ATM Burst Traffic Generator

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Abstract

Markov modulated process is widely used to model ATM (Asynchronous Transmission Mode) traffic sources because it can emulate the bursty and correlated traffic arrival. We proposed a hardware sample generator emulating the bursty behavior of Markov process and developed circuits for 2-state Markov modulated process and N-state homogeneous Markov modulated process. The generator can produce traffic imitating cell arrival of various voice and video sources. Our testing circuit can be fitted into a moderate-sized FPGA chip and can generate up to 20M cell arrivals per second.

1. Introduction

Future communication is expected to employ ATM based networks, which can support a wide variety of services, ranging from digitized voice to real-time high resolution video [9]. In order to test and evaluate the performance of the network and the switch, it is necessary to generate cell arrival closely resembling the real traffic. Recording and reproducing the real traffic can be difficult and expensive because the process requires large storage space and high processing speed [1,12]. The alternative is to use a concise mathematical model to imitate the behavior of the traffic. Markov modulated process can mimic the randomness, burstiness and correlation of the arriving traffic. It has been used to model a wide variety of traffic sources and its accuracy has been verified against the actual data [3,6,10]. The key to produce Markov modulated arrivals is to generate burst samples that reflect the behavior of a finite state Markov chain. This can be done by software, as other stochastic processes [14]. However, because the computation is fairly involved, generators based on software simulation cannot provide necessary speed to test high-performance ATM switch and link, which may have a bandwidth of several giga bits per second [1,12]. Therefore, it is necessary to employ custom hardware to obtain higher cell arrival rate. In this paper, we proposed a hardware burst generator emulating the behavior of Markov process and developed circuits for 2-state Markov modulated process and N-state homogeneous Markov modulated process. The remaining paper is organized as follows. Section 2 reviews Markov modulated process; Section 3 describes the construction of 2-state Markov burst generator; Section 4 describes the construction of N-state homogeneous Markov burst generator; and last section summarizes the study.

2. Markov modulated process

Network traffic is frequently modeled by a modulated process, which includes a “top-level” process and “bottom-level” process [3]. In the top level, there are normally several phases, representing the burst levels of traffic. The top-level process controls the duration of each phase and the transition among the phases. The bottom-level process is the actual cell arrival process, and is normally Bernoulli process or Poisson process. Some parameters of the cell arrival process depend on the phase of the top-level process and thus it is modulated by the top-level process. A representative cell arrival from a 2-phase modulated process is shown in Figure 1. The phase 0 and phase 1 alternate, and their durations are random and controlled by two different random variables. The occurrence of a cell is a Bernoulli process, and the probability of occurrence depends on the phase. The plot shows that the mean duration of phase 1 is larger and the probability of cell occurrence in phase 1 is smaller.

![Figure 1. A typical 2-state modulated cell arrival](image)

The top-level process is normally modeled by a Markov chain with finite number of state [3]. Each state in the chain represents a phase. A simple 2-state Markov chain with transition rates of \( a \) and \( b \) is shown in Figure 2. The system alternates between two states.
The duration resided in each state (i.e., the length of each phase) is not constant but controlled by a random variable with exponential distribution. The mean durations of the two states are \( a^{-1} \) and \( b^{-1} \) respectively [14].

![Figure 2. A 2-state Markov chain](image)

For an \( N \)-state Markov chain, there are \( N(N-1) \) possible transitions. It is seldom employed because of the large number of parameters. A simpler homogeneous model is more useful. The \( n \)-state homogeneous Markov chain is shown in Figure 3. There are total \( N \) (where \( N=n+1 \)) states in the Markov chain and the state transition is similar to a typical birth-death process. We name this process "homogeneous" because the transition rates are not arbitrary. Their values follow a special pattern and depend on the current state of Markov chain. For state \( i \), forward transition rate and backward transition rate are \((n-i)a \) and \( ib \) respectively. Thus, the process can be specified by three parameters, \( N \), \( a \) and \( b \), which represent the number of states, the basic forward transition rate and the basic backward transition rate.

![Figure 3. An \( N \)-state Markov chain](image)

After we combine the top-level and bottom-level processes, the overall process becomes Markov Modulated Poisson Process (MMPP) or Markov Modulated Bernoulli Process (MMPB) [3]. These processes are very versatile and can model a wide variety of traffic patterns, including voice sources, mixed data and voice source, aggregate voice source as well as video sources with and without scene change [3,4,6,8,13]. The key to implement an MMPP/MMBP sample generator is the top-level burst generator. The output of the burst generator indicates the current state of the Markov chain and is used to control the operation of bottom-level generator. Once it is constructed, the bottom level process can be easily incorporated [7].

