Simulation of Timely Reliability in Truck Platooning Communication Networks

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Introduction

What's up with truck platooning?

What is Truck Platooning?

Truck platooning is an emerging technology being tested in Europe, Japan, and the USA. It involves multiple trucks automatically following one another at a preset distance, optimizing spacing to reduce drag and improve fuel efficiency by up to 17%.

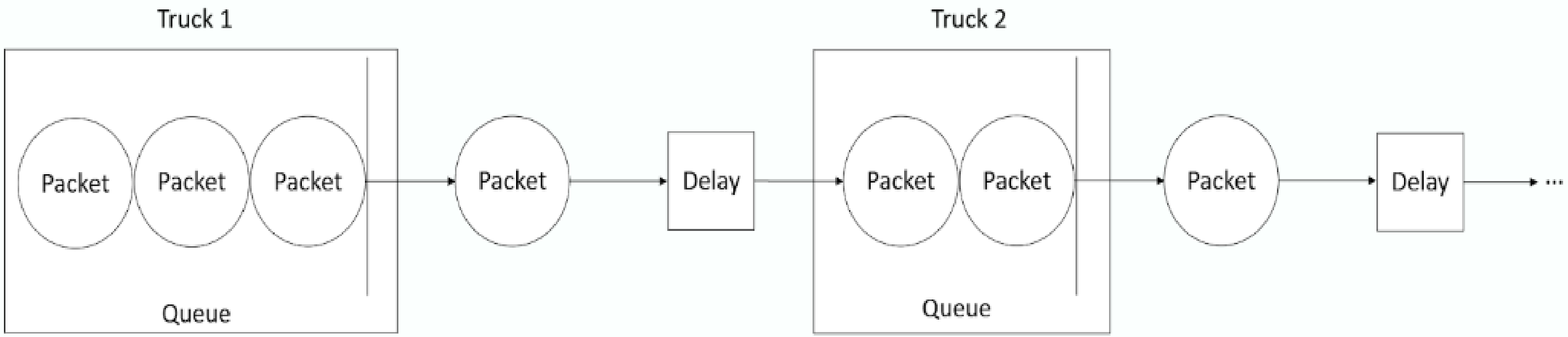
Problem

as data travels sequentially through the platoon, issues like packet loss, queuing delays, and reduced reliability arise, especially as the number of trucks increases.

Solution

Simulate a multi-queue communication network to evaluate and optimize delay reliability through analysis of key influencing factors

Multi-Queue Model



Truck

Act as server nodes that process and forward packets sequentially (FIFO) through their queues

Packet

The entities of the model. Transmitted between trucks through each queue and experience simulation factors such as delays, service times, and potential loss

Delay

Delay is the simulated time incurred during packet transmission between trucks, contributing to overall system time and reliability metrics

Key Factors

Truck Count

The number of trucks in a platoon directly impacts the system's communication reliability and delay

Queue Capacity

The number of packets each truck can hold can influence packet loss and system efficiency

Packet Delays

The time taken for a packet to be processed and transmitted between trucks affects system reliability and latency

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Methodology and Implementation

An overview

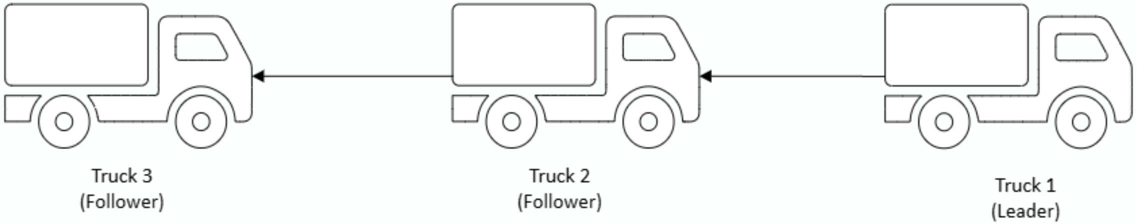
Methodology

- Identify the ideal configuration that balances performance and reliability.
- number of trucks, packet delay, and distance between trucks

Simulation Parameters

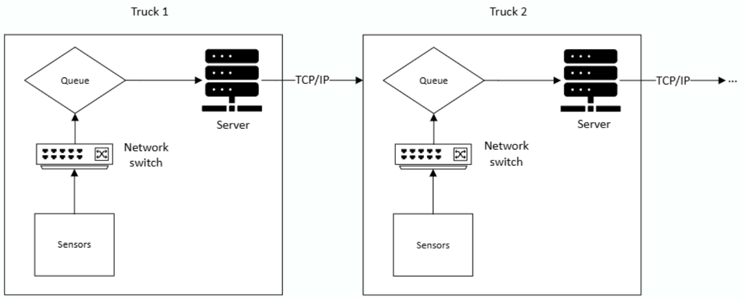
Our project simulation is configured with the initial conditions below:

- **Interarrival Time Rate:** 2800 packets/millisecond (mean arrival rate)
- **Service Time Rate:** 3000 packets/millisecond (mean processing rate)
- **Maximum Queue Length:** 50 packets
- **Packet Delay:** 0.03 milliseconds (constant per truck)
- **Trials:** 100 independent trials per truck configuration



Simulation Overview

- Entities:
  - Packet
- Server: Truck
- List: FIFO queue for packets
- Events:
  - Arrival: Packet enters the truck or is dropped
  - Departure: Packet processed and removed from truck
- Activity: Truck packet processing time
- Delay: Packet wait time in the queue.



