Stochastic Network Calculus Model for AWGN Fading in Underwater Wireless Communication Networks

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ABSTRACT

A fundamental issue in underwater acoustic wireless channels is in analyzing the backlog bounds, delay bounds and the loss bounds that directly impact the Quality of Service (QoS) performance in networks. Transmitting data over AWGN Channel is the simplest and the fundamental model for acoustic wireless communication. In this paper, we have developed a Stochastic Network Calculus model for AWGN channel and analyze its performance guarantees. The traffic and service models are derived under the probability delay, backlog and loss bounds for the physical layer. The results obtained are compared with the numerical results and verified for the tightness of bound. To the best of our knowledge this is the first work in taking in modeling AWGN channel for underwater acoustic data transmission.

INTRODUCTION

Underwater acoustic communication applications have experienced massive growth and commercial success in recent years. Effective acoustic communication occurs only when acoustic receiver understands the exact message transmitted by the acoustic transmitter. Acoustic wireless channels are characterized by fading, multipath, limited bandwidth, frequency and time selectivity, which makes system design a challenge (F.De.Rango, 2012). Fading refers to the distortion that a carrier-modulated communication signal experiences over certain propagation media (Jesus Lior, 2013). The concept of acoustic communication brings forth questions like reliability in transfer of data between the pair of acoustic communicator in a given time. Transmitting a data over Additive White Gaussian Noise (AWGN) channel is the simplest and fundamental model in the acoustic wireless communication channel (Yuming Jiang, 2008). Stochastic Network Calculus (SNC) is the latest mathematical tool to measure the performance analysis of current packet switched communication networks (Yuming Jiang, 2003). Yuming Jiang introduces the concept of SNC and its applications in this research works (Yuming Jiang, 2005). But, to the author’s knowledge, there are no findings in providing QoS guarantees to data traffic in underwater wireless communications. In this paper AWGN channel for underwater wireless communication is modeled using Stochastic Network Calculus (SNC). It was found that Modeling with appropriate mathematical tool impacts in proving good Quality of Service (QoS) guarantees. The most frequent performance measurements in fading channel are given in Fig 1. ergodic capacity; outage capacity and delay limited capacity. Ergodic capacity is achieved, when the acoustic transmitter has no channel state information. It is the expected values of the instantaneous capacity, where the expectations are with respect to all channel realizations. Ergodic capacity is alone not an appropriate solution for delay sensitive applications. To overcome the drawbacks of ergodic capacity, the concept of outage capacity has been developed (Yuming Jiang, 2009). It quantifies the capacity in terms of chosen outage probability. The outage capacity is the maximum rate that can be maintained by probability, throughout the data transmission (Yuming Jiang, 2006). The final delay limited capacity is the maximum achievable transmission rate, which can be guaranteed for all fading states. However, the delay-limited capacity is zero in much common fading process like Rayleigh (Dilip Roy, 2004) and Rician fading (Jan Sijbers, 1998).
From the ISO/OSI Model (M. Fidler, 2006) it is clear that physical layers parameters have significance impact in the upper layers in the data transmission. In the existing work, there are variety of research works (A. Ghavai, 2008) considers the cross layer QoS analysis. These investigate the impact on the Physical layer parameters like fading, coding, modulation. On the data-link layer (Y. Polyanskly, 2009), the authors investigated the impact of the adaptive modulation and coding in the data transmission performance of the data link layer. To author’s knowledge, the impact of the channel coding on the QoS performance in data-link layer is not considered. Shannon channel capacity, assuming the infinite code length with no dispersion has been used as service rate for performance analysis and no channel decoding errors are considered (A. Ghavai, 2008). In this paper, we have developed an acoustic communications cross-layer QoS performance guarantees approach to study the physical layer code word length on the acoustic transmission data and derived backlog, delay and loss parameters for the acoustic channel. In addition this paper addresses the connecting translating acoustic channel coding characteristics to the upper layer QoS performance. Based on traffic, service models and block code words in physical layer, probabilistic delay and backlog bounds are derived using SNC. This serves as the origin work for researchers working in modeling an acoustic channel communication, because to the best of our knowledge this is the foremost work taking coding effect in cross layer for the QoS analysis in acoustic channel communication.

