Athernet: Acoustic-based User Space Network Stack

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Abstract

Athernet is a user-space TCP/IP stack with full functionality and handy utilities built on the acoustic channel. This report describes the main architecture design and the technical implementation of the Athernet.

Keywords: network stack, acoustic link, network protocol

1 Introduction

This work is submitted in partial fulfilment of the course CS120: Computer network at ShanghaiTech University. The network stack is an essential topic in computer networks and has various implementations. To comprehensively understand it, we are asked to implement our network stack Athernet.

Unlike traditional wireless or wired methods, Athernet uses sound waves to transmit data between devices. The stack has implemented the basic functionalities of the standard TCP/IP and can be used with existing network infrastructure. Additionally, the system has the potential to be used in areas where wireless communication is not feasible, such as underwater communications.

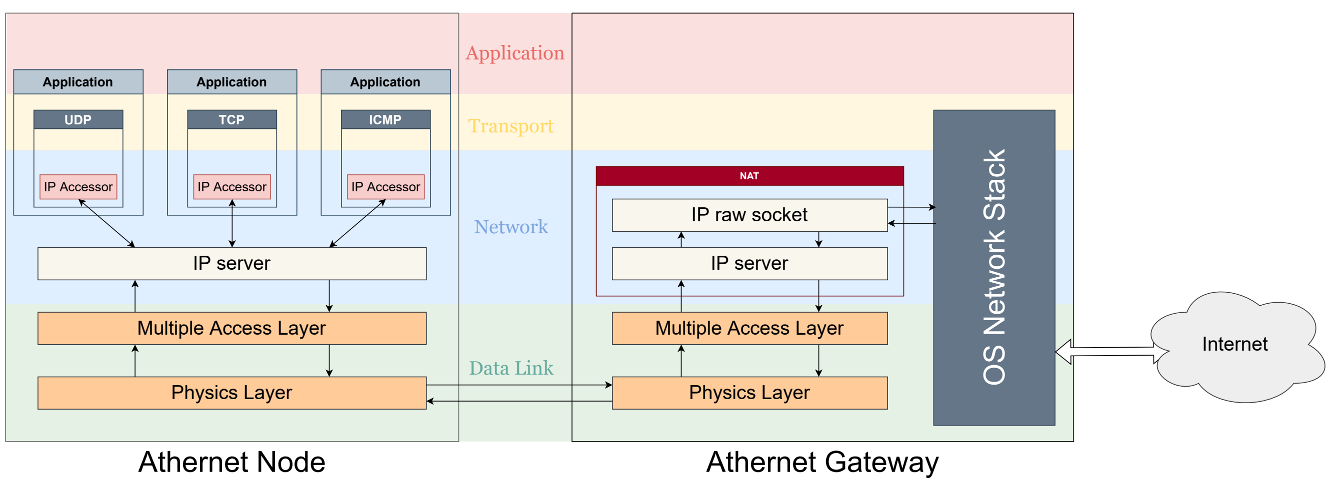

Figure 1: the overview architecture of the Athernet network stack

The network stack is composed of the following four layers where each layer is built on the previous one.

- **The link layer:** The link layer provides reliable bidirectional data transmission in local area. It is decomposed into two sublayers namely the *physics sublayer* and the *media access control sublayer*. The physical layer is responsible for the converting digital data into audio signal or the reverse process and sending/receiving data through sound waves. It supports both noisy wireless medium and audio cable media. Two different modulation schemes are implemented for the two scenarios: a passband modulation scheme that combines *BPSK* and *OFDM* for the wireless scenarios and a baseband modulation scheme using *4B5B* with *NRZI* for the cable connected scenarios. The media access layer deals with collisions that may happens when multiple nodes sends signal to the media simultaneously. *CSMA/CA* is implemented to provide reliable data transmission.

- **The network layer:** *Internet Protocol(IP)* is implemented for inter-network data transmission. An daemon process called the *IP server* regularly sends packets to peers and receives packets from peers. To allow programs in the next layer to access the network layer service, *IP accessor* which communicates with the *IP server* using unix domain socket is created. The *network address translation(NAT)* is also implemented in this layer, which enables the communication between Athernet LAN and the Internet.

