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# ATN network – Basic traffic models for services

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*Abstract - Traffic models are at the heart of any performance evaluation of data ATN networks. An accurate estimation of network performance is critical for the success of broadband networks. Such networks need to guarantee an acceptable quality of service (QoS) level to the users. Therefore, traffic models need to be accurate and able to capture the statistical characteristics of the actual traffic. Traditional short-range and non-traditional long-range dependent traffic models are presented. Number of parameters needed, parameter estimation, analytical tractability, and ability of traffic models to capture marginal distribution and auto-correlation structure of actual traffic are discussed.*

Keywords: ATN, service, traffic model, network

## I. INTRODUCTION

The need for information networks capable of providing diverse and emerging communication services such as data, voice and video, motivated the standardization of broadband networks.

Performance modelling techniques are needed to determine which congestion control techniques should be used. Performance modelling techniques include:

- analytical techniques,
- computer simulation,
- experimentation.

Performance models require accurate traffic models which can capture the statistical characteristics of actual traffic. If the traffic models do not accurately represent actual traffic, one may overestimate or underestimate network performance.

## II. MARKOV AND EMBEDDED MARKOV MODELS

In many situations, the activities of a source can be modelled by a finite number of states. In this model, a voice source is either idle or busy. When it is busy, it will only transmit packets during speech activity. In general, increasing the number of states results in a more accurate model at the expense of increased computational complexity.

For a given state space $S = s_1, s_2, \ldots, s_M$, let $X_n$ be a random variable which defines the state at time *n*. The set of random variables $\{X_n\}$ will form a discrete Marko chain, if the

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probability of the next Value $X_{n-1} = s_j$ depends only on the current state. This is known as Markov property. If state transitions occur at integer values (0, 1, *n*,), the Markov chain is discrete time. Otherwise, the Markov chain will be continuous time.

Markov property implies that the future depends neither on the current state and not on previous states nor on the time already spent in the current state. This restricts the random variable, which describes the time spent in a state to a geometric distribution in the discrete case and to an exponential distribution in the continuous case.

A semi-Markov process is obtained by allowing the time between state transitions to follow an arbitrary probability distribution. If the time distribution between transitions is ignored, the sequence of states visited by the semi=Markov process will be a discrete time Markov chain, and is referred to as an embedded Markov chain.

In a simple Markov traffic model, each state transition represents a new arrival. Therefore, inter-arrival times are exponentially distributed (for continuous time case), and their rates depend on the state from which the transition occur. The rest of this section discusses various Markov and embedded Markov models that have been used to model network traffic.

### A. On-off and IPP models

The on-off source model is the most popular source model for voice. In this model, packets are only generated during talk spurts (on state) with fixed inter-arrival time. The time spent in on and off states is exponentially distributed with mean $\alpha^{-1}$ and $\beta^{-1}$, respectively.

The interrupted Poisson process (IPP) is also a two-state process. Arrivals only occur in the active state according to a Poisson distribution with rate $\lambda$. Hence, IPP and on-off models differ in inter-arrival time during the active (on) state.

### B. Alternating state renewal process

The alternating state renewal process is a two state process, $s_1$ and $s_2$, with no self transition. Therefore, the embedded Markov chain is alternating between $s_1$ and $s_2$. The traffic amplitude is 0 while in state $s_1$ and 1 while state $s_2$. Let the mean sojourn time in $s_1$ and in $s_2$ to be $d_1$ and $d_2$, respectively. Then, the steady state probabilities for being in state $s_1$ is $P_{s1} = \frac{d_1}{(d_1 + d_2)}$, and for $s_2$ is $P_{s2} = \frac{d_2}{(d_1 + d_2)}$.

The superposition of identical independent alternating state renewal processes has a binomial distribution.

### C. Markov modulated Poisson process

A Markov modulated process, also called doubly stochastic process, uses an auxiliary Markov process in which the current state of the Markov process controls (modulate) the probability distribution of the traffic.

