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H. Wang
P. Wang
C. Zhang
Y. Yang
Chongqing University of
Posts and Telecommunications

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Joint Scheduling Architecture for Deterministic Industrial Field/Backhaul Networks
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Abstract

The joint scheduling between industrial field network and backhaul network is important to satisfy the requirements of deterministic delay for data flows in factories. This document describes a joint scheduling architecture for deterministic industrial field/backhaul networks. Taking WIA-PA, an international standard about industrial wireless field network, and IPv6-based backhaul network as an example, this document depicts how the joint scheduling architecture works in detail.

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1. Introduction

Deterministic network is one of essential elements of industrial network. With the help of deterministic network, industrial field network can greatly enhance the network performance in terms of reducing transmission delay. Thus, applying deterministic network into the whole industrial network has attracted a lot of attention recently. Deterministic network is mainly focused on the industrial field networks, such as ISA100.11a [IEC62734], WirelessHART [IEC62591] and WIA-PA [IEC62601]. In order to solve the problem of data transmission in different industrial field networks, and the issue of data flows between industrial field networks and wide area networks, industrial backhaul network is deployed in factory. However, there are little considerations about joint scheduling scheme that can be applied to industrial networks.

The emerging Software Defined Networks (SDN) technology on the Internet brings a new choice to solve joint scheduling problem. SDN has been proposed as a new network architecture in recent years. The network architecture separates the network control plane from the forwarding plane, which brings a revolution for the network architecture. By separating control plane from forwarding plane ,and the open communication protocol, SDN breaks the closure of traditional network device provider. Besides, open interfaces and free programmability also make network management more efficient and flexible.

In document [I-D.bas-usecase-detnet] and [I-D.finn-detnet-architecture] submitted by the IETF DetNet working group, deterministic network based on Ethernet has been researched already. They propose a network architecture based on SDN technology that can accurately control the transmission of data streams. However, the characteristics of the industrial backhaul network and the actual condition of industrial field deterministic networks are not considered. Firstly, the data that transmits in industrial backhaul network is highly sensitive to transmission delay. Secondly, the existing deterministic networks have been widely deployed in industrial field environment, thus the direct replacement for original networks will consume many workers and material resources.

Based on existing research in document [I-D.finn-detnet-architecture], this document proposes a joint scheduling architecture for deterministic industrial networks. It will firstly replace the industrial backhaul networks and other non-deterministic networks located in industrial networks with deterministic Ethernet network. Then this document proposes a joint scheduler based on SDN technology. By deploying the deterministic network in complete industrial network, it can realize the end-to-end deterministic scheduling between different industrial field networks.

2. Joint Scheduling Architecture

There are many types of network controllers in industrial networks, which constitute the control plane of the whole industrial network together. The control plane is very important in the entire network, especially when it refers to cross-domain transmission of time-sensitive data. The control plane architecture affects the performance of the network greatly. It is becoming a hot research on how to give full play to the performance of their respective networks when multiple controllers are in the joint work.

However, there is no unified standard for the joint architecture of multiple controllers in the industry presently. The mainstream of architecture includes distributed architecture and centralized architecture.

2.1. Distributed Architecture

Distributed architecture is known as East-West architecture. In the architecture, the status of all network controllers are equal, these controllers connect with each other to form an unstructured network, and implement cross-domain transmission task by exchanging information, as shown in Figure 1.