- FIFO Queue: Each truck processes packets FIFO
- Queue Overflow Handling: When the number of packets exceeds the truck's queue capacity (50 packets), additional packets are dropped from the queue
- Time Constraints: Packets that exceed the maximum allowable processing or transmission time are also dropped, representing failures due to latency.

Calculating Reliability

- The primary metric used is delay reliability
- Is the proportion of packets that have a waiting time longer than the specified time threshold
- For our project we calculate the delay reliability as follows:
    - Rs = (Packets successfully processed/Total packets) * (0.999)^n * (0.999)^n-1

Where n is the number of trucks. This helps account for packet loss caused due to delays or queue overflows

- Gives an accurate framework for analyzing the reliability of multi-truck communication networks

03

Analysis

The Simulation

15 Trucks

10,000 Packets

100 Replications

$\bar{X} = 0.46035$

$S = 0.001891978$

$N = 1{,}000{,}000$

Average and Standard Deviations of simulation

	Average	Standard Deviation
Percent of packets that reach the final truck	97.1%	0.001892%
Time required to reach final truck	$0.46ms$	$1.34E-15ms$

The percentage of packets the reach the final truck can easily be determined from the constant switch and router reliability, and the extremely low standard deviations show how consistently these results appear.

What does this mean?

Prediction Interval

99% [0.4555,0.4652]

Confidence Interval

99% [0.46035, 0.46036]

- Consistent Packet Reliability
- Little Variance in Reliability
- The bulk of the delay is caused by the switch, so the system doesn't experience packet loss at the router.

Continuous Time Dynamic System

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\end{bmatrix} = \begin{bmatrix}0 & 0 & 0\\ 1 & -1 & 0\\ 0 & 1 & -1\end{bmatrix}\begin{bmatrix}x_1\\ x_2\\ x_3\end{bmatrix} + \begin{bmatrix}1\\ 0\\ 0\end{bmatrix}u$$

$$\begin{bmatrix}\dot{x}_2\\ \dot{x}_3\end{bmatrix} = \begin{bmatrix}-1 & 0\\ 1 & -1\end{bmatrix}\begin{bmatrix}x_2\\ x_3\end{bmatrix} + \begin{bmatrix}1\\ 0\end{bmatrix}x_1$$

$$\begin{bmatrix}\dot{x}\\ \ddot{x}\end{bmatrix} = \begin{bmatrix}0 & I\\ -L_f & -L_f\end{bmatrix}\begin{bmatrix}x\\ \dot{x}\end{bmatrix} + \begin{bmatrix}1\\ 0\end{bmatrix}u$$

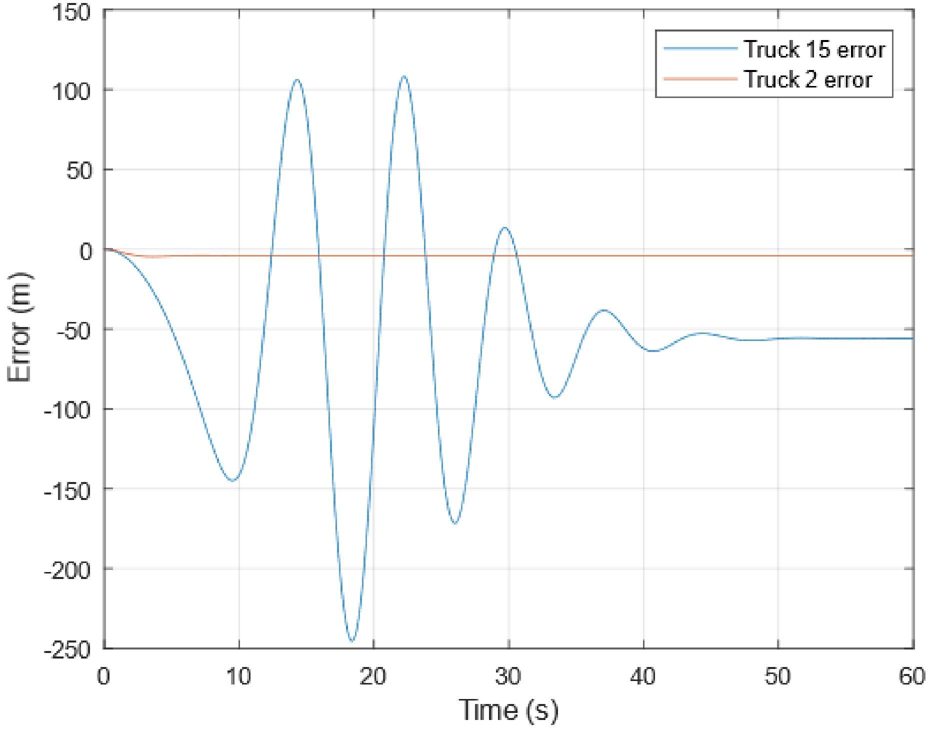
$$L_f = -\begin{bmatrix}0 & 0\\ I_{n-1} & 0\end{bmatrix} + I_n$$