The rest of this research article is organized as follows. Section II shows the basic notations, operators and properties of stochastic network calculus. Section III explains underwater acoustic AWGN fading channel using stochastic network calculus. Section IV includes performance analysis bounds. Section V, the simulation results and performance evaluation are explained. Section VI concludes the research article with future work.

**Basic Notations Of Stochastic Network Calculus:**

**A. Basic Notations:**

Fundamentally SNC has its root from Queuing theory (R. Cruz, 1991). In this section, the basic notations and concepts of SNC are introduced. A process is defined as the function of time \( t \). The various network elements is represented as amount of traffic arriving to the network \( A(t) \) (arrival process), the amount of traffic leaving the network \( A'(t) \) (departure process), the amount of service provided by the network \( S(t) \) (Service process) and the amount of service failed to be provided by the network \( I(t) \) (Impairment process). We assumed all process are non-negative and increasing functions and by convention \( t=0 \), i.e.,

\[
0 \leq s \leq t, \quad A(s,t) = A(t) - A(s), \quad A'(s,t) = A'(t) - A'(s),
\]

and

\[
S(s,t) = S(t) - S(s) \quad \text{and} \quad I(s,t) = I(t) - I(s).
\]

By default, \( A(0) = A'(0) = S(0) = 0 \). We denote by \( \mathcal{F} \) the set of non-negative wide-sensing increasing functions, and \( \overline{\mathcal{F}} \) the set of non-negative decreasing functions, i.e.,

\[
\mathcal{F} = \{ f(\cdot) : \forall 0 \leq x \leq y, 0 \leq f(x) \leq f(y) \}
\]

\[
\overline{\mathcal{F}} = \{ f(\cdot) : \forall 0 \leq x \leq y, 0 \leq f(y) \leq f(x) \}
\]

For any random variable \( X \), its distribution function is denoted by \( F_X(x) \equiv \text{Prob}\{ X \leq x \} \), belongs to \( \mathcal{F} \), and its complementary distribution function, \( \overline{F}_X(x) \equiv \text{Prob}\{ X > x \} \), belongs to \( \overline{\mathcal{F}} \). During model transform, we put a stronger requirement on the bounding function, denoted by \( \overline{\mathcal{G}} \), the set of functions in \( \overline{\mathcal{F}} \). Where, for each function \( g(\cdot) \in \overline{\mathcal{G}} \), its \( n \)th-fold integration is bounded for any \( x \geq 0 \) and still belongs to \( \overline{\mathcal{G}} \) for any \( n \geq 0 \), i.e.,

\[
\overline{\mathcal{G}} = \left\{ g(\cdot) : \forall n \geq 0, \left( \int x^n dy \right) g(y) \in \overline{\mathcal{G}} \right\}
\] (1)
B. Operators in Stochastic Network Calculus:

The following operations are defined under the $(\min, +)$ algebra and will be used in this work:

1. **Convolution of functions** $f$ and $g$ is
   \[
   (f \triangledown g)(x) = \inf_{y \geq 0} \left[ f(y) + g(x - y) \right]
   \]
   The **deconvolution** of function $f$ and $g$ is
   \[
   (f \ast g)(t) = \sup_{s \geq 0} \left\{ f(t + s) - g(s) \right\}
   \]

We also adopt: $[x]^+ = \min\{x, 0\}$, $[x]^- = \min\{x, 1\}$

2. **Pointwise minimum** of $f$ and $g$ is
   \[
   (f \wedge g)(x) = \min[ f(x), g(x) ]
   \]
   The **pointwise maximum** of function $f$ and $g$ is
   \[
   (f \vee g)(x) = \max[ f(x), g(x) ]
   \]

