Network Packet Loss Simulation

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Objective

The objective of this project is to simulate network packet loss using a Monte Carlo approach and compare the empirical results with the theoretical expectation of a binomial distribution. This provides insight into probabilistic modeling and the behavior of packet transmission over a lossy network.

Simulation Overview

The core idea is to simulate sending 1000 packets multiple times (experiments), where each packet has a 2% chance of being lost. This loss behavior is modeled using the binomial distribution.

Methodology

The simulation makes use of NumPy's `np.random.binomial` function to generate binomial random variables. Each variable represents the number of lost packets in a single experiment.

Binomial Distribution

For a binomial random variable $X \sim \text{Binomial}(n, p)$:

- n is the number of packets sent per experiment (here 1000)
- p is the probability of packet loss (here 0.02)
- Expected value is $E[X] = np$

Key Components in Code

- **simulate_packet_losses**: Uses `np.random.binomial` to simulate the number of lost packets across experiments.

- **calculate_binomial_expected_value**: Computes the expected loss based on $n \times p$.
- **compute_statistics**: Calculates mean, standard deviation, minimum and maximum of losses.
- **plot_histogram**: Displays the distribution of lost packets with the expected loss as a vertical line.
- **plot_convergence**: Shows how the average loss converges to the expected value as the number of experiments increases.
- **simulate**: Coordinates all the above steps for a single simulation.
- **main**: Runs three simulations with different experiment counts (100, 1000, 10000) to observe convergence behavior.

Simulation Repeats

The simulation was repeated three times with increasing number of experiments to observe convergence:

- 100 experiments
- 1000 experiments
- 10000 experiments

This was done to visualize the effect of sample size on the accuracy of simulation results compared to the expected value.

Results

For each of the three simulations, the following outputs were generated:

- A histogram showing the frequency of lost packets.
- A convergence plot showing the running average of lost packets approaching the expected value.

Visualizations

Note: Each row displays two side-by-side plots: the left shows the histogram of losses, and the right shows the convergence chart.

