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Analysis of WAIC QoS Guarantees using Wireless LAN Technology

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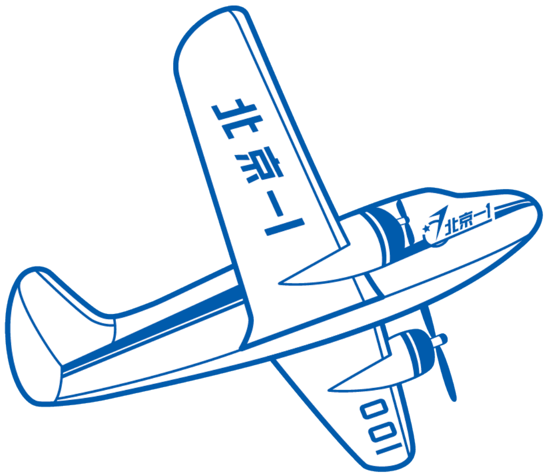
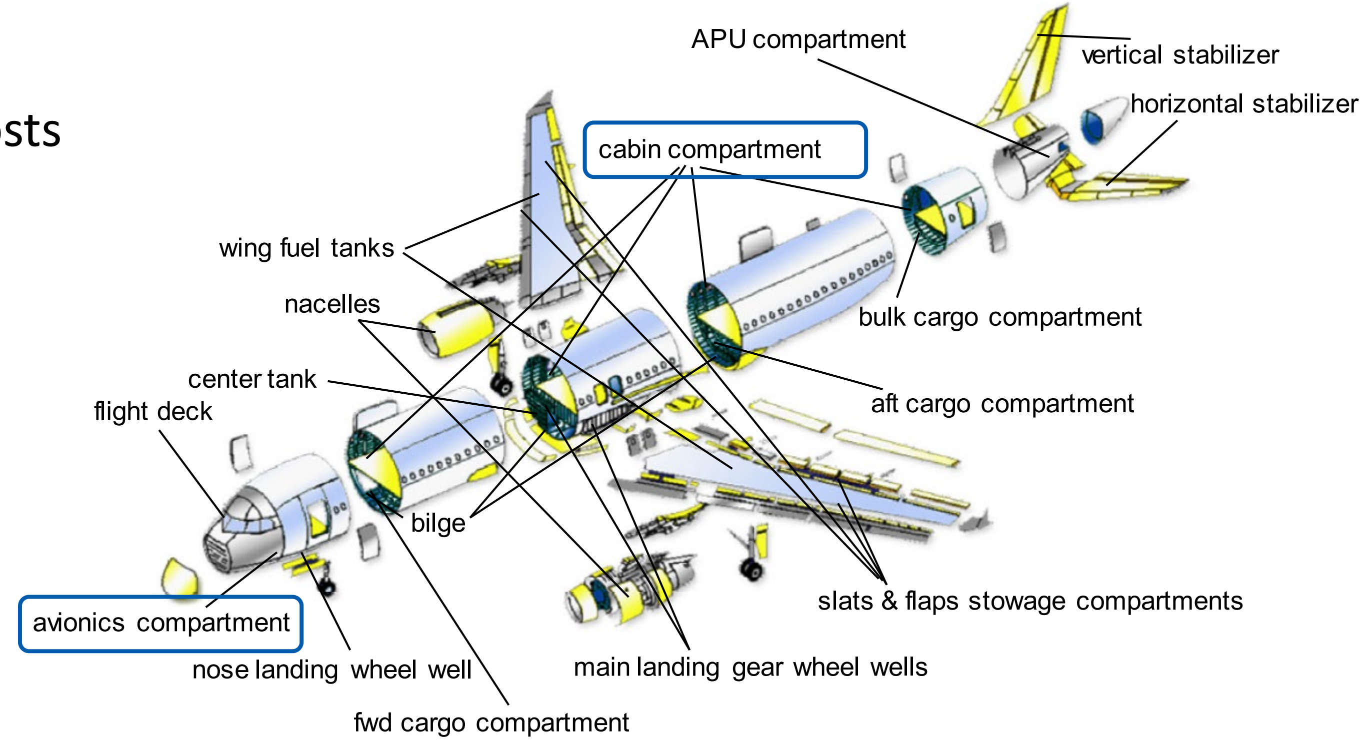


Introduction

Wireless avionics intra-communication(WAIC)

Avionics systems have high requirements for the effectiveness and reliability of communication.