In this model, while in state $s_k$, the arrivals occur according to a Poisson process with rate $\lambda_k$. The introduction of MMPP process allows the modelling of time-varying sources while keeping the analytical solution of relates queuing performance tractable.

The MMPP parameters can be estimated easily from the empirical data as follows: quantize the arrival rate into finite number of rates, which corresponds to the number of states. Each rate corresponds to a state in the Markov chain. The transition rate from state *i* to state *j*, denoted by $q_{ij}$, is estimated by quantizing the empirical data and by calculating the fraction of times that the state (rate) *i* switched to state (rate) *j*. Note that an MMPP process with $M+1$ states can be obtained by the superposition of *M* identical independent IPP sources.

MMPP can model a mixture of voice and data traffic. In this case, the arrivals of voice packets while in state *k* are assumed to be Poisson with rate $\lambda_k$. Data packets are also Poisson with rate $\lambda_d$. The resulting rate of state $s_k$ will be $\lambda_k + \lambda_d$. The performance measures such as queuing distribution and the moments of the delay distribution are obtained using MMPP/G/1 queue analysis.

### D. Markov modulated fluid models

Fluid models characterize the traffic as a continuous stream with a parameterized flow rate (such as bits/sec.). These models are appropriate in the case where individual units of traffic (packets or cells) have little impact on the performance of the network.

Fluid models are conceptually simple and their simulation has an important advantage over other models. Consider for example, an event simulation for an ATM multiplexer. All models that distinguish between cells and consider the arrival of each cell as a separate event, consume vast amount of memory and CPU resources. In contrast, fluid models characterize the incoming cells by a flow rate. An event is only triggered when the flow rate changes. Since flow rate changes happen much less frequently than cell arrivals, considerable saving in computing and memory resources are achieved [1].

A fluid model that is typically used to model traffic is the Markov modulated fluid model. In this model, the current state of the underlying Markov chain determines the flow (traffic) rate. While in state $s_k$, traffic arrives at a constant rate $\lambda_k$. This model is a Markov modulated constant rate model and is used in [7], [20] to model VBR video sources.

In [7], the continuous bit rate is quantized into a finite set of discrete levels and sampled at random Poisson points (i.e. inter-sample time is exponentially distributed). The number of states in the Markov chain is equal to the number of quantized levels. Since Markov processes have exponentially decaying auto-covariance function, the auto-covariance of the empirical data is approximated by $C(\tau) = Ce^{-a\tau}$.

There are many Markov chains that satisfy the above auto-covariance function and the average of the empirical data. The birth-death Markov chain is used for its simplicity in [20]. In this model, the bit rate while in state *i* is constant and is given by *iA*, where *A* is the quantization step size. The transition rates are chosen such that lower bit-rate-states tend to jump to higher-bit-rate states and vice-versa. This model captured approximately the first 10 lags of the auto-correlation function of the empirical data. This is due to a faster decay in the auto-correlation function of the actual data. Moreover, jumps are only allowed to neighbouring states in birth-death Markov chain, so the model lacks the ability to capture abrupt changes in the arrival rate between frames.

In order to capture scene changes in the above model, [7] extended the model by allowing the rate to be integer multiples of two basic levels: high level $A_h$, and low level $A_l$. It uses a two-dimensional Markov chain in which the state is defined by two indices $i$ and $j$, where 0 “$i$” $M$ and 0 “$j$” $N$. While in state $(i, j)$, the flow rate is $(iA_l + jA_h)$.

The queuing performance of this model is still analytically tractable and it has been considered in [20]. The model has many parameters and exponentially decaying auto-correlation function. The complexity of analytical solution increases by adding more activity levels.

## III. REGRESSION MODELS

Regression models define explicitly the next random variable in the sequence by previous ones within a specified time window and a moving average of a white noise - [24]:

- Autoregressive models,
- Discrete autoregressive models.

## IV. TES MODELS

Transform-expand-sample (TES) models are non-linear regression models with modulo-1 arithmetic. They aim to capture both auto-correlation and marginal distribution of empirical data.