In distributed architecture, controller can exchange different network topologies and the accessibility of information by east-west interface, and each controller can establish a global network topology. From a global network perspective, each controller is equal, thus it can serve as a server role as well as the ability to start deterministic cross-network transmission task.

```
             +-----------------------------------------------------+
             |                                                     |
  Application |    +--------+       +--------+        +-------+     |
  Plane      |    |  APP  |        |  APP  |        | APP  |      |
             |    +----+---+       +----+---+        +---+---+     |
             |         |                |                |         |
             +---------+----------------+----------------+---------+
                       |                |                |
 ---------------------------------------------------------------------
                       |                |                |
             +---------+----------------+----------------+---------+
             |         |                |                |         |
  Control    |    +----+-----+     +----+-----+     +----+-----+    |
  Plane      |    |Controller|------>|Controller|------>|Controller|    |
             |    |          |<------|          |<------|          |    |
             |    +----------+     +----------+     +----------+    |
             |         |                |                |         |
             +---------+----------------+----------------+---------+
                       |                |                |
 ---------------------------------------------------------------------
                       |                |                |
                  +----+-----+     +----+-----+     +----+-----+
   Forwarding     |  WIA-PA  |------>| backhaul |------>|  WIA-PA  |
   Plane          |  network |<------|  network |<------|  network |
                  +----------+     +----------+     +----------+
```

Figure 1. Distributed Architecture

2.2. Centralized Architecture

Centralized architecture is also called a vertical multi-level architecture. In this architecture, the control plane is divided into two parts, one part is the basic control plane, which is composed of a variety of network controllers, and another is a main network controller, which is responsible for controlling the basic control plane. The detailed description of centralized architecture is shown in Figure 2.

```
                      +--------------------------------------------------------------+
                      |                                                              |
        Application   |     +---------+        +---------+         +--------+        |
        Plane         |     |   APP   |        |   APP   |         |  APP   |        |
                      |     +---------+        +----+----+         +--------+        |
                      |                             |                                |
                      +-----------------------------+--------------------------------+
                                                    |
        ---------------------------------------------------------------------------------
                                                    |
                      +-----------------------------+--------------------------------+
                      |                             |                                |
                      |                       +------+------+                         |
                      |          +------------|    Main    |------------+            |
                      |          |            | Controller |            |            |
        Control       |          |            +------+------+            |            |
        Plane         |          |                  |                   |            |
                      |     +----+-----+       +----+-----+        +----+-----+      |
                      |     |Controller|       |Controller|        |Controller|      |
                      |     +----+-----+       +----+-----+        +----+-----+      |
                      |          |                  |                   |            |
                      +----------+------------------+-------------------+------------+
                                 |                  |                   |
        ---------------------------------------------------------------------------------
                                 |                  |                   |
                            +----+-----+       +----+-----+       +----+-----+
         Forwarding         |  WIA-PA  |------>| backhaul |------>|  WIA-PA  |
         Plane              |  network |<------|  network |<------|  network |
                            +----------+       +----------+       +----------+
```

Figure 2. Centralized Architecture

The centralized architecture does not need to expand east-west interface. It only needs to establish a connection with the basic controllers using southbound interface. After the connection is established, the main controller obtains the every topology of network domain by the API interface provided by the basic controllers, and storages global network topology. Main controller can also assign tasks to basic controllers by API interface.

2.3. Joint Scheduling Architecture

In practical application, distributed architecture not only needs to extend the east-west interface, but also maintains a global network topology in each controller. Only each controller maintains such a global network topology, can it ensure the deterministic control of whole network.

For deterministic industrial network, the scale of network is not very large. Besides, in industrial backhaul network, a single SDN controller is sufficient to meet the demands of control. If centralized architecture is directly applied to an industrial network, it will not only be unable to make full use of advantages of the multi-controller architecture, but also cause unnecessary information interaction between controllers wasting network resource.