- reduce cable weight and maintenance costs
- aircraft structure health monitoring, sensing, control, voice, video and fieldbus communications
- Communication band: 4.2-4.4GHz



Challenge: provide QoS guarantees such as BER, transmission rate, latency

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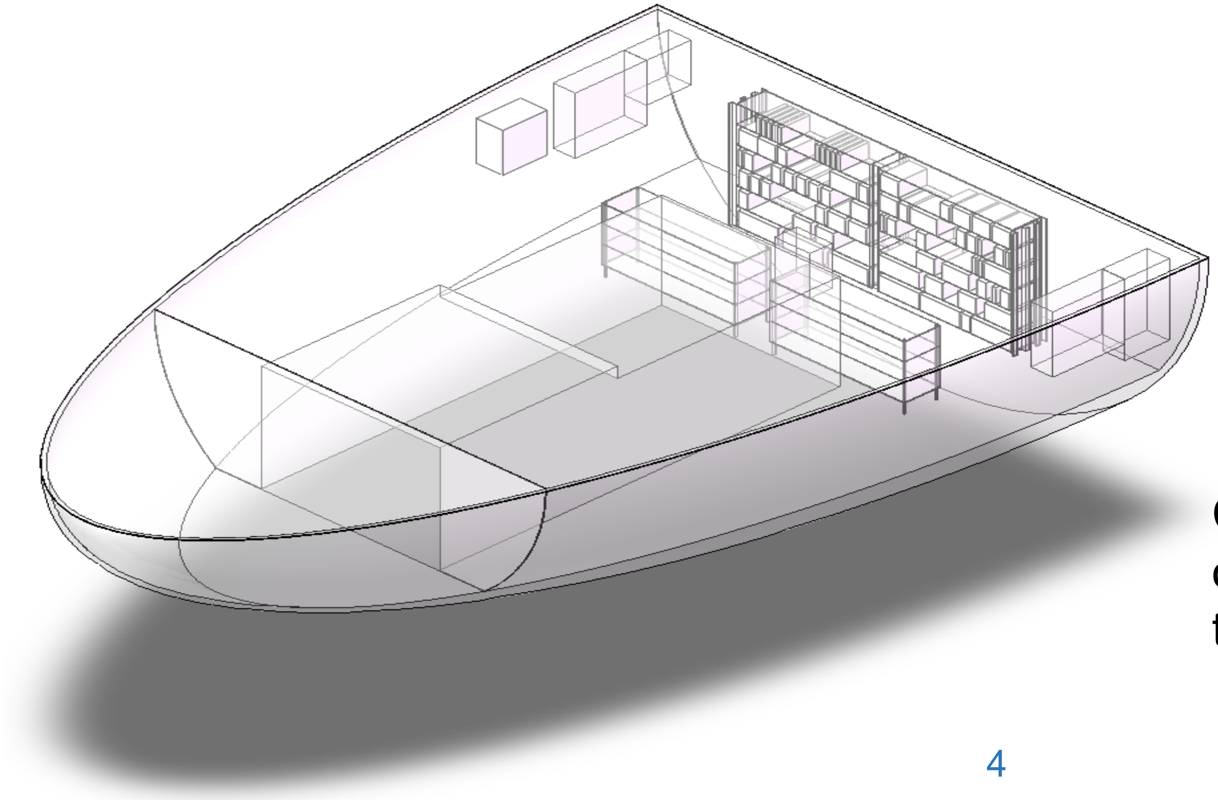
Avionics compartment channel modeling