- **The transport layer:** Various transport layer protocols are implemented including *transmission control protocol(TCP)*, *user datagram protocol(UDP)* and *internet control message protocol(ICMP)*. Athernet socket, a set of APIs that resembles the socket API in rust standard library, are exposed for applications to use the transport layer services.
- **The application layer:** A simple *file transfer protocol(FTP)* client supporting a set of restricted control commands and only passive transmission mode is implemented on Athernet TCP to demonstrate the capability of Athernet. For Athernet to support the pre-existing applications which are built on OS TCP/IP stack, a SOCKS5 proxy server is implemented that redirects network traffics through Athernet.

Figure 1 shows the overall architecture of the Athernet. The Athernet nodes are interconnected and can connect to the Internet through the Athernet gateway, which runs a NAT.

The paper is devided into five parts. Through chapter two to five, we describes the design of the four layers of our network stack. In the last chapter, we analyze the problems in our design and make a technical summary.

2 Data Link

The foundation of the entire network stack is the data link layer which provides reliable bidirectional packet transmission between two nodes in a shared noisy acoustic medium. The data link layer consists of the physics sublayer and the medium access control sublayer.

2.1 Physics Sublayer (PHY)

Bulit on the audio I/O library, PHY enables basic data transmission with no delivery or integrity guarantee. A PHY frame is a sequence of PCM audio signal samples that represents a chunk of bytes. It is the transmission unit on this layer. Each frame contains a fixed preamble signal at the beginning for detection as well as synchronization and a payload signal that encodes 0/1 bits.

For data transmission, PHY layer constructs a frame from a chunk of bytes and send it through the medium. For data receiving, PHY layer repeatedly pulls audio samples from the medium and seek for PHY frame based on the frequency-domain feature of the preamble. When a frame is identified, the payload signal is extracted and decoded.

2.1.1 Preamble Signal Design

A linear chirp signal whose instaneous frequency increases and decreases linearly is picked as the preamble.

$$x_p(t) = \begin{cases} \pi \dfrac{f_b - f_a}{T} t^2 + 2\pi f_a t & t \in [0, T] \\ \pi \dfrac{f_a - f_a}{T} (t - T)^2 + 2\pi f_b (t - T) & t \in [T, 2T] \end{cases}$$

$x_p(t)$ is a linear chirp signal whose lowest and highest instaneous frequency is f_a and f_b respectively.

2.1.2 Modulation and Demodulation

In order to transmit and receive digital signals, a modulation scheme has to be implemented.

For wireless scenario, strong background noisy is detected from 0Hz to 6000Hz, so a passband modulation scheme combining binary phase shift keying (BPSK) and orthogonal frequency-division multiplexing (OFDM) is implemented. BPSK encodes bits with phase changes:

$$x_0(t) = \sin(2\pi f t)x_1(t) \qquad = \sin(2\pi f t + \pi) = -\sin(2\pi f)$$

are used to represent 0 bit and one 1 respectively. The physics layer sends a bit by pushing samples of the modulated signal to audio I/O driver. To recover a bit from audio signal, physics layer calculates the dot product of the receive samples and the samples of $x_0(t)$.

$$x_0(t) \cdot x_0(t) > 0 \quad x_0(t) \cdot x_1(t) < 0$$

A zero bit is produced if the dot product is positive, otherwise a one bit is produced.

As for cabel-connected scenario, baseband transmission is possible as low frequency background noise has less power compared with wireless scenario.

2.1.3 Frame Detection

2.2 Medium Access Control sublayer

the medium access control layer regulates access to the shared medium and implements error detection and retransmission mechanism.

3 Network

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3.1 Internet Protocol

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3.2 Network address translation

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4 Transport

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4.1 Internet Control Message Protocol

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4.2 User Datagram Protocol

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4.3 Transmission Control Protocol

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4.3.1 TCP Stream

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4.3.2 TCP Listener

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5 Application Layer

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5.1 File Transfer Protocol

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5.2 Tunneling

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6 Conclusion

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