In addition, we shall need the normal convolution for independent case analysis:

The **normal convolution** of functions $f$ and $g$ is
\[
(f \ast g)(x) = \int_0^x f(x - y) dg(y) \quad (2)
\]

C. Performance Metrics, Traffic and Server Models:

The following measures are of interest in service guarantee analysis under network calculus:

1. The backlog $B(t)$ in the system at time $t$ is defined as:
   \[
   B(t) = A(t) - A^*(t). \quad (3)
   \]
   The delay $D(t)$ at time $t$ is defined as:
   \[
   D(t) = \inf \{ \tau \geq 0 : A(t - \tau) - A^*(t) \leq \alpha \}
   \]
   Stochastic traffic arrival curve and service curves are core concepts in stochastic network calculus. There are different definitions of stochastic arrival curve and stochastic service curve. For traffic arrival models, we have:

**Definition 1:**

The **traffic-amount-centric (t.a.c) model**

A flow $A(t)$ is said to have a **traffic-amount-centric** stochastic arrival curve $\alpha \in \mathcal{F}$ with bounding function $f \in \mathcal{F}$, denoted by:
\[
A \sim \text{ta}\{ f, \alpha \},
\]

If for all $t \geq 0$ and $x \geq 0$, it holds
\[
\text{Prob}\left\{ A(s, t) - \alpha(t - s) > x \right\} \leq f(x) \quad (5)
\]

**Definition 2:**

The **virtual-backlog-centric model (v.b.c)**

A flow $A(t)$ is said to have a virtual-backlog-centric stochastic arrival curve $\alpha \in \mathcal{F}$ with bounding function $f \in \mathcal{F}$, denoted by:
\[
A \sim \text{vb}\{ f, \alpha \},
\]

if for all $t \geq 0$ and all $x \geq 0$, it holds
\[
\text{Prob}\left\{ \sup_{0 \leq s \leq t} A(s, t) - \alpha(t - s) > x \right\} \leq f(x) \quad (6)
\]

**Definition 3:**

The **max-virtual-backlog-centric model (m.b.c)**

A flow $A(t)$ is said to have a maximum-virtual-backlog-centric stochastic arrival curve $\alpha \in \mathcal{F}$ with bounding function $f \in \mathcal{F}$, denoted by:
\[
A \sim \text{mb}\{ f, \alpha \},
\]

if for all $t \geq 0$ and all $x \geq 0$, it holds
\[
\text{Prob}\left\{ \sup_{0 \leq s \leq t} A(s, u) - \alpha(s - u) > x \right\} \leq f(x) \quad (7)
\]

**Definition 4:**

The **weak stochastic model (w.s)**

A server is said to provide a flow $A(t)$ with a **weak stochastic service curve** $\beta \in \mathcal{F}$ with bounding function $g \in \mathcal{F}$, denoted by $S \sim \text{ws}\{ g, \beta \}$, if for all $t \geq 0$ and all $x \geq 0$, it holds
\[
\text{Prob}\left\{ A \otimes (t) - A^*(t) > x \right\} \leq g(x)
\]

**Definition 5:**

The **stochastic service curve model (s.s.c)**

A server is said to provide a flow $A(t)$ with a **stochastic service curve** $\beta \in \mathcal{F}$ with bounding
function \( g \in \mathcal{F} \), denoted by \( S \sim \text{sc} \langle g, \beta \rangle \), if for all \( t \geq 0 \) and all \( x \geq 0 \), it holds
\[
\text{Prob}\left( \sup_{0 \leq s \leq t} \left[ A \otimes \left( s \right) A^r \left( s \right) \right] > x \leq g \left( x \right) \right)
\]

**Definition 6:**

The strict stochastic service curve model (s.s.s.c)

A server is said to provide a strict stochastic service curve \( \beta \in \mathcal{F} \) with bounding function \( g \in \mathcal{F} \), denoted by \( S \sim \text{ssc} \langle g, \beta \rangle \), if during any period \( (s,t) \) the amount of service \( S(s,t) \) provided by the server satisfies
\[
\text{Prob}(S(s,t) < \beta(t - s) - x) \leq g(x)
\]

From these definitions, the properties of stochastic network calculus, including the stochastic backlog bound and stochastic delay bound is provided. It has been proved that \( \left( \mathcal{F}, \wedge, \otimes \right) \) is a complete dioid, which is defined to have all the properties listed in Lemma 1.