Raytracing algorithm

- Shooting and bouncing rays (SBR) method
- Image method



$$\tau_{rms} = \sqrt{\frac{1}{P_T}\sum_{i}^{L} P_i \tau_i^2 - \bar{\tau}^2}$$

$$\bar{\tau} = \sqrt{\frac{1}{P_T}\sum_{i}^{L} P_i \tau_i}$$

$$B_{C50} = \frac{1}{5\tau_{rms}}.$$

Coherence bandwidth: the frequency interval over which the channel's complex frequency transfer function has a correlation of at least 0.5

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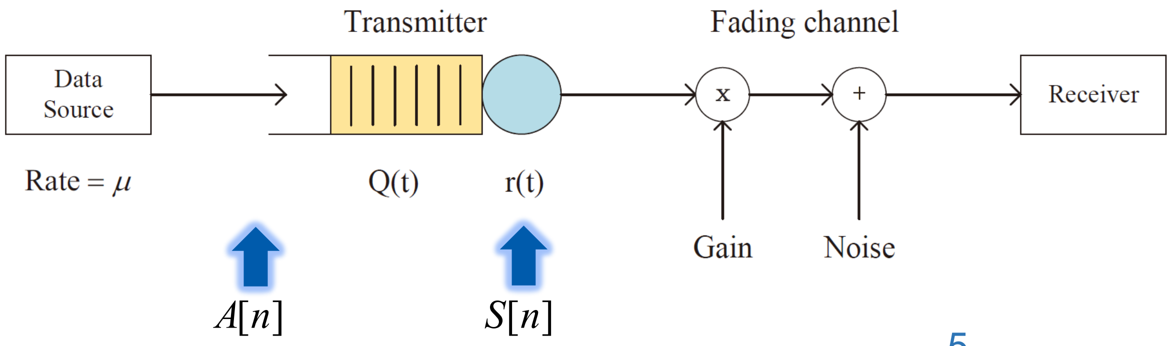
Effective capacity

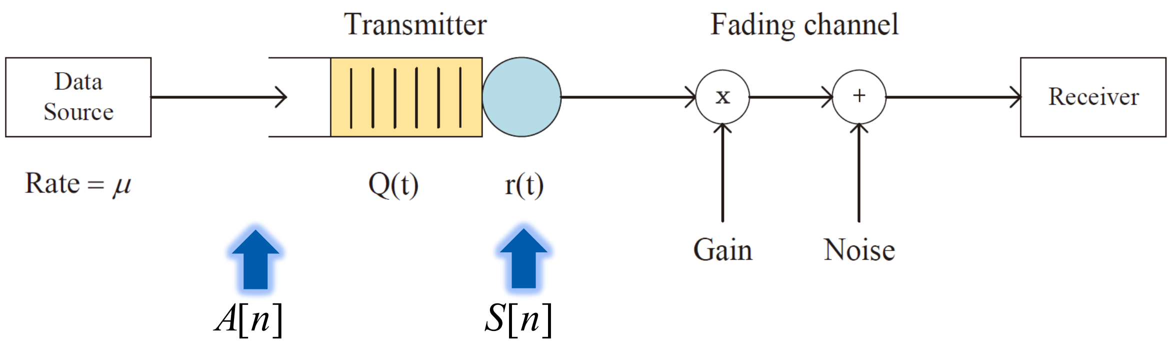
EC model shows the maximum source rate that the channel can handle with the required delay constraint.

