Adaptive-Link Dynamic FEC and Penalty Tuning Guide

1. Overview

The script uses a Kalman filter to smooth the estimated noise level derived from the error ratio of packet losses and FEC (Forward Error Correction) recoveries. This filtered noise level is then used to adjust the link's performance score and trigger FEC changes if needed. Tuning these parameters helps in striking a balance between responsiveness and stability in noisy environments.

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2. Kalman Filter Tuning

The Kalman filter in this script is used to update the noise estimate based on incoming measurements. It relies on four key parameters:

- **kalman_estimate**:
  The current estimate of the noise level.
  Tuning Tip: Start with a realistic initial estimate. If the system is very stable, a lower initial value may be preferred. If measurements are expected to be high or volatile, consider a slightly higher starting point.

- **kalman_error_estimate**:
  The uncertainty associated with the current noise estimate.
  Tuning Tip: A smaller error estimate makes the filter trust its current estimate more, while a larger error value makes it more receptive to new measurements. If you see abrupt changes in your noise reading, increasing this value may help smooth the output.

- **process_variance**:
  Represents the expected variability in the noise level over time (i.e., how much the true noise might change from one measurement to the next).
  Tuning Tip:

  - **Lower Process Variance:** Leads to a more stable (less responsive) filter; useful in stable environments.

  - **Higher Process Variance:** Makes the filter adapt faster to changes; beneficial in highly dynamic conditions.
    Recommendation: Start with a small value (e.g., 1e-5) and adjust if the filter appears too sluggish or too reactive.

- **measurement_variance**:
  Captures the expected error or noise in the measurements themselves.
  Tuning Tip:

  - **Lower Measurement Variance:** Increases the filter's reliance on new measurements, making the estimate more responsive but potentially more jittery.

- **Higher Measurement Variance:** Causes the filter to smooth out changes more aggressively, which is beneficial if the measurements are noisy.
  Recommendation: Begin with a moderate value (e.g., 0.01) and fine-tune based on how reliable and consistent your measurements are.

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3. Noise Level Settings Tuning

These settings determine how the raw noise measurement is interpreted and applied to adjust the final link performance score and FEC behavior.

- **min_noise & max_noise**:
  Define the lower and upper thresholds for the noise level.
  - **min_noise:**
    - Below this threshold, no penalty is applied.
    - **Tuning Tip:** If you are observing penalties even in seemingly good conditions, consider lowering this threshold.
  - **max_noise:**
    - Above this threshold, the maximum penalty (or full FEC change) is applied.
    - **Tuning Tip:** In very noisy environments, you may wish to increase this value to avoid over-penalizing minor fluctuations.
- **deduction_exponent**:
  Controls the nonlinearity of the penalty deduction ratio.
  Tuning Tip:
  - A higher exponent will make the penalty increase more steeply once the noise exceeds min_noise.
  - A lower exponent will provide a more gradual increase.
    Recommendation: Adjust this parameter based on how aggressively you want to penalize noise once it rises above the minimum threshold.
- **min_noise_for_fec_change & noise_for_max_fec_change**:
  Define the range over which the FEC change logic operates.
  - **min_noise_for_fec_change:**
    - Below this value, no increase in FEC is triggered.
  - **noise_for_max_fec_change:**
    - At or above this level, the maximum FEC change (e.g., a change value of 5) is triggered. **Tuning Tip:**
  - If you are not observing timely FEC adjustments in the face of rising noise, you might lower the min_noise_for_fec_change or adjust the ratio between the two values.

- Conversely, if FEC changes are too aggressive, increase these thresholds to require higher noise levels before making changes.

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4. Tuning Guidelines & Best Practices

A. Testing and Monitoring

- **Establish a Baseline:**
  Record the current performance under typical conditions before making changes.
- **Gradual Adjustments:**
  Change one parameter at a time and monitor its effect. This helps in isolating the impact of each change.
- **Real-World Scenarios:**
  Test under various link conditions (stable, dynamic, intermittent noise) to ensure your settings are robust across different environments.

B. Balancing Responsiveness and Stability

- **Kalman Filter Sensitivity:**
  - For environments where the noise level changes rapidly, increase the process variance and decrease the measurement variance.
  - In more stable conditions, decrease the process variance to prevent the filter from overreacting to transient spikes.
- **Penalty and FEC Adjustments:**
  - If you notice frequent fluctuations in the link score, consider raising min_noise or increasing the deduction_exponent to avoid over-penalizing minor variations.
  - For FEC changes, ensure that the thresholds (min_noise_for_fec_change and noise_for_max_fec_change) are aligned with the observed noise behavior during peak times.

C. Environmental and Use-Case Considerations

- **Consistent Link Quality:**
  If your environment is typically quiet with low interference, you may favor settings that prevent unnecessary FEC changes.
- **Highly Variable Conditions:**
  In scenarios where interference is common, a more aggressive FEC change mechanism (lower min_noise_for_fec_change and/or a steeper deduction exponent) may improve performance by quickly adapting to deteriorating conditions.

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5. Example Tuning Process

1. **Initial Setup:**
   Use the default configuration values and run the system to gather baseline performance metrics.
2. **Data Collection:**
   Log the filtered noise ratio, final link score, and FEC changes over time.
3. **Adjust Kalman Filter Parameters:**
   - If the filtered noise is lagging behind rapid changes, consider increasing the process_variance or lowering the measurement_variance.
   - Conversely, if the filter is too jumpy, lower the process_variance or raise the measurement_variance.
4. **Refine Noise Thresholds:**
   - If penalties are applied too frequently, raise the min_noise value slightly.
   - If penalties or FEC changes occur too late during increased noise conditions, lower the corresponding thresholds.
5. **Iterate:**
   Continue testing under different scenarios and fine-tune parameters until a satisfactory balance between responsiveness and stability is achieved.

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6. Conclusion

Tuning the Kalman filter and noise level settings is a balancing act between quickly reacting to genuine changes in link quality and avoiding overreaction to transient noise spikes. By carefully adjusting the process and measurement variances, along with setting appropriate noise thresholds and penalty exponents, you can optimize the system for both stable and dynamic operating conditions. Regular monitoring and incremental adjustments based on real-world performance data are key to achieving optimal performance.

This guide should serve as a comprehensive starting point to help you fine-tune your configuration settings for improved link reliability and performance.