**Lemma 1:**

\( \left( \mathcal{F}, \wedge, \otimes \right) \) is a complete dioid having properties:

(i) Closure property:
\( \forall f, g \in \mathcal{F}, f \wedge g \in \mathcal{F}; f \wedge g \in \mathcal{F} \)

(ii) Associativity:
\( \forall f, g \in \mathcal{F}, (f \wedge g) \wedge h = f \wedge (g \wedge h) \)

(iii) Commutativity:
\( \forall f, g \in \mathcal{F}, f \wedge g = g \wedge f \)

(iv) Distributivity:
\( \forall f, g \in \mathcal{F}, (f \wedge g) \wedge h = (f \wedge h) \wedge (g \wedge h) \)

(v) Zero element: \( \forall f \in \mathcal{F}, f \wedge e = f \).

(vi) Absorbing zero element:
\( \forall f \in \mathcal{F}, e \otimes f = e \)

(vii) Identity Element: \( \forall f \in \mathcal{F}, f \wedge e = e \wedge f = f \)

(viii) Idempotency of addition:
\( \forall f \in \mathcal{F}, f \wedge f = f \)

In addition we have following properties:

**Lemma 2:**

\( \forall f_1, f_2, g_1, g_2 \in \mathcal{F}, \)

(i) Comparison: \( f_1 \wedge f_2 \leq f_1 \wedge f_2 \leq f_1 \otimes f_2 \)

(ii) Monotonicity:
\[ f_1 \geq f_2 \quad \text{and} \quad f_2 \geq g_2, \quad \text{then} \quad f_1 \wedge f_2 \leq f_1 \wedge g_2; \]
\[ f_1 \wedge f_2 \leq f_1 \wedge f_2 \leq f_1 \wedge g_2; \]

**Definition 7:**

In an acoustic network system, duration is termed as a loss period of it begins, when the server is full and the arrival rate is higher than the service rate and it results in the loss. If \( A_{\text{pl}} \left( s, t \right) \) is a loss period, then the amount of loss during the time \( (s,t) \), then the loss bound is expressed as,
\[
P\left\{ L(s,t) > x \right\} = P\left\{ A_{\text{pl}} \left( s, t \right) > x \right\} - D_{\text{pl}} \left( s, t \right) > x
\]

With the above definitions, various properties of stochastic network calculus, including the stochastic backlog bound and the stochastic delay bound have been proved.

**Modeling Awgn Channel For Underwater Acoustic Networks:**

Research on SNC (Yan Zhang, 2012) provides insights into stochastic service guarantees of packet networks for acoustic network applications. In the concept of Stochastic Service Curve as a probabilistic bound on the service received by an aggregation of flows or a single flow is represented (Le Boudec, 2001). In (Humin She, 2011), the stochastic network calculus by providing a network service curve formulation that is capable of calculating stochastic end-to-end delay and backlog bounds for a number of arrival and service distributions is provided. In (M. Fidler, 2006), a server model that facilitates stochastic service guarantee analysis and addresses the delay guarantee, backlog guarantee, output characterization and concatenation property. Even though there are various researches on the theories of SNC, only a few study the mapping of theory to real-time network applications. In (Yuming Jiang, 2012), a Markov chain model of a wireless channel is provided; it doesn't provide a closed-form service curve, whereas we need a stochastic service quality for fading that uses closed-form service curves.