Assumptions:

- The model is discrete in time
- The duration of a data frame (one slot) is T_f (equivalent to the length of a fading block)
- The source arrival rate $R[n] = A[n]/T_f$ and the service rate $C[n] = S[n]/T_f$ are independent and identically distributed (IDD) random variables (RVs) in different slots



Effective capacity



$$\Lambda_A(\theta) = \log(\mathbb{E}[exp(\theta A)])$$

$$\Lambda_S(-\theta) = \log(\mathbb{E}[exp(-\theta S)])$$

$$\alpha^{(b)}(\theta) = \frac{\Lambda_A(\theta)}{T_f \theta}$$

the EB of the arrival rate

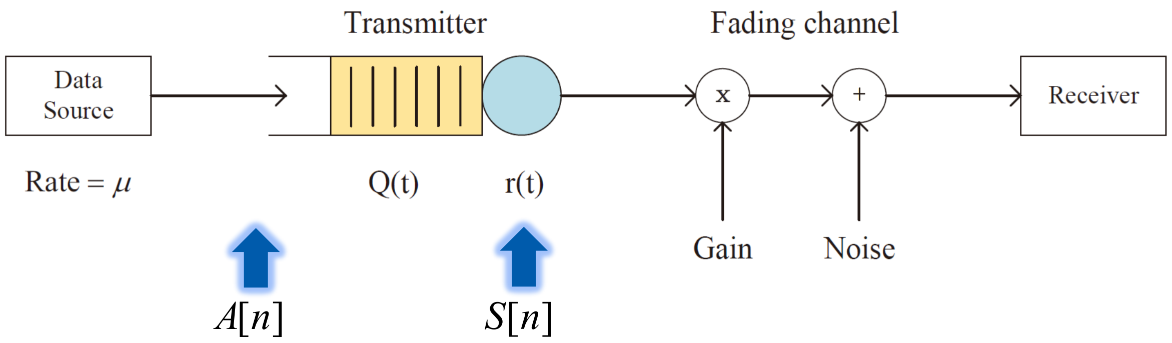
$$\boxed{\alpha^{(c)}(\theta) = -\frac{\Lambda_S(-\theta)}{T_f \theta}}$$

the EC of the service rate

$$\alpha^{(b)}(\theta^*) = \alpha^{(c)}(\theta^*) \Rightarrow \lim_{x\to\infty} \frac{\log(\Pr(Q(\infty) > x))}{x} = -\theta^*$$

A larger value of θ^* represents a faster decay rate, which provides a more stringent QoS guarantee.

Effective capacity



$$\lim_{x\to\infty}\frac{\log(\Pr(Q(\infty)>x))}{x}=-\theta^{*} \Rightarrow \Pr(Q(\infty)>x)\approx e^{-\theta^{*}x}$$

more accurate approximations, the upper bound on the actual value.

- $\Pr(Q(\infty)>x)\approx \Pr(Q(t)>0)e^{-\theta^{*}x}$ **Backlog**
- $\Pr(D[n]>D_{\max})\approx \Pr(Q[n]>0)e^{-\theta^{*}\mu D_{\max}}$ **Delay-violation probability**
- $\Pr(Q[n]>0)\approx \frac{\mathbb{E}[R[n]]}{\mathbb{E}[C[n]]}$ **Non-empty buffer probability**

*The trade-off between QoS guarantees and system throughput should be considered.