Considering the problems existing in above two architectures, this document proposes a joint scheduling architecture based on the architecture document [I-D.finn-detnet-architecture]. The architecture is optimized according to the characteristics of deterministic industrial network. A single SDN controller can unite the WIA-PA network system manager to manage the entire industrial network, and provide support for the deterministic scheduling of cross-network data transmission through industrial backhaul network located in different WIA-PA networks.

```
               +-------------------------------------------------------------+
               |                                                             |
   Application |    +--------+          +--------+          +-------+        |
   Plane       |    |   APP  |          |   APP  |          |  APP  |        |
               |    +--------+          +----+---+          +-------+        |
               |                             |                               |
               +-----------------------------+-------------------------------+
                                             |
  ----------------------------------------------------------------------------------
                                             |
               +-----------------------------+-------------------------------+
               |                             |                               |
   Control     |  +--------------+      +----+-----+      +--------------+   |
   Plane       |  |    WIA-PA    |------|   SDN    |------|    WIA-PA    |   |
               |  |System Manager|      |Controller|      |System Manager|   |
               |  +------+-------+      +----+-----+      +-------+------+   |
               |         |                   |                    |          |
               +---------+-------------------+--------------------+----------+
                         |                   |                    |
  ----------------------------------------------------------------------------------
                         |                   |                    |
                    +----+-----+        +----+-----+        +-----+----+
    Forwarding      |  WIA-PA  |------->| backhaul |------->|  WIA-PA  |
    Plane           |  network |<-------| network  |<-------|  network |
                    +----------+        +----------+        +----------+
```

Figure 3. Joint scheduling architecture

Figure 3 depicts the joint scheduling architecture. The architecture can be mainly classified into three planes:

- o Forwarding plane: this plane contains various types of network equipment belonged to different networks. It is the physical entities for network transmission. To obtain the desired network functions from network manager, devices should abstract their own resources to provide to its network manager respectively.

- o Control plane: this plane is composed by WIA-PA system manager and SDN controller. Joint scheduler is integrated into the SDN controller by a way of plugin, and other WIA-PA system managers communicate with joint scheduler by establishing a connection with the SDN controller. Meanwhile, joint scheduler implement the management of industrial backhaul network by directly invoking the corresponding module of SDN controller.

o Application plane: this plane provides users with a unified interface about many variety of resources for the whole network. At the same time, it also provides an intuitive and user-friendly interface, which shields the complex network information of the original.

When application plane triggers a joint scheduling task, SDN controller calculates path and allocates resource according to the task request from the application plane. Upon finishing calculation, SDN controller sends them using the unified joint scheduling interface to corresponding network manager, and then the network manager sends them to the industrial field network.

Based on joint scheduling architecture, joint scheduler can realize control and scheduling for the entire industrial network, thus it can provide a real-time guarantee for each data stream.

3. Joint Scheduling Scheme

Taking WIA-PA network and IPv6-based backhaul network as an example, this section describes how the joint scheduling architecture works. Existing WIA-PA scheduling scheme only applies to WIA-PA field network. Scheduling scheme will fail once data transfers to backhaul networks. Joint scheduling scheme is an innovation and expansion compared to WIA-PA scheduling scheme.

Firstly, original scheduling scheme based on SDN in industry backhaul network is added to the proposed scheduling scheme, thus, data can flow in the industrial backhaul network.

Secondly, by conducting an optimization for original WIA-PA scheduling scheme, original scheduling scheme can work with joint scheduler, and simultaneously be applied to cross-domain network.

Thirdly, due to the specificity of cross-border transmission services, the joint scheduling scheme for WIA-PA network VCR_ID and route ID is reclassified.

Finally, due to system manager allocates short address to field device based on WIA-PA network address information independently. Thus the short address of field device in entire industrial network is uncertain. In order to identify the field device belonged to different network domains, the network identifier (PAN_ID) is applied to the joint scheduling scheme to identify different WIA-PA networks.

After the SDN controller initiates joint scheduling module, WIA-PA system manager will actively establish a connection with the united scheduler. After the scheduler receives a cross-border transmission request, joint scheduler will send a request for obtaining topology information and node information to WIA-PA System Manager. Then, the scheduler will assign paths and network resources according to this information by pre-defined scheduling algorithm. After the path and network resources have been calculated, joint scheduler will configure and deploy networks by the corresponding network controller.