### A. Acoustic Channel Model:

Acoustic AWGN Channel fading model is the simplest and fundamental data transmission in acoustic wireless network. Consider a system model of a discrete-time flat-fading acoustic channel, can be expressed by, \( Y = h_{\text{j}} e^{r} X + Z \), where \( X, Y \) are the acoustic channel input and output respectively. \( Z \) is the independent and identically distributed Gaussian noise; \( h_{\text{j}} e^{r} \) is the channel
gain with amplitude $|h_t|$ which is a random variable with a AWGN fading distribution, and phase $\varphi$ that is uniformly distributed in $[-\pi, \pi]$. Fig. 2 provides the systems model of a fading acoustic channel.

Fig. 2: System Model of a Fading Acoustic Channel

For AWGN Channel with Signal to Noise Ratio (SNR) $P$, finite block length coding with finite block length $n$, and error probability $\epsilon$ and equal-power, the maximum rate $r$, achieved

$$r = C_1(P) \sqrt{\frac{V_1(P)}{n}} Q^{-1}(\epsilon) + \frac{1}{2n} \log(n) \quad (8)$$

Where $C_1(P)$ is the capacity of the acoustic channel capacity and it is expressed as

$$C_1(P) = \frac{1}{2} \log_2(1 + P).$$

The acoustic characteristics channel referred to channel dispersion $V_1(P)$ is given by

$$V_1(P) = \frac{P + 2}{2(P + 1)} \log^2 e. \quad (9)$$

When the acoustic Channel has bandwidth $W$, the equation (3) can be expressed as information transmission rate

$$R = 2W \left[ C_1(P) - \sqrt{\frac{V_1(P)}{n}} Q^{-1}(\epsilon) + \frac{1}{2n} \log(n) \right]$$

**Performance Bound Analysis:**

We analyze the results of performance bounds with traffic sources transmitted data over the acoustic fading channel. We consider two scenarios: (a) when the acoustic transmitting traffic source periodically transmits data, and that can be modeled by deterministic arrival curve; (b) when the acoustic transmitting traffic source transmits data randomly, and that be modeled by a stochastic arrival curve. Let $A_{pkt}(t)$ and $D_{pkt}(t)$ denote the packet flow arrival process and packet flow departure process, respectively. When the acoustic data packet is transmitted, each data packet is segmented and encoded into a number of information data block bits in the acoustic physical layer. These data blocks then coded with a code word with finite block length. The corresponding data block traffic process in the acoustic physical layer is expressed as $A_{cw}(t)$ and $D_{cw}(t)$. In Physical layer the data blocks are coded with code words and transmitted over the acoustic wireless channel with data transmission rate $R$. Therefore for the system backlog at time $t$ is expressed as

$$B_{pl}(t) = A_{pl}(t) - D_{pl}(t)$$

And the data block traffic process is expressed as,

$$B_{cw}(t) = A_{cw}(t) - D_{cw}(t)$$

And the delay is given as,

$$D(t) = h(A_{pl}, D_{pl}) = \inf d : A_{pl}(t - d) = D_{pl}(t+d)$$

Where $h(A_{pl}, D_{pl})$ denotes the maximum horizontal distance between.

**A. Deterministic Service Curve Bounds:**

Delay and backlog bounds for data transmission over AWGN Channel are considered. The data-link layer traffic arrival process is mapped to the physical layer information bits data block arrival process. It is expressed as,

$$A_{cw}(t) = f(A_{pl}(t))$$

The mapping function is dependent on the acoustic channel coding process. It is assumed that following all data packets have the same length $\sigma$ and the mapping is expressed as,

$$A_{cw}(t) = \sum_{i=1}^{\hat{t}(i)}$$

Where $\hat{t}(i) = \frac{\sigma}{k}$

$$\hat{t}(i) = \text{Total information bits of each data block in physical layer}$$

