefore,

$$\Pi_j^* = p_j\Pi_0^* + p_j\Pi_1^* + p_{j-1}\Pi_2^* + p_{j-2}\Pi_3^* + \ldots + p_{j-k+1}\Pi_k^* + \ldots \ \ldots \ \ldots + p_0\Pi_{j+1}^*,$$

which can be compactly written as

$$\Pi_j^* = p_j\Pi_0^* + \sum_{k=1}^{j+1} p_{j-k+1}\Pi_k^* \,;\, j = 0,\ 1,\ 2,\ \ldots\ , \qquad \text{(A1)}$$

where

$$p_j = \frac{a^j}{j!}e^{-a}.$$

From total probability theorem, we have

$$p_j = \int_0^\infty \frac{(\lambda x)^j}{j!}e^{-\lambda x}dB(x),$$

where $B(x)$ is the service time distribution.

Let the probability generating function of Π_j^* be $G(z)$, then

$$G(z) = \sum_{j=0}^\infty z^j\Pi_j^*$$
$$= \sum_{j=0}^\infty z^j\left\{p_j\Pi_0^* + \sum_{k=1}^{j+1} p_{j-k+1}\Pi_k^*\right\}$$
$$= \Pi_0^*\sum_{j=0}^\infty z^j p_j + \sum_{j=0}^\infty z^j \sum_{k=1}^{j+1} p_{j-k+1}\Pi_k^*.$$

Let us consider the second part of the above relation:

$$\sum_{j=0}^\infty z^j \sum_{k=1}^{j+1} p_{j-k+1}\Pi_k^*$$
$$= \sum_{j=0}^\infty\sum_{k=1}^{j+1} z^j p_{j-k+1}\Pi_k^*$$
$$= \sum_{k=0}^\infty\sum_{j=1}^{k+1} z^k p_{k-j+1}\Pi_j^* \text{ ; (interchanging the index } k \text{ and } j)$$
$$= \sum_{k=0}^\infty\sum_{j=1}^{\infty} z^k p_{k-j+1}\Pi_j^* \text{ ; (Since } k \text{ varies from 0 to } \infty)$$
$$= \sum_{j=1}^\infty\sum_{k=0}^{\infty} z^k p_{k-j+1}\Pi_j^*$$
$$= \sum_{j=1}^\infty\Pi_j^*\sum_{k=0}^{\infty} z^k p_{k-j+1}$$
$$= \sum_{j=1}^\infty\Pi_j^*\sum_{k'=0}^{\infty} z^{k'+j-1} p_{k'}.$$

Taking, k-j+1=k' when k=0 and j=1, then k' = 0-1 + 1 = 0, the above expression can be written as

$$= \sum_{j=1}^\infty\Pi_j^*\sum_{k=0}^{\infty} z^{k+j-1} p_k.$$

Now,

$$G(z) = \Pi_0^*\sum_{j=0}^\infty z^j p_j + \sum_{j=1}^\infty\Pi_j^*\sum_{k=0}^{\infty} z^{k+j-1} p_k. \qquad \text{(A.2)}$$

Again we have

$$p_j = \int_0^\infty \frac{(\lambda x)^j}{j!}e^{-\lambda x}dB(x),$$

which implies

$$\sum_{j=0}^\infty z^j p_j = \int_0^\infty\sum_{j=0}^\infty z^j\frac{(\lambda x)^j}{j!}e^{-\lambda x}dB(x)$$
$$= \int_0^\infty\sum_{j=0}^\infty \frac{(z\lambda x)^j}{j!}e^{-\lambda x}dB(x)$$
$$= \int_0^\infty e^{z\lambda x}e^{-\lambda x}dB(x),$$

or

$$\sum_{j=0}^\infty z^j p_j = \int_0^\infty e^{-x(\lambda - z\lambda)}dB(x). \qquad \text{(A.3)}$$

We know the LST of $F(x)$ as

$$f^*(\theta) = \int_0^\infty e^{-\theta x}dF(x). \qquad \text{(A.4)}$$

From (A.3) and (A.4), we have

$$\sum_{j=0}^\infty z^j p_j = b^*(\lambda - \lambda z). \qquad \text{(A.5)}$$

From (A.2) and (A.5), we have

$$G(z) = \Pi_0^*.b^*(\lambda-\lambda z) + \sum_{j=1}^\infty \Pi_j^* z^{j-1}\sum_{k=0}^\infty z^k p_k.$$
$$= \Pi_0^*.b^*(\lambda-\lambda z) + \sum_{j=1}^\infty \Pi_j^* z^{j-1}b^*(\lambda-\lambda z)$$
$$= b^*(\lambda-\lambda z)\left\{\Pi_0^*. + \sum_{j=1}^\infty \Pi_j^* z^{j-1}\right\}$$
$$= b^*(\lambda-\lambda z)\left\{\Pi_0^*. + \Pi_1^* + \Pi_2^* z + \Pi_3^* z^2 + \ldots \ \ldots \ \ldots\right\}$$
$$= b^*(\lambda-\lambda z)z^{-1}\left\{\Pi_0^* z + \sum_{j=1}^\infty z^j\Pi_j^*\right\}$$
$$= b^*(\lambda-\lambda z)z^{-1}\left\{\Pi_0^* z + G(z) - \Pi_0^*\right\},$$

$$\Rightarrow G(z)\left\{1 - b^*(\lambda-\lambda z)z^{-1}\right\} = b^*(\lambda-\lambda z)z^{-1}\Pi_0^*(z-1)$$

$$\Rightarrow G(z) = \frac{b^*(\lambda-\lambda z)z^{-1}\Pi_0^*(z-1)}{\left\{1 - b^*(\lambda-\lambda z)z^{-1}\right\}} = \frac{b^*(\lambda-\lambda z)\Pi_0^*(z-1)}{\left\{z - b^*(\lambda-\lambda z)\right\}}$$

$$\Rightarrow G(z) = (1-a)\frac{b^*(\lambda - \lambda z)(z-1)}{\{z - b^*(\lambda - \lambda z)\}} \quad [\because \Pi_0^* = (1-a)\,.$$

Now the probability states of M/G/1 are

$$\Pi_j^* = \frac{1}{j!} Lt_{z \to 0} \frac{d^j}{dz^j} G(z)\,;\, j = 0, 1, 2, 3\ldots$$

In M/D/1 model, $b^*(\lambda - \lambda z) = \exp\{-h\lambda((1-z)\}$.

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