TES models consist of two major TES processes [1, 15, and 16]:

- $TES^+$,
- $TES^-$.

$TES^+$ produces a sequence which has positive correlation at lag 1, while $TES^-$ produces a negative correlation at lag 1.

Before describing $TES^+$ or $TES^-$, we need to introduce a few definitions and annotations. The modulo-1 of a real number $x$, denoted as $\langle x \rangle$, is defined as

$$\langle x \rangle = x - \lfloor x \rfloor$$

Where $\lfloor x \rfloor$ is the maximum integer less than $x$?

Therefore, $\langle x \rangle$ is always non-negative. If the interval [0, 1) is viewed as a circle that is obtained by joining the points 0 and 1, one can define a circular interval $C[a,b)$, where a and $b \in [0,1)$, as all the points on the circular unit interval going clockwise from point $a$ to point $b$. Therefore,

$$C[a,b) = \begin{cases} [a,b), & \text{if } a \le b \\ [0,1) - [b,a), & \text{if } a \rangle b \end{cases}$$

### A. $TES^+$ and $TES^-$

$TES^+$ ($L$, $R$) is introduced in [19] and is characterized by two parameters, L and R. The sequence $\{U_n^+\}$ is generated recursively as follows: initialize $U_0^+ = U_0$, where $U_0$ is uniform in the interval (0, 1), Then $U_n^+$ is uniformly sampled random variable on the circular interval $C_{U_n^+} = \left[\left\langle U_{n-1}^+ + L\right\rangle, \left\langle U_{n-1}^+ + R\right\rangle\right)$.

In the $TES^-(L, R)$, the sequence is generated as in $TES^+$ with $U_n^-$ is uniform random variable over the circular interval

$$C_{U_{n-1}^-}[a,b) = \begin{cases} \left[\left\langle 1-U_{n-1}^- - L\right\rangle, \left\langle 1-U_{n-1}^- + R\right\rangle\right), & n\ even \\ \left[\left\langle 1-U_{n-1}^- - R\right\rangle, \left\langle 1-U_{n-1}^- + L\right\rangle\right), & n\ odd \end{cases}$$

$TES^+$ And $TES^-$ can also be characterized by $\alpha = L + R$, and $\phi = \frac{R - L}{\alpha}$. Note that $\alpha$ represents the length of the circular interval. The sample path realizations generated by simulation using $TES^+$ and $TES^-$ have shown discontinuity due to the crossing of the 0 point on the unit circular interval from both directions. For example, crossing clockwise will result in a jump from small values to large values. It was shown in [16] that a continuous sample path realization can be obtained by using a simple piece wise transformation $T_\xi$ called stitching, where

$$T_\xi = \begin{cases} \frac{x}{\xi}, & x \in [0, \xi) \\ \frac{1-x}{1-\xi}, & x \in [\xi, 1) \end{cases}$$

## V. LONG-RANGE DEPENDENT TRAFFIC MODELS

Stationary traffic models presented in the second and third sections have a correlation structure that is characterized by an exponential decay – [23]:

- Background on long-range dependence,
- Short-range and long-range dependence,
- Self-similarity.

## VI. CONCLUSION

Traffic models are used in traffic engineering to predict network performance and to evaluate congestion control schemes. Traffic models vary in their ability to model various correlation structures and marginal distributions. Models that do not capture the statistical characteristics of the actual traffic result in poor network performance because they either over estimate, or under estimate the network performance. Traffic models must have a manageable number of parameters and the estimation of these parameters needs to be simple. Traffic models which are not analytically tractable can only be used to generate traffic traces. These traffic traces can be used in simulations.

It appears that a model that can capture short-range dependence, long-range dependence, and an arbitrary distribution is needed. A systematic and simple method that can decouple the estimation of long-range and short-range parameters in the model needs to be developed.

Finally, analytical performance solutions for non-traditional traffic models need to be investigated for a single node, as well as for an end-to-end network model.

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