3.1. WIA-PA Network Joint Scheduling

In joint scheduling process, path deployment and resource allocation for WIA-PA network are performed by employing the WIA-PA system manager API interface. System manager will query the corresponding information of the field device in the network upon receiving the command about joint operation for the network information, and then return the received information to the joint scheduler. The system manager will configure communication resources for the corresponding gateway device, routing equipment and field equipment when it receives configuration commands from joint scheduler.

3.2. Protocol Conversion

For cross-domain transmission, industrial backhaul network is different from WIA-PA network which is not an IP-based Ethernet. Protocol conversion for WIA-PA packet in gateway is needed when data generated from WIA-PA network needs to transmit to another field network through industrial backhaul. Meanwhile, according to the joint scheduling scheme, SDN controller is able to recognize the WIA-PA data stream and allocate resources according to data stream type. Therefore, in the protocol conversion process, scheduling and control of WIA-PA data flow can be realized by SDN controller by combining the VCR of WIA-PA data stream and the priority filled in IPv6 header.

```
            +-------+
            | Start |
            +-------+
                |
          +-------------+
          |  Receiving  |
          |data packets |
          +-------------+
                |
          /-------------\          +--------------+
         /Whether is the \         | Forwarded to |
         |  management   |-- Yes -->|  the system  |
         \     data      /         |    manager   |
          \-------------/          +--------------+
               |
               No
               |
         +-----------+
         | Resolution|
         |   Packet  |
         +-----------+
               |
         /------------\            /------------\          +-------------+
        /   Find the   \          /   Find the   \         | Encapsulate |
        |corresponding |-- Yes -->| corresponding |-- Yes-->|   and sent  |
        \     VCR      /          \ IPv6 address /         |  IPv6 packet|
         \------------/            \------------/          +-------------+
               |                          |                        |
               No                         No                       |
               |                          |                        |
          +--------+                      |                        |
          |  End   |<---------------------+------------------------+
          +--------+
```

Figure 4. The process of protocol conversion in gateway

As shown in Figure 4, gateway will receive the address mapping configuration command from joint scheduler. Then VCR tables and IPv6 address-mapping tables will be formed according to this information. When gateway receives WIA-PA packets, it will firstly parse Route ID, Object ID and Instance ID, and find corresponding VCR from VCR tables. Meanwhile, the gateway finds the corresponding IPv6 address according to Route ID in IPv6 address mapping table. Then, gateway begins to encapsulate WIA-PA packets based on IPv6 format, fill VCR_ID in IPv6 header flow label field and the priority of WIA-PA packet in IPv6 header fields.

When receiving IPv6 packets from industrial backhaul networks, gateway will recognize VCR_ID from IPv6 packet header, and obtain packet VCR according to the VCR ID in VCR table, then replace it with the information of original packet.

3.3. Industrial Backhaul Network Scheduling

In deterministic network based on SDN, joint scheduler can recognize WIA-PA data stream by matching IPv6 flow label field. According to priority in IPv6 header field and VCR_ID type, joint scheduling can allocate the necessary resources to communication and ensure that important data flow is not affected when adding new data flows in existing network. It can also monitor the real-time data flow. To guarantee the real-time performance of critical data flows, redundant paths are also considered when necessary. The scheduling process of industrial backhaul network is shown in Figure 5.

```
                  +-------+
                  | Start |
                  +-------+
                      |
               +--------------+
               |Obtain network|
               |   topology   |
               +--------------+
                      |
          +-------------------+
          |    Calculate the  |
          | path and allocates|<----------------+
          |    resources      |                 |
          +-------------------+                 |
                      |                         |
             +----------+                       |
             |Query path|                       |
             +----------+                       |
                      |                         |
           /---------------\         +-----------------+
          /whether the path \        |  Calculate the |
          |meets the resource|- No ->|   weight and   |
          \  requirements   /        | adjustment path|
           \---------------/         +-----------------+
                     |
                    Yes
                     |
               +-------------+
               | Deployment |
               | flow table |
               +-------------+
                     |
                  +-----+
                  | End |
                  +-----+
```

Figure 5. The scheduling process of industrial backhaul network

When receiving the request for service, the joint scheduler will calculate route information and resource allocation. Once the path and resource allocation are determined, joint scheduling will confirm whether the resource and path are capable of meeting business requirements by the inside module of SDN controller. If it meets, then the flow table is deployed by SDN controller. Otherwise, the path information and resource allocation are recalculated to choose the correct paths to transmit data flow.

