TECHNICAL REPORT

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FF to Ethernet-APL Migration Concept

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FieldComm Group
Attention: President and CEO
9430 Research Boulevard
Suite 1-120
Austin, TX 78759, USA
Voice: (512) 792-2300
FAX: (512) 792-2310

http://www.fieldcommgroup.org

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1 Scope

1.1 Background

With the standardization of Ethernet-APL complete and products being introduced to the market, many members with Foundation fieldbus products can integrate with networks using Ethernet-APL technologies. An initial study team was formed in early 2022 to investigate possible technical solutions and prepared a report comparing 4 architectural concepts for integrating both technologies.

In early 2023, based on the input of the original study team, FieldComm Group (FCG) approved the creation of a formal project group to further define technical requirements for the Architecture A – Multipoint option (see Figure 1).

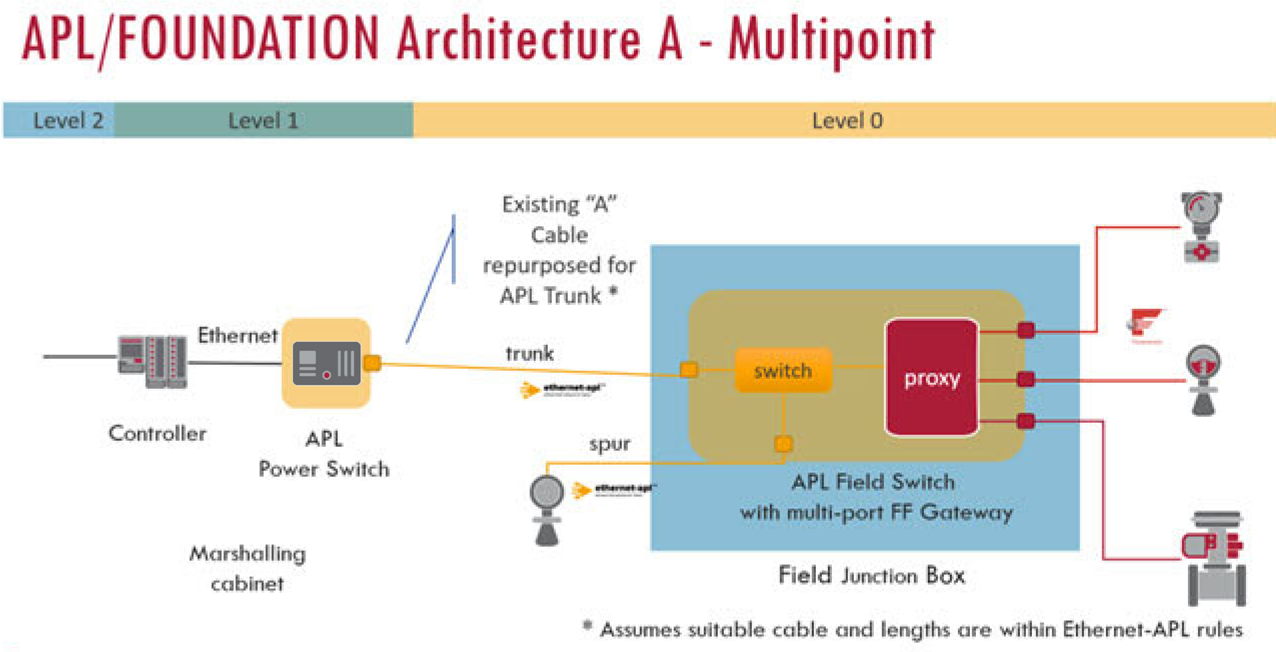


Figure 1 – Architecture A – Multipoint option

Architecture A shows a scenario where an existing FF Device Coupler would be replaced with an Ethernet Field Switch that supports both Ethernet-APL and Foundation Fieldbus H1. While Ethernet-APL and Foundation Fieldbus H1 were designed to support the same cabling, the electrical characteristics (signally, frequency, modulations) of the network are significantly different. This requires Ethernet-APL switches to support dual modes on switch ports, where a port can be used as a standard Ethernet-APL switch port or as a Foundation fieldbus H1 node.

Ethernet-APL specifies the lower two layers, physical and data link, of the standard OSI model for describing network protocols. Foundation Fieldbus H1 also includes an application layer, and the physical/data link layers are not directly compatible with Ethernet-APL. Therefore, in order for Foundation fieldbus host applications to communicate with Foundation Fieldbus devices over an Ethernet-APL field switch, the field switch must implement a gateway/proxy.