3. 2-state Markov burst generator

2-state burst generator generates sample duration according to the 2-state Markov chain. Because of the discrete nature of digital circuits, it is not possible to generate a continuous number, as required by the exponential sample of Markov chain. Thus, we use the geometrical distribution to approximate the exponential distribution. The geometrical distribution is characterized by a parameter \( p \) and is defined as

\[
f(n) = \begin{cases} 
(1 - p)p^{n-1} & \text{if } n \geq 1 \\
0 & \text{otherwise}
\end{cases}
\]

Because the geometrical distribution has an infinite tail, geometrical sample generator cannot be implemented by conventional lookup table technique. We implement the generator indirectly via a Bernoulli sample generator. It is based on the observation that for a Bernoulli trial with success probability of \((1-p)\) [11], the probability of first success occurring at the \( n \)th trial is \((1-p)p^{n-1}\), which represents the geometrical distribution. The Bernoulli generator can be easily constructed by using a pseudo random number (RN) generator and a comparison circuit shown in Figure 4 [7]. In this circuit, the output of pseudo RN generator is compared with the boundary point, which is determined by \( p \) and stored in the register \( R1 \). The compared result (output) indicates whether the trial is a success or a failure.

![Figure 4. Diagram of Bernoulli sample generator](image)
corresponding to the two failure probabilities, \( p_1 \) and \( p_2 \), are stored in registers R1 and R2 respectively. The current state signal from control path is used as output and also determines which one to be passed to the comparison circuit.

![Figure 5. Block diagram of 2-state burst generator](image)

Figure 5. Block diagram of 2-state burst generator

![Figure 6. State diagram of the control path of 2-state burst generator](image)

Figure 6. State diagram of the control path of 2-state burst generator

4. **N-state homogeneous Markov burst generator**

The \( N \)-state homogeneous burst generator is more complex. It is complicated by two factors. First, the transition rates (and thus the boundary points) are varying with the state of the Markov chain and thus an addition/subtraction circuit is needed. Second, for an intermediate \( i \) state of the Markov chain, the system may transit either to \( i-1 \) state or \( i+1 \) state, depending which direction obtains a successful trial first. Thus, we need two geometrical sample generators to keep track the evolution of both directions. The block diagram of \( N \)-state homogeneous burst generator and the state diagram of the control path are shown in Figures 7. It consists of for_geo generator and back_geo generator blocks, which are basically two geometrical sample generators whose boundary points can be decreased or increased by a fixed amount, as required by the forward and backward transitions of the homogeneous Markov chain. The block diagram of for_geo generator is shown in Figure 8. The registers R1 and R2 store the basic increment step (related to \( a \)) and the current boundary point (related to \( (n-i)a \)). The inputs \( a^+ \) and \( a^- \) control the increment and decrement of the current boundary points and the output \( sa \) indicates whether the trial is a success. back_geo generator is similar but with inputs \( b^+ \) and \( b^- \) and output \( sb \). The counter stores the current state of the Markov chain and its value can be incremented or decremented, controlled by two inputs. Since the increment and decrement signals are identical to back_geo generator, the \( b^+ \) and \( b^- \) signals are used. It outputs two status signals, \( a1 \) and \( an1 \), indicating the current state of the Markov chain is \( 1 \) and \( n-1 \) respectively.

![Figure 7. Block diagram of N-state burst generator](image)

![Figure 8. Block diagram of For_geo generator](image)
The state diagram of the control path of N-state burst generator is shown in Figure 9. There are three states, which keep track the current status of the Markov chain. S0, S1 and S2 represent that the Markov chain is in state 0, state n and other intermediate states respectively. The state machine uses sa and sb to determine which direction has obtained a success trial first, and increments/increments the counter, for_geo generator and back_geo generator accordingly. It uses s1 and sn1 signals to determine whether to transit to a new state.

We have built a testing circuit using Altera FPGA (Field Programmable Gate Array) chip [2,5] and the primitive results show that it can generate up to 20 M cells per second. Since an ATM cell contains 53 bytes, it can be used to test a system with a bandwidth up to 8 giga bits per second.

5. Summary

Markov modulated process is widely used to model ATM traffic sources. We proposed a hardware burst generator emulating the behavior of Markov process and developed circuits for 2-state Markov modulated process and N-state homogeneous Markov modulated process. The generator can produce traffic imitating cell arrival of various voice and video sources, and can generate up to 20M cell arrivals per second.

Bibliography