Dynamic Analysis for OpenThread Network Interoperability Testing Using Zephyr in Docker

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1. Introduction and Project Explanation

The increasing adoption of the **Thread networking protocol** in IoT applications highlights the importance of **interoperability testing** to ensure seamless communication between heterogeneous devices. This project aims to **evaluate OpenThread's network interoperability** using **Zephyr OS in Docker with QEMU**, enabling a **multi-node wireless sensor network (WSN) simulation**.

By leveraging **Dockerized Zephyr OpenThread nodes**, we will analyze network behavior across **different architectures (ARM, x86)**, study **IPv6 and RPL routing**, and assess **latency and reliability differences between platforms**. The objective is to ensure OpenThread **operates efficiently across diverse IoT environments**.

Expected Outcomes

- A **Docker-based Zephyr OpenThread network** simulating real-world IoT deployments.
- Identification of **network performance and reliability differences across multiple architectures**.
- Analysis of **OpenThread's IPv6, 6LoWPAN, and RPL protocol interactions**.
- **Recommendations for optimizing OpenThread's interoperability** in multi-platform IoT applications.

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2. Description of Work to Be Carried Out

The project will be structured into three main phases:

Phase 1: Setting Up Zephyr OpenThread in Docker

- Deploy **Zephyr-based OpenThread nodes** in a **Dockerized QEMU environment**.
- Configure **multi-node communication** (Router, End Device, Border Router) within the simulated network.
- Establish **IPv6 routing with 6LoWPAN compression** over OpenThread.

Phase 2: Network Interoperability Testing

- **Multi-Node Communication:**
  - Ensure seamless **IPv6 data exchange between OpenThread devices**.
  - Validate **RPL (Routing Protocol for Low-power networks)** in a dynamic multi-node environment.
- **Cross-Platform Performance Evaluation:**
  - Test OpenThread nodes on **ARM (MPS2-AN521, STM32F7) and x86 (UP Squared Board)**.
  - Measure **latency, packet loss, and routing efficiency across different architectures**.

Phase 3: Analyzing and Reporting Interoperability Results

- Capture and analyze network traffic using:
  - **`tcpdump` for packet capture** at the network level.
  - **Zephyr logging (`net_pkt`, shell, `net_capture`)** for in-depth OpenThread debugging inside Zephyr OS.
- Identify **potential bottlenecks in OpenThread routing and IPv6 communication**.
- Generate a **report on OpenThread's multi-node performance, scalability, and reliability**.

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3. Resources Needed

Software:

- **Zephyr OS (with OpenThread support)**
- **Docker** (for containerized testing)
- **QEMU** (for multi-architecture emulation)
- **tcpdump & Zephyr Logging (`net_pkt`, shell, `net_capture`)** (for network analysis)

Hardware (Emulated & Physical Devices):

- No dedicated hardware required for initial testing (**fully virtualized using Docker & QEMU**).
- **STM32F7 Series** → *(End Device, Router, Commissioner)*
- **MPS2-AN521** → *(Router, Leader, End Device)*
- **UP Squared Board** → *(Ideal for Border Router)*

Custom Dataset

This project will generate and use a **custom dataset**, which will include: - **Packet captures from `tcpdump`**, focusing on **IPv6, 6LoWPAN, and OpenThread control messages**. - **Zephyr OpenThread logs** from **`net_pkt`, shell debugging, and `net_capture`**. - **Interoperability test results** across **different architectures (ARM, x86)**, recording **latency, throughput, and error rates**. - **Routing behavior data** (RPL topology changes, leader elections, and network healing after failures). - **Performance benchmarks** comparing **OpenThread communication reliability on different hardware architectures**.

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4. Value of the Project

Relevance to IoT & Research

- **Ensures OpenThread interoperability across ARM and x86 architectures**, which is critical for IoT scalability.
- Provides insights into **network reliability and performance variations** in **multi-platform OpenThread deployments**.
- **Aligns with IoT network standards** by testing IPv6, 6LoWPAN, and RPL.

Impact on Industrial IoT (IIoT), Cyber-Physical Systems (CPS), and Critical Network Infrastructure (CNI)

- **IIoT:** OpenThread's role in **industrial automation, smart factories, and energy monitoring** is crucial for scalable wireless sensor networks.
- **CPS:** Testing OpenThread in Zephyr **ensures real-time, synchronized, and resilient communication** in CPS environments, such as **robotics, healthcare, and smart grids**.

- **CNI:** Evaluating **OpenThread's reliability and security in multi-node architectures** is vital for **critical infrastructure** (e.g., **power grids, emergency networks, and secure communications**).
- **Standardization Support:** Findings from this research can **contribute to OpenThread's adoption** in **mission-critical IoT deployments**.

Contribution to Course Objectives

- Develops hands-on experience with **Zephyr OS in Docker & QEMU** for IoT simulation.
- Demonstrates **real-world interoperability challenges in OpenThread networks**.
- Supports **standardization efforts in IoT connectivity and protocol testing**.

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5. Conclusion

By combining **Zephyr, Docker, QEMU, and OpenThread**, this project delivers a **structured approach to testing network interoperability** across **multiple architectures**. The findings will contribute to **optimizing OpenThread deployments** in **IoT, IIoT, CPS, and CNI applications**, ensuring **scalability, reliability, and cross-platform compatibility**.