The project group charter was called to develop a technical requirements document (this document) for the implementation of the Architecture A - Multipoint option.

1.2 Charter

The scope of this document was defined in the charter:

This Project Group considers Ethernet-APL for IS (Intrinsically Safe) and non-IS Ethernet as upgrade path for existing FF-H1 physical layer segments. The results of this project group will enable both IS (Ethernet-APL) and non-IS FF segments to reduce the cost[1]. The project group will examine and document the interaction of other Ethernet protocols with the proposed solution to enable a blend of safety and non-safety protocols. The project group will use the selected Architecture A-Multipoint as the base architecture for this effort.

Why Architecture A?

Hardware reasons

– Space constrains within the existing plant infrastructure
– Practical way to migrate one device at a time on its failure
– Same hardware could support both PA / FF and Ethernet-APL
– Power management of instruments is simpler

For hardware Architecture A, software investigation areas

– Software aspect is a concern as control in the field is not a requirement
– Leave the backhaul protocol to the vendors. Project group should investigate how to apply backhaul protocol choice
– Simplify the FF application layer for the Link Master [LAS (Link Active Scheduler), FBAP (Function Block Application Process) etc.]

Constraint: No change to the field device. No requirement to update the Standardized Connection Points (SCP).

Concerns to be addressed:

– Ethernet-APL can offer a media redundancy (MRD) with a redundant cable to the APL switch. The connection to the device is a single point of failure. The project group explores the scope of redundancy and how to leverage existing techniques.

FF to Ethernet-APL Working Group Specific Work products:

– Technical requirements document for Architecture A – Multipoint
– Help draft a message to the market that there is a path forward and vendors will offer specific solutions to migrate to Ethernet-APL. The message will include a plan for FF migration path to APL as well as provide guidance to vendors and market of realistic future. Present Architecture A, but also communicate that vendor can create other solutions.

2 Comparison between FF-H1 and Ethernet-APL

In order to consider the migration of FF-H1 to Ethernet-APL, it is important to understand the differences between them. This chapter discusses the similarities and differences between FF-H1 and Ethernet-APL from three perspectives: architecture, physical layer, and host/engineering level. These perspectives are detailed in the subsequent sections.

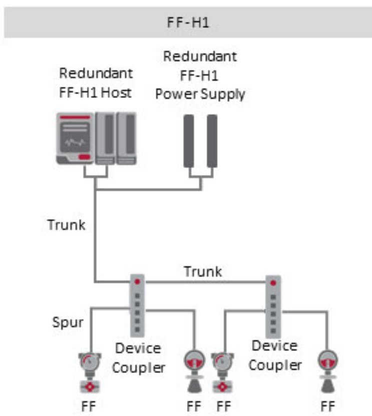
In addition to these three perspectives, it’s important to understand that FF-H1 also includes an application layer (protocol) as part of the standard. The Ethernet-APL standard only provisions the physical layer. In other words,

[1] Cost reduction analysis is not covered in this document.

Ethernet-APL is always coupled with protocols such as HART-IP, PROFINET, EtherNet/IP, OPC UA and other industrial Ethernet protocols. The FF-H1 protocol is not Ethernet-based and therefore, not able to adapt directly to Ethernet-APL.

2.1 Architecture

The differences are explained for each architectural aspect. Figure 2 illustrates this.



Aspect	FF-H1	Ethernet-APL
Connection	Multidrop	Point to Point
Intermediate Device	Device Coupler	APL Switch
Controller / IO	On a Segment	On an Ethernet Control Backbone
Topology	Trunk and Spur	Trunk and Spur
Cable Type	Type A	Type A

