A Framework for Industrial Identifier Addressing

Yifan Xu
School of Software, Tsinghua University
Beijing, China
xuyifan20@mails.tsinghua.edu.cn

Fan Dang*
Global Innovation Exchange, Tsinghua University
Beijing, China
dangfan@tsinghua.edu.cn

Jingao Xu
School of Software, Tsinghua University
Beijing, China
xujingao13@gmail.com

ABSTRACT

We propose a novel framework for industrial identifiers addressing in industrial networks. It includes the Industrial Identifier Resolution Protocol (IIRP), which combines an ARP-like table lookup, Ethernet frames broadcast, and caching mechanisms on switches to support quick and accurate identifier-MAC resolution. Furthermore, we introduce a hardware-based lookup algorithm for switch tables that employs Ternary Content-Addressable Memory (TCAM) to search the table quickly and efficiently, as well as a mechanism that triggers TCAM and SRAM updates to ensure the accuracy of identifier-MAC mapping.

CCS CONCEPTS

• **Networks** → **Cross-layer protocols**; **Switches**.

KEYWORDS

Industry identifiers, switch, addressing

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1 INTRODUCTION

Industrial networks play a crucial role in modern manufacturing and automation systems, enabling seamless communication and control between devices. Traditionally, as for local area networks (LANs) in a factory, switches rely on MAC addresses to perform link-layer frame forwarding. However, in industrial environments, devices often come with specific industrial identifiers (IIDs) assigned by standards organizations like GS1, Handle, or OID [1]. These IIDs carry valuable information about the device, such as its type, purpose, or location. To establish communication among devices using IIDs while leveraging the existing MAC-based switch infrastructure for link-layer communication, it is necessary to first resolve the IIDs to corresponding MAC addresses.

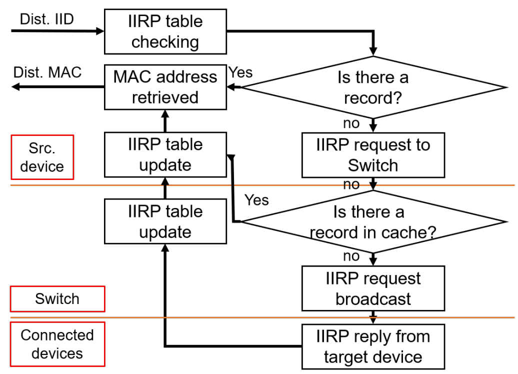

Figure 1: IIRP process overview.

However, there is no out-of-box resolution protocol to bridge the gap between IIDs and MAC addresses within the LAN environment. Therefore, in this paper, we aim to address the challenge of integrating IIDs into the LAN environment without modifying the existing network architecture. We propose a novel IID addressing framework that resolves IIDs to MAC addresses. By running an Industrial Identifier Resolution Protocol (IIRP), a combination of IIRP table lookup, Ethernet frames broadcast, and caching mechanisms on switches, we ensure timely and accurate IID-MAC mapping. Furthermore, to achieve high-performance lookup operations on switches, we introduce a hardware-based lookup algorithm that leverages Ternary Content-Addressable Memory (TCAM). Additionally, we present a self-learning mechanism to trigger TCAM and SRAM updates, ensuring the consistency of the mapping information.

By designing such a framework, we enable seamless communication between devices using IIDs while preserving the existing network infrastructure and the benefits it provides.

2 THE DESIGN OF IIRP

We elaborate on the design of IIRP in this section. As shown in Fig. 1, the IIRP resolution process begins with the source

*Corresponding Author.