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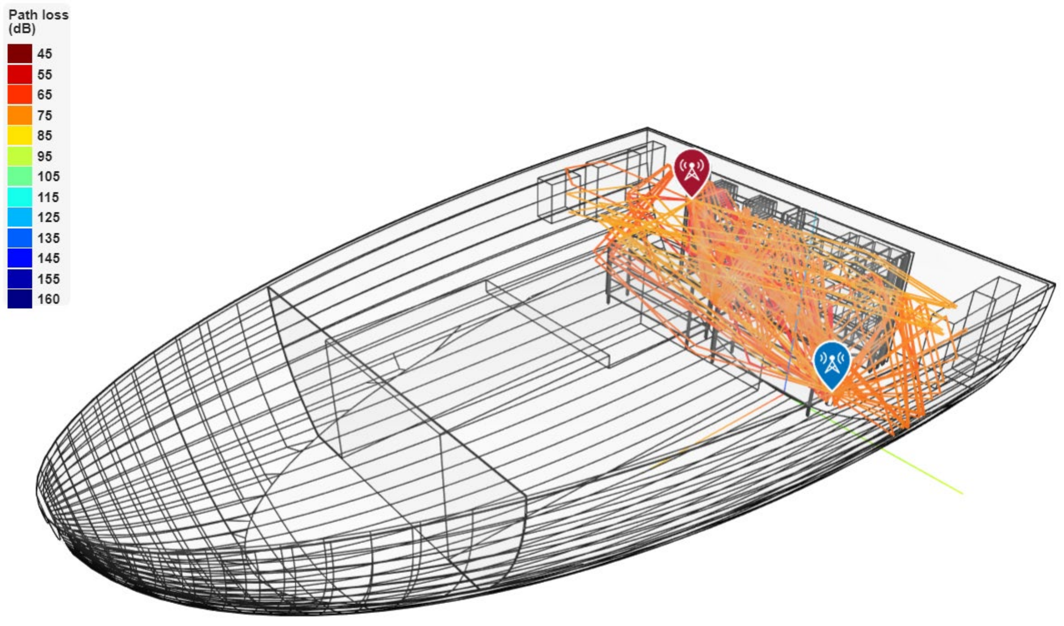
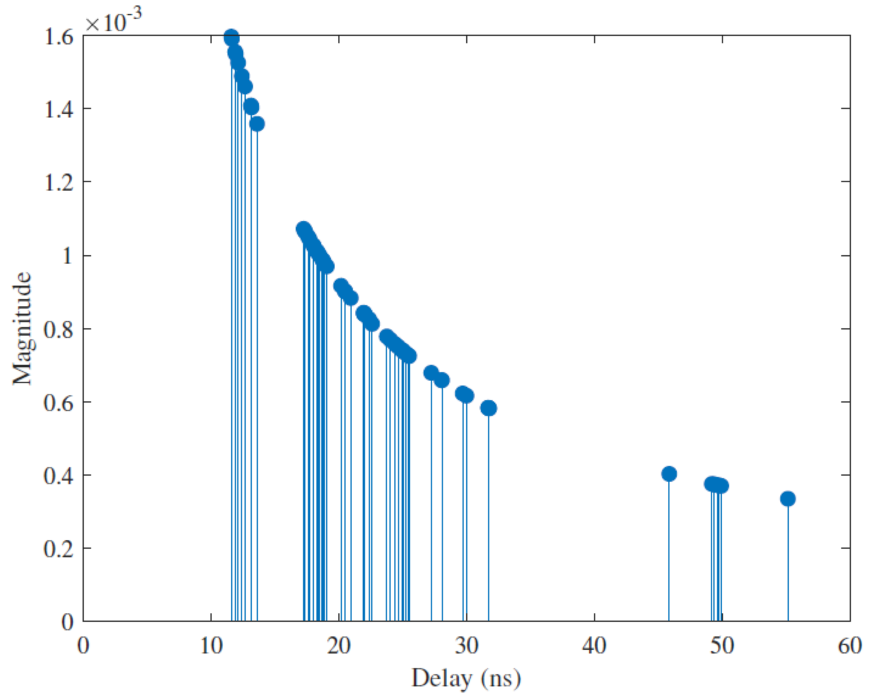
Simulation and analysis