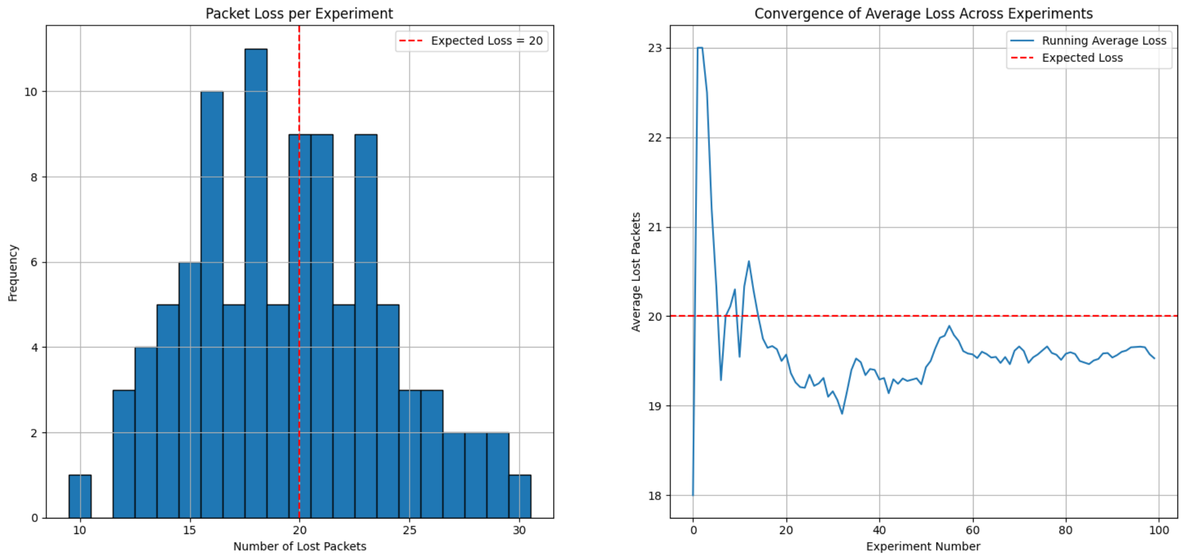

Figure 1: 100 experiments

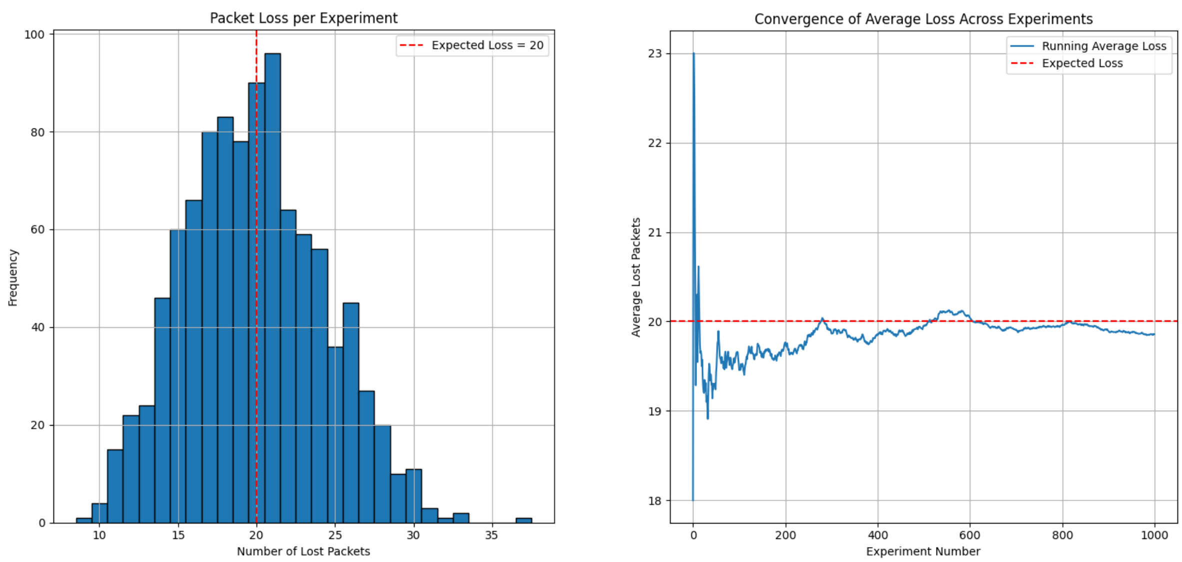

Figure 2: 1000 experiments

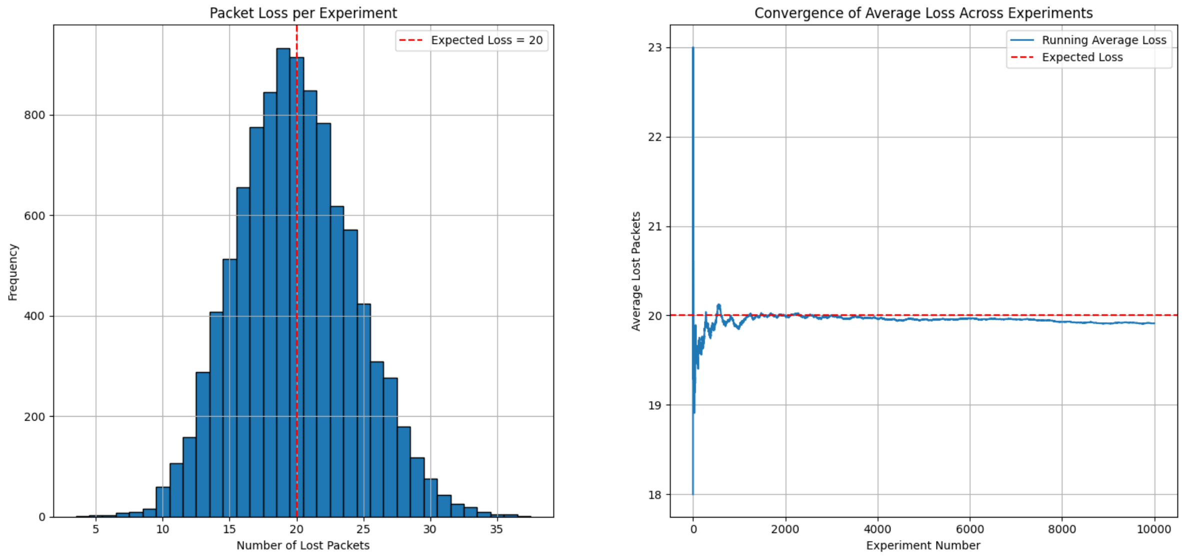

Figure 3: 10000 experiments

Conclusion

This project successfully demonstrated how to simulate a binomial process using random number generation and visualize its statistical properties. As the number of experiments increased, the simulated average packet loss converged closely to the theoretical expected value of 20 packets. This validates the effectiveness of Monte Carlo simulation in approximating probabilistic models.