3.4. Bandwidth guarantee method

Bandwidth guarantee method is implemented on the basis of joint scheduling mechanism, in order to solve the problem that industrial backhaul networks can not identify fine-grained and cross-network data transmission. By filling the priority information and the RouteID defined in WIA-PA network into the IPv6 header, the SDN controller can not only identify cross-network transmission of the WIA-PA data stream, but also obtain priority information about the WIA-PA data stream. In industrial backhaul network, the SDN switch employs the mechanism of priority queue to allocate network bandwidth. Thus SND switch can distribute WIA-PA data streams into corresponding queues of ports according to the received flow table from SDN controller. Therefore, the bandwidth of data stream is guaranteed.

By using the above methods, joint scheduling mechanism can distinguish data streams in a fine-grained way and guarantee bandwidth when data transmits in industrial backhaul network. For example, real-time data in WIA-PA network is sensitive to delay, thus it should be allocated more bandwidth to reduce transmission delay. For not urgent data, it can be assigned less bandwidth to reserve bandwidth for real-time data. Meanwhile, SDN controller can flexibly adjust bandwidth allocation strategy to relieve network congestion.

4. Security Considerations

5. IANA Considerations

This memo includes no request to IANA.

6. References

6.1. Normative References

6.2. Informative References

[IEC62734]
ISA/IEC, "ISA100.11a, Wireless Systems for Automation, also IEC 62734", 2011, <http://www.isa100wci.org/enUS/Documents/PDF/3405-ISA100-WirelessSystems-Future-brochWEB-ETSI.aspx>.

[IEC62591]
IEC, "Industrial Communication Networks - Wireless Communication Network and Communication Profiles - WirelessHART - IEC 62591", 2010, <https://webstore.iec.ch/p-preview/info iec62591%7Bed1.0%7Den.pdf>

[IEC62601]
IEC, "Industrial networks - Wireless communication network and communication profiles - WIA-PA - IEC 62601", 2015, < https://webstore.iec.ch/preview/info iec62601%7Bed2.0%7Db .pdf>

[I-D.finn-detnet-problem-statement]
Finn, N. and P. Thubert, "Deterministic Networking Problem Statement", draft-finn-detnet-problem-statement-05 (work in progress), March 2016.

[I-D.finn-detnet-architecture]
Finn, N., Thubert, P., and M. Teener, "Deterministic Networking Architecture", draft-finn-detnet-architecture-08 (work in progress), August 2016.

[I-D.bas-usecase-detnet]
Kaneko, Y., Toshiba and Das, S, "Building Automation Use Cases and Requirements for Deterministic Networking", draft-bas-usecase-detnet-00 (work in progress), October 2015.

Authors' Addresses

Heng Wang
Chongqing University of Posts and Telecommunications
2 Chongwen Road
Chongqing, 400065
China

Phone: (86)-23-6248-7845
Email: wangheng@cqupt.edu.cn

Ping Wang
Chongqing University of Posts and Telecommunications
2 Chongwen Road
Chongqing, 400065
China

Phone: (86)-23-6246-1061
Email: wangping@cqupt.edu.cn

Chang Zhang
Chongqing University of Posts and Telecommunications
2 Chongwen Road
Chongqing, 400065
China

Phone: (86)-23-6246-1061
Email: zc910522@126.com

Yi Yang
Chongqing University of Posts and Telecommunications
2 Chongwen Road
Chongqing, 400065
China

Phone: (86)-23-6246-1061
Email: 15023705316@163.com