A. Channel Modeling and Fading Distribution Fitting



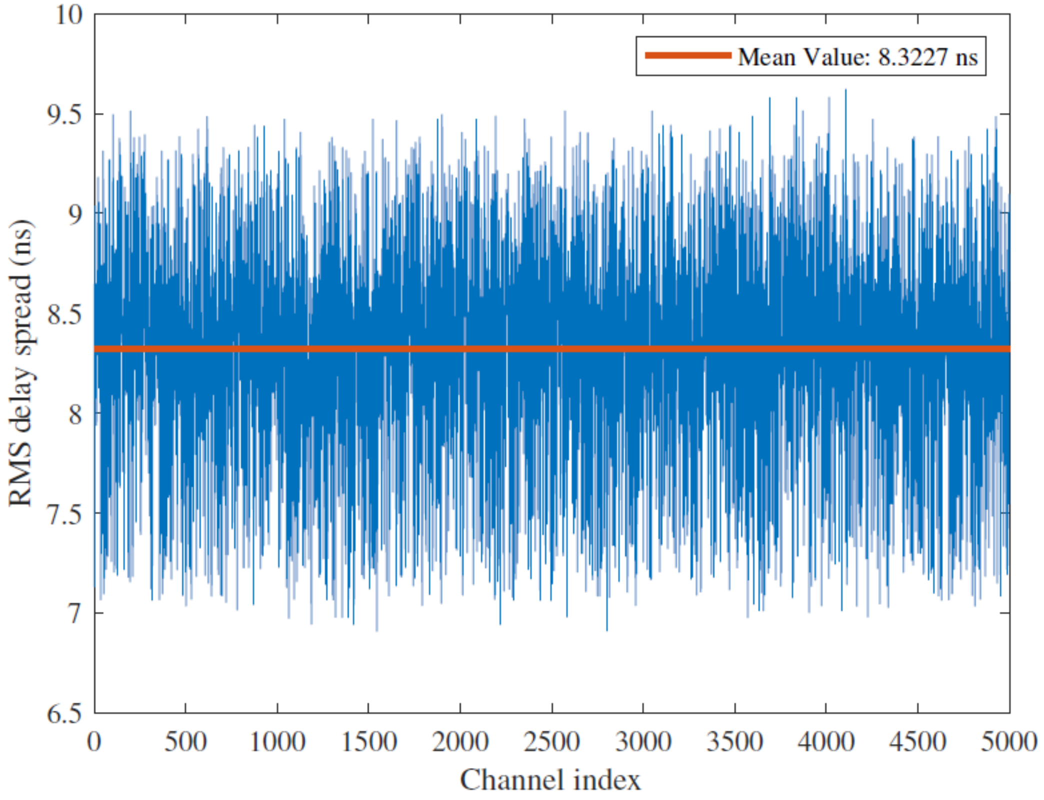
Carrier frequency 4.3GHz



Power delay profile

Simulation and analysis

A. Channel Modeling and Fading Distribution Fitting



5000 simulations to calculate the RMS delay

TABLE I
RAY TRACING ALGORITHM RESULTS

Distance (cm)	RMS delay spread $\overline{\tau_{rms}}$ (ns)	Coherence Bandwidth B_{C50} (MHz)
60	7.0365	28.4232
75	8.3227	24.0307
90	7.3460	27.2257

the basic IEEE 802.11 bandwidth is 20MHz, the avionics compartment channel is a **quasi-static channel** with a weak frequency selectivity.

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Simulation and analysis

A. Channel Modeling and Fading Distribution Fitting

TABLE II
CHANNEL DISTRIBUTION K-S TEST WITH $\alpha = 1\%$

Distribution	p-value
Rayleigh	1.5602×10^{-32}
Nakagami-m	1.5507×10^{-8}
Weibull	0.0013
Rice	**0.0283**