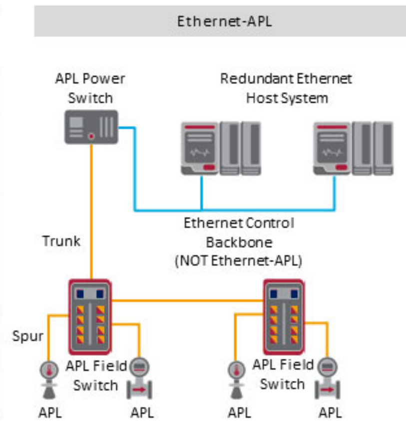


Figure 2 – Architectural differences

2.1.1 Point-to-Point vs Multidrop

In Ethernet-APL, by virtue of the network switching technology and APL Power Class designations for the ports, each field device will make a connection to the network through the APL field switch and will be point-to-point. The nature of the switching technology is the physical decoupling between ports to prevent interferences such as signal crosstalk and short circuits. The Ethernet-APL physical layer will bridge the field device connection to the control network and the power source for the field device will be available on every Ethernet-APL port. In Foundation fieldbus, the differences are subtle but are there. The fieldbus device coupler will create the connection for the field device to the H1 segment. Unlike the Ethernet-APL switch, the device coupler does not have an integrated power supply. In fieldbus, there is one power source for the trunk, typically originating in the control room, and each spur is making a parallel connection to the trunk line. Since this parallel connection exists throughout the entire H1 segment, the architecture is referred to as multidrop.

2.1.2 APL Field Switch vs FF Device Coupler

With both technologies, field devices need to connect to the network through a connection point. In Ethernet-APL, this device is known as a Field Switch. In FF, this device is known as a Device Coupler. Although similar in function, the elements of the products are different.

An Ethernet-APL Field Switch includes the functions: Uplink network connection, switch management, media conversion from a high-level network to a 2-wire network and connect the physical Ethernet-APL port cable for the field device.

A Foundation fieldbus Device Coupler includes the functions: Trunk connection with the ability to connect or terminate the trunk segment and connect the physical FF-H1 spur cable for the field device.

Both devices are typically placed in a Junction Box (JB) in the field. However, due to complexity of the functionalities and circuitries APL switches have, larger power consumption is necessary. This fact results in an enclosure of the APL switch with a larger heat dissipation. Furthermore, when a JB is in a Hazardous Area, not only the APL switch enclosure but also the surface of the JB is strictly required to be a lower temperature than explosion protection specifies. Therefore, the size of the APL switches is expected to be bigger than that of FF H1 couplers. In some cases, JBs that have been used in an FF H1 installation would be difficult to reuse with the new Ethernet-APL hardware.

2.1.3 Host System on a Segment vs Controllers on Backbone Ethernet

For Foundation fieldbus, the host system that establishes communication is located inside of the FF network. This host, known as an H1 host, typically resides in a Distributed Control System (DCS) cabinet. Some DCS systems support redundant H1 controllers to increase the availability of communication on the segment. Each fieldbus device on the segment will participate in the control strategy running behind the dedicated H1 card (or redundant pair). The control network in the plant will be above the H1 cards.

For Ethernet-APL, the controller that establishes communication is located on the control network, or the North side of the Ethernet-APL network. A key difference compared to FF-H1 is that there is not a special host hardware requirement beyond choosing the Ethernet control protocol of choice. The communication cards in the DCS (PROFINET, EtherNet/IP, etc) are directly connected to the control network. Because the Ethernet-APL devices have IP addresses and directly connect to the control network themselves, it allows for flexibility in how the control strategy is realized.

2.1.4 Same Trunk and Spur Topology

In the Ethernet-APL standard, one topology that is introduced is called “Trunk and Spur”. This same topology is used in FF-H1. A requirement that drove this topology in APL is a recognition that this is a familiar topology in fieldbus deployments. User stories for cable reuse also feed into this. Recognition of this topology ultimately sets the user up with a migration possibility to Ethernet-APL because the topology is the same and the existing cables can be reused after following a site-specific survey (see chapter 2.2.2).

2.1.5 Same “Type A” Cable

The preferred Ethernet-APL cable is IEC 61158-2 fieldbus Type A. Type A cable was originally designed for a transmission speed of 31.25 kbit/s rather than the 10Mbit/s needed for Ethernet-APL. Many of the Type A cables currently in use have been tested and found to meet the Ethernet-APL specification. See chapter 2.3.1 for a cable category system that lowers the possible usable cable length based on electrical performance for those cables that do not meet the Ethernet-APL maximum cable length requirements.

2.2 Physical Layer and Cable

Next to architecture, the specifications that should be identified as differences between FF-H1 and Ethernet-APL are the communication physical layer and the cable.