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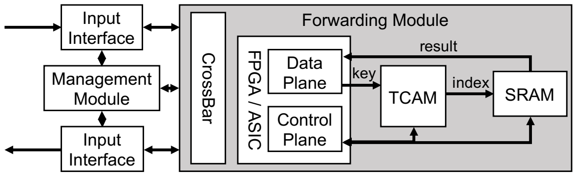

Figure 2: Switch Overview.

device searching the local IIRP table for the corresponding MAC address associated with the destination IID. The IIRP table serves as a mapping database between IIDs and MAC addresses, along with a Time-To-Live (TTL) value for each entry. If a matching entry is found, the source device retrieves the MAC address and proceeds with the standard link-layer communication process. However, if no matching entry exists in the IIRP table, the source device launches an IIRP request, encapsulating the destination IID in the *Payload* field of a broadcast Ethernet frame with the *Destination MAC* field set as "FF-FF-FF-FF-FF-FF". A complete IIRP request frame structure is as follows: ***(preamble, Destination MAC, Source MAC, EtherType, Source IID, Payload, CRC)***. In order to separate the IIRP request from other Ethernet frames, a new *EtherType* should be registered. For helping the switch self-learning, a new *Source IID* field is appended following the *EtherType* field. Each *Source IID* field consists of identifier type, length, and identifier value so that it is compatible with diverse lengths of different types of IIDs.

The source device then broadcasts this frame onto the LAN through the switch. The switch quickly searches its IIRP table in the cache at first. The cache design helps speed up the resolution process and save network resources as discussed in the following section. If there is a corresponding record, the switch extracts the destination MAC address and returns it to the source device. Otherwise, it broadcast the request to all ports. Upon receiving the broadcast frame, each device on the LAN checks if its IID matches the requested IID. The target device sends back its MAC address in a unicast frame whose structure is similar to the IIRP request, where a new *EtherType* should also be applied, followed by its *Source IID*.

At last, the source device updates its IIRP table with the retrieved MAC address, associating it with the requested IID.

3 HARDWARE-BASED RESOLUTION

To optimize the IID resolution process and enhance its efficiency, we leverage hardware-assisted lookup algorithms utilizing TCAM and combine it with TCAM-based index retrieval and SRAM-based result retrieval. Since the switches have to deal with much larger traffic than hosts, our solution targets them as the first priority. By the way, it can be easily applied on the hosts or routers as well if they would like to speed up the IID resolution process.

The hardware-assisted lookup algorithm takes advantage of TCAM, a specialized type of memory. It has the ability to simultaneously compare a desired pattern against all prestored entries, allowing for a single clock cycle search operation across the entire entry list, making it ideal for fast table lookup [3]. The virtual IIRP table is separately stored in TCAM and SRAM. Each TCAM entry includes the IID (type and value) and the index pointing to an SRAM address where the corresponding MAC address and TTL are stored.

Fig. 2 exhibits the switch modification. We make a little incrementation to the forwarding module, using FPGA for prototype validation and rapid development, and then transition to ASIC for mass production. When an IIRP request is received through the input interface and the destination IID is extracted from the frame by the Data Plane, the lookup process begins by using the IID as the input key. The TCAM performs a parallel search and returns the index of the matching entry. It is then used to retrieve the corresponding MAC addresses from the SRAM-based result storage.

The switch incorporates a **self-learning** mechanism similar to the traditional switch table self-learning process to update the IIRP table including TCAM and SRAM, ensuring that it accurately reflects the current mappings between MAC addresses and IIDs. This self-learning process utilizes the traffic from industrial devices that pass through the switch (IIRP requests and replies). During the self-learning process, the switch updates the IIRP table by adding or updating entries of TCAM and the content in the corresponding SRAM address based on the observed MAC addresses and IIDs.

Even though the unique hardware structure of TCAM enables its greater lookup efficiency than SRAM, it causes slower updates due to the Priority Order Constraint (POC), making it a bottleneck in IIRP table update [2]. We leverage several available approaches [2, 4] to tackle the problem.

4 CONCLUSION

In this paper, we present a novel framework for IID addressing in industrial networks. Our proposed solution addresses the challenges of incorporating IIDs into existing network infrastructure without requiring substantial changes. We introduce the IIRP for IID-MAC mapping and design a hardware-assisted lookup algorithm utilizing TCAM to achieve efficient and accurate resolution. It provides a scalable and efficient approach for resolving IIDs and facilitating seamless communication within industrial networks.

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