The probability density function (PDF) of the channel gain (Rician) is

$$p(x) = \frac{(1+K)e^{-K}}{\Omega}\exp\left(-\frac{(1+K)x}{\Omega}\right)I_0\left(2\sqrt{\frac{K(K+1)x}{\Omega}}\right)$$

$$K = 1.17212, \Omega = 9.7975 \times 10^{-5}$$

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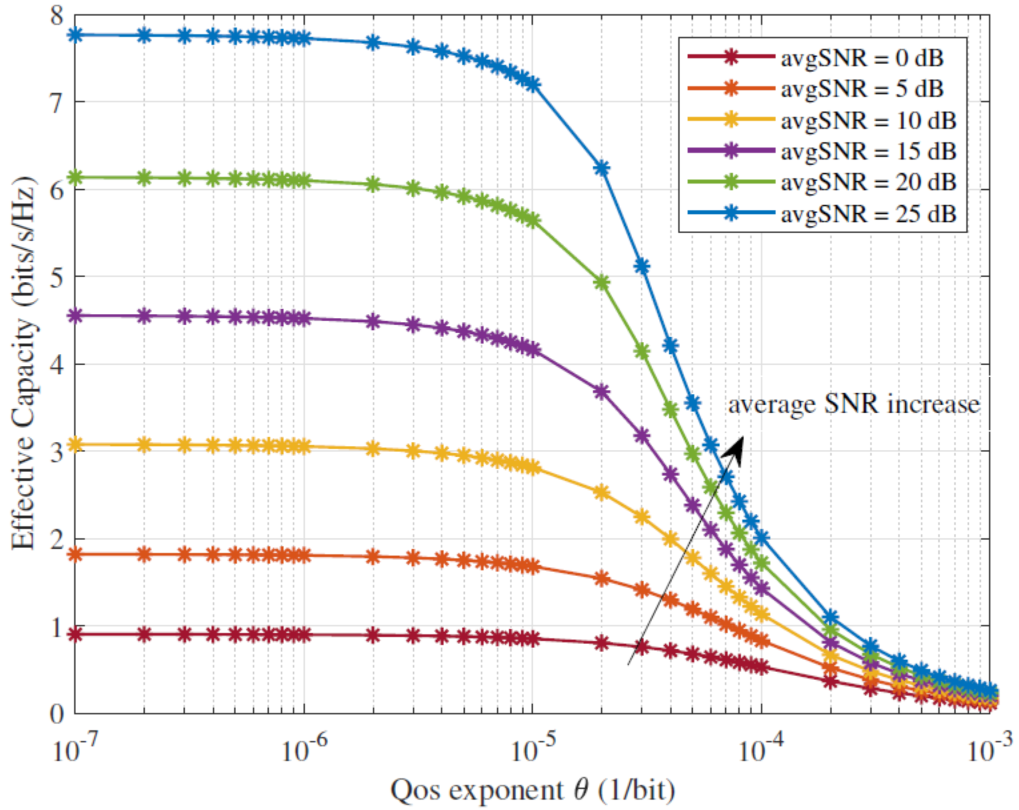
Simulation and analysis

B. Delay-violation Probability Approximation

$$p(x)=\frac{(1+K)e^{-K}}{\Omega}\exp(-\frac{(1+K)x}{\Omega})I_0\left(2\sqrt{\frac{K(K+1)x}{\Omega}}\right)$$

$$\beta=\frac{1}{\theta T_f B} \qquad \rho=\frac{E_S}{N_0}$$

$$\begin{aligned}E_c(\rho,\theta) &= -\frac{\Lambda_S(-\theta)}{\theta T_f B} = -\frac{1}{\beta}\log_2(\mathbb{E}[(1+\rho x)^{-\beta}]) \\ &= \frac{K}{\beta\ln 2}+\log_2(\frac{\Omega\rho}{1+K}) \\ &\quad -\frac{1}{\beta}\log_2\left(\sum_{n=0}^{\infty}\frac{K^n}{\Gamma(n+1)}U(\beta;\beta-n;\frac{1+K}{\Omega\rho})\right)\end{aligned}$$



$$U(\beta;\beta-n;\frac{1+K}{\Omega\rho}) = \frac{1}{\Gamma(n+1)\Gamma(\beta)}G^{2,1}_{1,2}\left(\frac{1+K}{\Omega\rho}\middle|\begin{matrix}1-\beta\\0,n+1-\beta\end{matrix}\right)$$