$$y = Cx + D$$

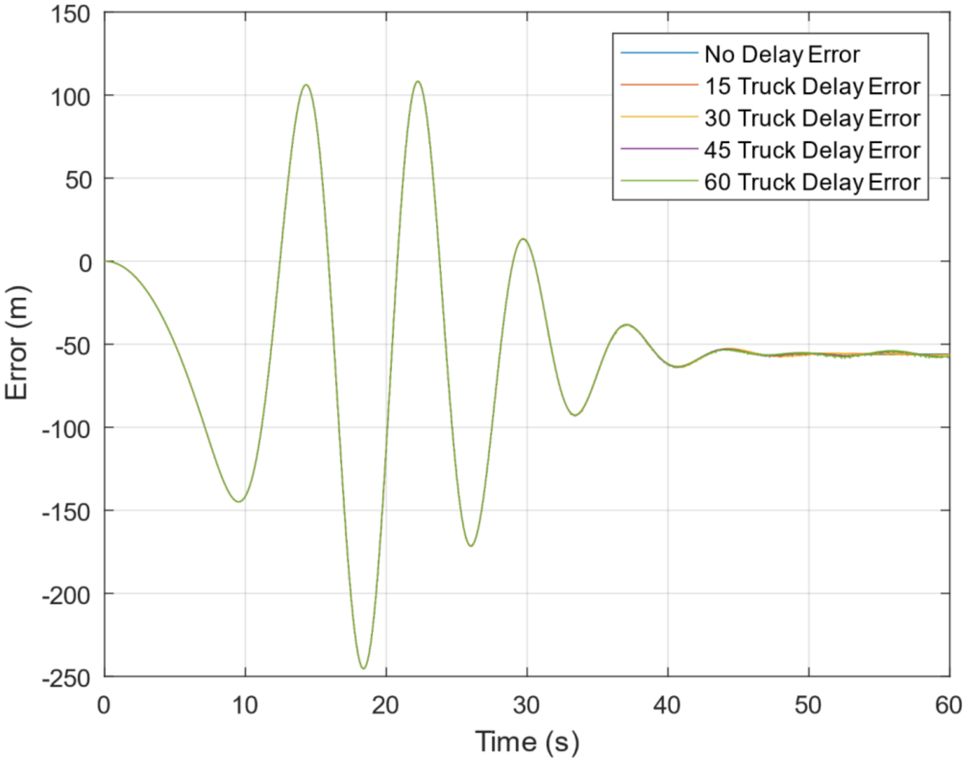
Response Analysed as System Error

System error is the difference between the output and the input

Truck 15s odd shape is due to how far it is from the input in the path.

