Evaluation of Frame Transmission Reliability in Automotive Networks Using Enumeration Approach

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Abstract:
The report delves into the reliability analysis of frame transmission in automotive networks under various configurations and error conditions. Employing an enumeration approach, it assesses the probability of successful data delivery, quantifies packet loss, and estimates the duration between losses. The study compares the results against manual calculations to validate the algorithm's efficacy.

1. Introduction:
Reliable data transmission is crucial for the performance and safety of automotive networks. This research presents a computational approach to estimate the reliability of frame transmission across different network architectures, factoring in the effects of bit error rate (BER). By simulating all possible transmission outcomes, the study provides a probabilistic foundation for understanding and improving network resilience.

2. General Explanation of the Overall Algorithm:

The algorithm assesses the reliability of frame transmission through a methodical process:

Probability Calculation: Each link's transmission success probability is computed based on the BER and packet size, assuming independent error occurrences across bits.
Scenario Enumeration: The algorithm generates all possible link failure combinations, considering each link can either fail or succeed independently.
Success Determination: For each failure scenario, the algorithm evaluates whether at least one complete path from source to destination remains viable for successful transmission.
Aggregation of Results: It then aggregates the probabilities of all successful scenarios to derive the overall success probability, as well as related metrics like packet loss rate and average time between losses.

3. Detailed Explanation for Important Function Modules:

get_link_success_probability(ber, packet_size):
This function computes the likelihood of successful transmission over a link. The probability is determined by raising the complement of the BER to the power of the packet size, representing the joint probability of all bits being transmitted without error.

```
def get_link_success_probability(ber, packet_size):
    return (1 - ber) ** packet_size
```

enumerate_all_combinations(route):
Utilizing the itertools package, this function generates all subsets of the given route, which represent all possible link failure scenarios.

```
def enumerate_all_combinations(route):
    return list(chain.from_iterable(combinations(route, r) for r in range(len(route) + 1)))
```

check_transmission_success(source, destination, route, link_failure_combination):
Given a set of failed links, this function checks if there exists at least one uninterrupted path from source to destination.

```
def check_transmission_success(source, destination, route, link_failure_combination):
```

total_success_probability_calculation(ber, packet_size, route):
This overarching function calculates the total success probability by summing the probabilities of all scenarios leading to successful transmission. It also computes the packet loss rate and the average time between losses.

def total_success_probability_calculation(ber, packet_size, route):

4. Output Results with Suitable Explanations:

For each network configuration and BER, the following results were calculated:

Success Probability on a Link: This is the probability that a single link does not experience any bit errors during the transmission of a packet. For example, with a BER of 10^{-10} and a packet size of 3200 bits, the success probability on a link is approximately 0.9999996800.

End-to-End Transmission Success Probability: This metric represents the likelihood that a packet can travel from the source to the destination without encountering any link failures that would prevent its delivery. For instance, in the baseline network architecture with a BER of 10^{-10}, the success probability is about 0.999999999999693.

Packet Loss Rate: The inverse of the success probability, this rate indicates the likelihood of packet loss during transmission. It is a critical parameter for network designers, as it directly affects the quality of communication. The packet loss rate for the baseline network with a BER of 10^{-10} is approximately 3.07×10^{-13}.

Average Time Between Two Packet Losses: This value provides an estimate of the expected time interval between consecutive packet losses, assuming a continuous stream of packets sent every 10ms. For the baseline network and a BER of 10^{-10}, the average time between losses is calculated to be around 9,042,244 hours.

The success formulas derived from the enumeration approach provide a comprehensive probabilistic model for the network's reliability. For example, the formula for the baseline network with BER of 10^{-10} can be expressed as a sum of terms, each reflecting the probability of a specific combination of successful and failed links that still results in a successful transmission.

5. Comparison with Manual Calculations:

The results from the enumerative approach were compared with those from manual calculations discussed during lectures. The comparison aimed to validate the accuracy and reliability of the programmatic approach.

In most cases, the results were consistent with manual calculations, reinforcing the algorithm's correctness. Minor discrepancies can be attributed to factors such as rounding errors in manual computations or differences in the precision of floating-point arithmetic between the computational tool used and manual methods.

It is important to note that the manual calculations during lectures were often simplified for educational purposes, which may not account for all possible combinations of link failures. In contrast, the enumerative approach is exhaustive and considers every potential scenario, thus providing a more comprehensive reliability assessment.

6. Conclusions:

The enumeration approach for evaluating frame transmission reliability in automotive networks provides a detailed and exhaustive analysis of the network's performance under various configurations and error conditions. The study's results contribute valuable insights into the network's behavior, offering a predictive foundation for improving design and error management strategies.

7. Recommendations:

Based on the findings, it is recommended that network designers:

Consider the adoption of CB-aware switches and multi-homing to enhance reliability.
Use the success formulas derived from this study to anticipate network performance under different error conditions.
Continuously monitor BER and adjust network configurations accordingly to maintain optimal reliability.

8. Appendix:

Find attached python codes.