$\hat{t}(i) = \text{Number of information bits}.$

The all information bits process at the physical layer, the channel provides constant rate service with transmission rate $R$. The deterministic service curve is given as follows,
\[
\beta_n(t) = R t = 2W \left[ C_1(n) - \frac{\sqrt{V_1(n)}}{n} Q^{-1}(e) + \frac{1}{2n} \log(n) \right] t (12)
\]

B. Periodic Arrival Process:
In this section deterministic data traffic arrival process is considered. Packets at the data-link layer arrive at times \( \{ U + n \} \), where \( n = 0, 1, \ldots \) and \( U \) is the uniformly distributed on the interval \([0,1]\). The physical layer information bits arrival process is also bounded by the deterministic arrival curve with

\[
\alpha_{cw}(t) = \frac{\hat{\sigma}}{\tau} t + \hat{\sigma} (13)
\]

Given the physical layer service curve (12) and arrival curve (13), the following stochastic network calculus delay and backlog performance bounds are derived.

C. Stochastic Service Curve Bounds:
When mapping between the two layers, following result for the traffic process at the data-link layer is obtained.

\[
\frac{\hat{\sigma}}{\tau} \leq R, \text{ for any time } t \geq 0,
\]

\[
D_{plc}(t) \leq \frac{\hat{\sigma}}{R},
\]

\[
B_{plc}(t) \leq \hat{\sigma}
\]

Where \( \hat{\sigma} \) is given by (11) and the transmission rate \( R \) is given by (10). When we consider a Poisson packet arrival process \( A_{plc}(t) \) with average arrival rate \( \lambda \). Then the information bits in the data block arrival process become the compound Poisson process. When the arrival of a single packet leads to a batch of arrivals for coding in the physical layer, the arrival process becomes the compound Poisson process. The stochastic arrival curve \( \alpha_{cw}(t) \) with bounding function \( f(x) \) is given by,

\[
\alpha_{cw}(t) = \frac{\lambda t}{\theta} e^{\theta t} - 1, \quad f(x) = e^{-\theta}
\]

The physical layer, following the same argument in above periodic arrival process, the stochastic network calculus QoS guarantees can be proved for the Poisson packet arrival process at the data-link layer as,

\[
Pr\left\{ D_{plc}(t) \geq \frac{\hat{\sigma} + x}{R} \right\} \leq f(x)
\]

\[
Pr\left\{ B_{plc}(t) \geq \sigma + x \right\} \leq f(x)
\]

D. Loss analysis in AWGN acoustic channel:
Stochastic arrival curve and service curve assumes that packets have different length and the server adopts a FIFO mechanism for the service time as \( \hat{\sigma} \). We assume that arrival traffic follows a Poisson process with average arrival rate \( \lambda \).

\[
P\left\{ A_{plc}(s + t) - A_{plc}(s) = n \right\}
\]

\[
n = e^{-\lambda t} \left( \frac{\lambda t}{n} \right)^n
\]

Then the traffic arrival curve is expressed as follows,

\[
P\left\{ A_{plc}(s,t + s) - \lambda t > x \right\} = P\left\{ A_{plc}(s,t) - A_{plc}(s) > \lambda t + x \right\}
\]

It is hard to calculate the bounding function and the approximation result (Yuming Jiang, 2012) provided gives much simpler bounding function as follows,

\[
P\left\{ A_{plc}(s,s + t) \right\}
\]

\[
e^{-x} \left( t + x \right)^{t + x} \left( t + x \right)
\]

The service time for each packet in the physical layer of acoustic channel is considered to be a fixed values and the stochastic service curve is obtained by,

\[
D_{plc}(s,s + t) = ct
\]

And the loss bound analysis is obtained as,

\[
P\left\{ L(s,s + t) > x \right\} \leq \left( x + ct \right)^t (14)
\]