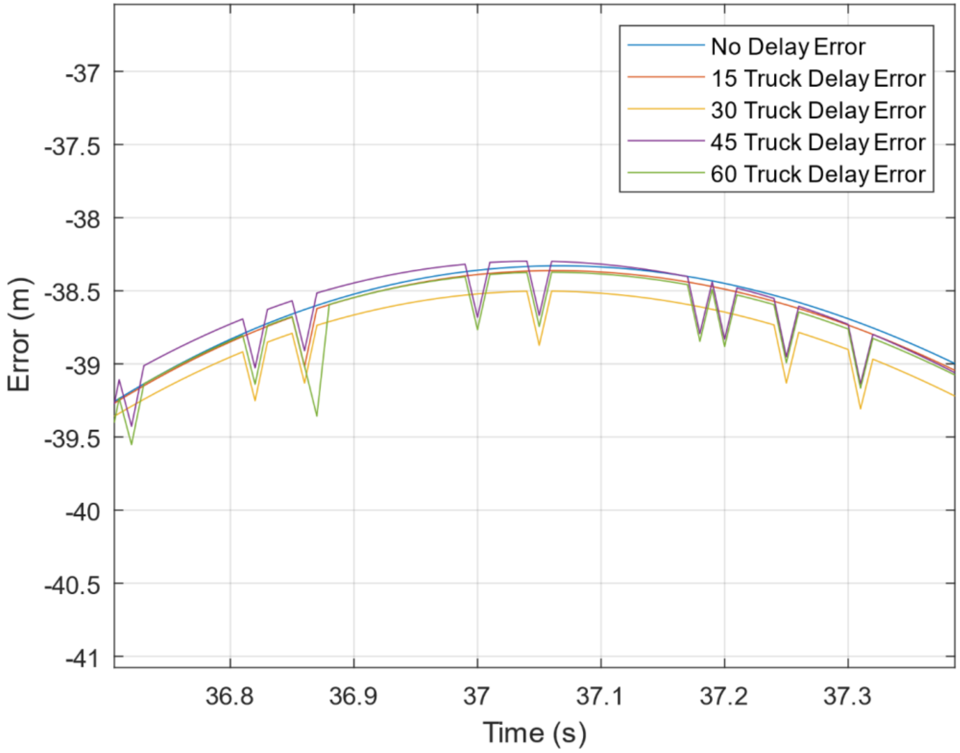


Delay and Packet Loss Error Comparison



NO NOTICEABLE DIFFERENCE BETWEEN ERRORS!

Small Response Differences



- Each tick in the response represents a lost packet
- The error differences are seemingly random

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Conclusion

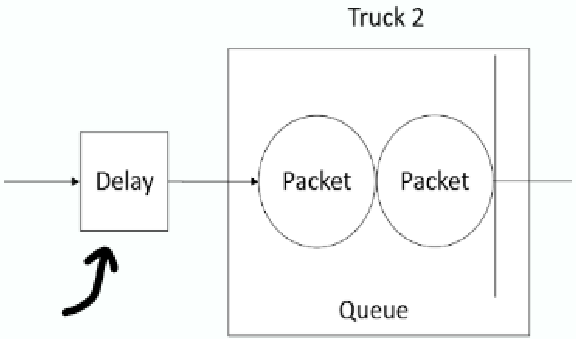
What our results tell us

Our system showed

Low standard Deviation

Small Prediction and Confidence intervals

Error was consistent no matter the number of trucks



- Switch delay caused almost all packet loss
- Tells us that packets lost due to queueing was negligible
- Queue capacities and FIFO (first-in-first-out) queue discipline prevent overwhelming packet drops
- The linear relationship between truck numbers and delay aligns closely with theoretical expectations

What this means

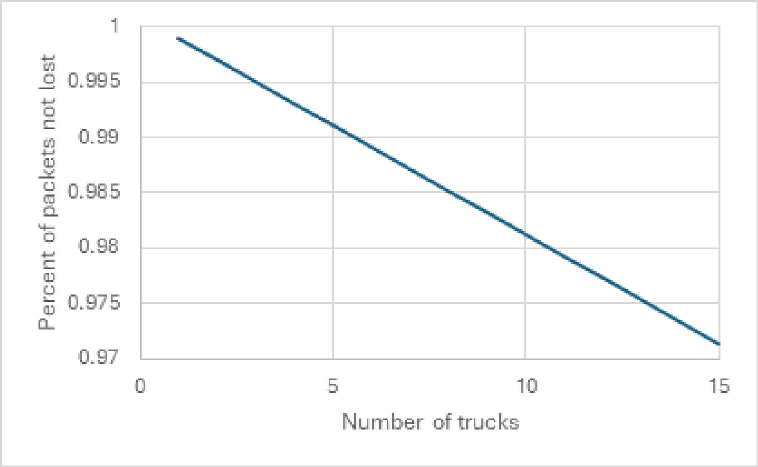


Fig 6. Relationship between the packets that were not lost, and the number of trucks

Predictable Packet Loss

The amount of packets that successfully reach the final truck is almost directly correlated to the number of trucks in the system with very minimal variation.

Robustness

Despite increases in delays and packet loss with platoon size, the system remains reliable under optimized conditions. The router's ability to process packets faster than they arrive contributes to overall system stability.

Final Thoughts

- The simulation confirmed that the multi-queue model is effective for analyzing communication in truck platooning systems
- Although uninteresting, the analysis shows that there are minimal risks associated with packet loss due to queueing
- Supported by both theoretical and simulated predictions
- Results support using larger platoons in real-world applications without compromising safety or performance, provided queues are properly configured

Future Works

Further research into the subject involving challenging scenarios such as varying network conditions, non-uniform truck spacing, or external disturbances

Provide a pathway for advancing truck platooning as a sustainable, efficient solution for long-haul transportation.

Grant Colwell, is conducting his research paper on communication systems within truck platooning and plans to pursue further studies on the subject

Shift focus to routing and its affect in communications