Simulation and analysis

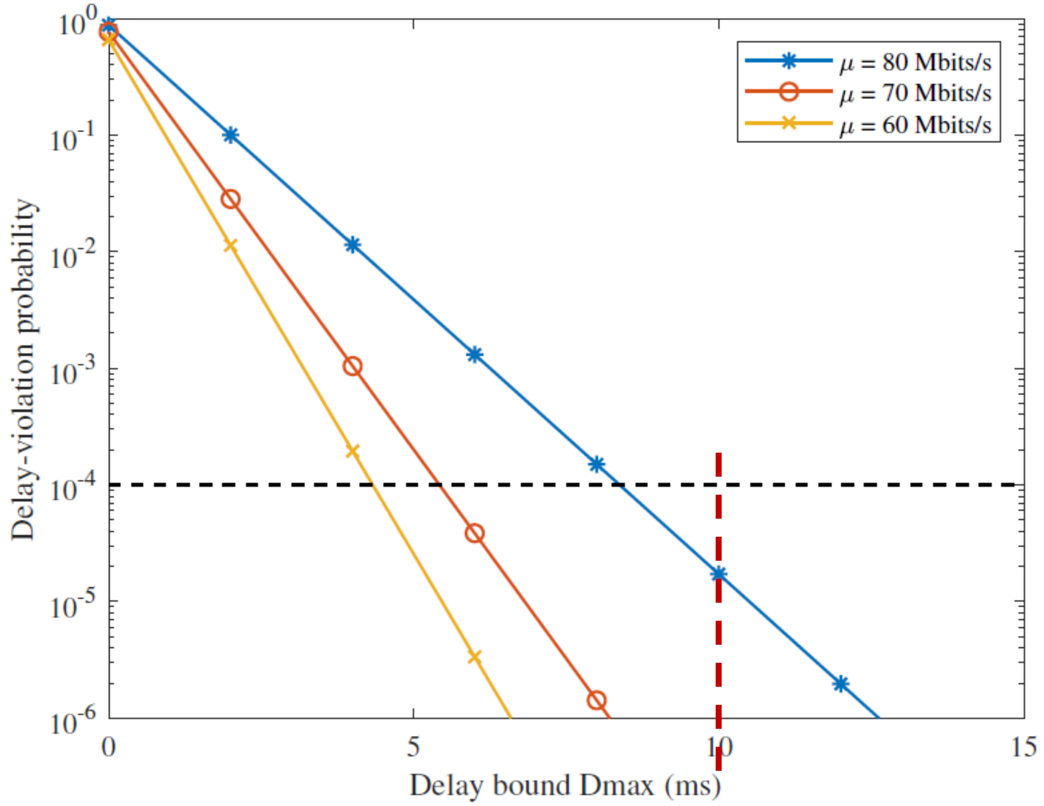
B. Delay-violation Probability Approximation

Solving the non-linear equation $\mu = E_C(\rho, \theta^*)$

$\rho = 15\text{dB}$ constant arrival rate

$$\Pr(D[n] > D_{\max}) \approx \Pr(Q[n] > 0) e^{-\theta^* \mu D_{\max}}$$

$$\Pr(Q[n] > 0) \approx \frac{\mathbb{E}[R[n]]}{\mathbb{E}[C[n]]} = \frac{\mu}{\mathbb{E}[C[n]]}$$



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Conclusion

- We model a kind of avionics compartment channel by ray tracing algorithm, analyse its characteristics by calculating PDP and RMS delay spread, and then get its channel fading distribution by data fitting.

- We use the EC to approximately calculate delay-violation probability under different
constant arrival rates with low computation cost.

- Results show that with a rate-constrained arrival traffic, the theoretical upper bound on queueing delay can be kept within the QoS boundary, coinciding with analytical results.

FUTURE WORK

frequency-selective channel

variable-bit-rate sources

THANKS FOR WATCHING

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