Simulation And Performance Evaluation:
In this section, we present the performance evaluation of the derived mathematical models using simulations. In order to validate the tightness of the bound, we have simulated using the well-known commercial network simulation software tool OPNET, and compared the results of the simulation with their respective analytical results. The simulation parameters used are mentioned in Table. 1. A simulation setup for analyzing the effects of AWGN Channel fading in an underwater acoustic network is deployed using transmitter and receiver node
Table 1: Simulation Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel Bandwidth</td>
<td>100 kHz</td>
</tr>
<tr>
<td>Transmit Power</td>
<td>5W</td>
</tr>
<tr>
<td>Noise Power Spectral Density</td>
<td>2 DB</td>
</tr>
<tr>
<td>Carrier Frequency</td>
<td>90 kHz</td>
</tr>
<tr>
<td>Node Count</td>
<td>25</td>
</tr>
<tr>
<td>Delay</td>
<td>2s</td>
</tr>
<tr>
<td>Server</td>
<td>2</td>
</tr>
<tr>
<td>Transmission Time</td>
<td>7.75 s</td>
</tr>
<tr>
<td>Transmission Range</td>
<td>100 m</td>
</tr>
<tr>
<td>Packet Size</td>
<td>1024B</td>
</tr>
</tbody>
</table>

Fig. 3 shows the OPNET simulation environment with twenty-five nodes and two servers to monitor the data arrival rate and the service rate among the nodes.

Fig. 3: Simulation Set up

OPNET by default supports wireless radio signal communication. In order to model an acoustic channel, there is a need to modify the coding’s that supports acoustic channel communication. The radio transmitter node attributes and the radio receiver attributes are modified to corresponding acoustic transmitter and acoustic receiver nodes. In order to simulate the acoustic link, modifications should be done in the following stages of the OPNET Transceiver pipeline:

1. Propagation Delay stage
2. Received Power stage
3. Bit error stage
4. Background Noise stage
5. Signal to Noise ratio stage and Channel Match Stage

Fig 4, shows the relationship between the delay bound violation probability and the SNR value.

Fig. 4: SNR vs Delay Bound
It shows that, when there is higher channel capacity, it impacts the violation probability and the violation probability on the delay decreases. This is because, when we increase the code block length and the transmission rate it lowers the violation probability delay bound. Fig 5 explains the amount of traffic received in one the receiver node. The delay bounds with different packet interarrival rate are considered and the delay increases and with respect to the system load increases.

**Fig. 5: Traffic arrival at the Receiver side**

The system is essentially a queuing system as the system load increases it obviously results in worst delay performance.

Fig 6 explains the relationship between the loss factor and the service rate monitored by the server place in the simulation. When the packet size increases, the amount of loss decreases and the corresponding loss factor decreases. The functions fits the curves, which means that two parameters like arrival curve, service curve and packet size are certain, we can adjust the other curve to get the proper value of loss factor that describes the loss bound.

**Fig. 6: Loss factor vs Service rate**

Fig. 7, illustrates the packet delay and loss delay distributions. It shows the simulated results and the analytical theoretical results.
Fig. 7: Numerical Results vs. Simulated Results

From the graph it becomes obvious that the simulation bounds and the analytical bounds are closely matched. This indicates that the physical layer channel coding has significant impact on the data packet delay performance and the loss analysis performance factor. When the channel transmission rate is modified in our simulation results, the significant impact of the code word block length is noticed. From this figure, we can see that all the simulation results are within the bound of the analytical results. The simulation results are verified and the tightness of bounds is found to be good.

Conclusion And Future Work:

In this research work, we have constructed both the analytical modeling and its simulations, to understand the AWGN Channels fading effects in acoustic communication using stochastic network calculus. The analysis method is validated with respective simulations for performance of delay, backlog and loss. The stochastic traffic and service process are incorporated into the acoustic channel characteristics in the physical layer. To the best of author’s knowledge this is first work in introducing loss, delay and backlog for cross layer QoS analysis in acoustic transmission networks. In future, we would enhance the mode with more traffic and service process for more dynamic networks.

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