2.2.1 Physical Layer

For communication physical layer, Fieldbus (FF-H1 and PROFIBUS PA) uses the specific physical layer aspect standardized in IEC 61158-2. An electrical circuit for FF-H1, built according to the specification in IEC 61158-2, is called a Media Attachment Unit (MAU). Since the MAU is specific for Fieldbus it cannot have an IP or a MAC address. As a result, fieldbus networks cannot be connected to Ethernet directly.

On the other hand, Ethernet-APL uses 10BASE-T1L that is standardized in IEEE 802.3. IEEE 802.3 is widely known as an Ethernet Physical Layer standard. A chip set that provides 10BASE-T1L circuity is called a PHY chip.

2.2.2 Maximum Cable Length

For both FF-H1 and Ethernet-APL, the use of Type A cables standardized in IEC61158-2 is recommended.

For FF-H1, the maximum cable length specification of Type A cable, before taking cable power loss into account, is 1900 m for all Trunk and Spur cable lengths combined. The maximum spur cable length is 120m, which is reduced depending on the maximum number of field devices connected to an FF-H1 segment. Also, the widely used intrinsically safe concepts (FISCO) limits the maximum spur cable length to 60 m.

In this cable length specification, Ethernet-APL has the advantage compared to FF-H1. Ethernet-APL's maximum length for a typical Type A cable is 1000 m for each Trunk and 200 m for each Spur. There is no total cable length specification. The difference is due to the Point-to-Point versus Multidrop topology as described in section 2.1.1.

However, for both FF-H1 and Ethernet-APL, voltage drop due to current consumption must be considered depending on the wire diameter of the cable. By this, maximum cable length must be calculated on a case-by-case basis.

2.2.3 Power Consumption

The power consumption of Ethernet-APL field switches and field devices has a considerable impact on the feasibility of migration from FF-H1 to Ethernet-APL infrastructure. The power consumption of Ethernet-APL devices is substantially higher than that of FF-H1 devices, which may limit the allowable cable length for the trunk due to power losses caused by cable resistance.

The following examples illustrate these limitations; however, it is not generally representative due to the wide range of FF-H1 segment designs implemented by customers. The feasibility must be tested segment by segment to save time with typical segments. The assumption is that the FF-H1 field devices will be replaced with Ethernet-APL field devices over time. As a result, the calculation for the segment load considers the power requirements of Ethernet-APL field devices.

Segment conditions

– Trunk cable type: AWG-18 (~0.8 mm^2)
– Ambient temperature: +50°C
– Number of field devices: 12

FF-H1 conditions

– Fieldbus power supply: 28V@500mA
– Coupler: Zone 2 (Ex ic spurs) and Zone 1 (Ex ia spurs)
– Average current consumption per FF-H1 field device: 15mA
– FF-H1 spur cable length: 30m

Ethernet-APL conditions

– Power switch: 46V@2A
– Ethernet-APL spur cable length: 200m
– Field Switch: Zone 2 (Ex ic spurs) and Zone 1 (Ex ia spurs)
– Average current consumption per Ethernet-APL field device: 56mA (assumption is that Ex ia field device consumes the max. current provided by the switch)

	Zone 2	Zone 1
FF-H1	~1500 m	~1100 m
Ethernet-APL	~450 m	~345 m

Table 1: Maximum Trunk Cable Length Comparison Depending on Coupler/Switch Type

The values given in Table 1 may differ depending on the switch implementation but are suitable for a comparison. As can be observed, employing FF-H1 infrastructure allows for substantially longer trunk cable lengths compared to Ethernet-APL.

2.2.4 Intrinsically Safe Concept

FF-H1 specifies device profiles, including intrinsically safe profiles: FISCO (Fieldbus Intrinsically Safe COncept) and the Entity concept. Both concepts are specified in the IEC60079-11 and IEC60079-25 international standards for intrinsically safe explosion protection.

In IEC TS 60079-47, the Intrinsically Safe Concept for Ethernet-APL is specified as 2-WISE (2 Wire Intrinsically Safe Ethernet).

2-WISE is based on FISCO and uses the same maximum safety values and cable characteristics. The most significant distinction is the number of devices that can be connected to the intrinsically safe power supply.

FISCO and 2-WISE installations are evaluated in such a way that port, auxiliary device, and cable interconnection is simplified. There is no need to compare the safety parameters to examine the connectivity of intrinsically safe ports. APL field switches with an FF-H1 proxy may thus provide dual certification for FISCO and 2-WISE.

In contrast to 2-WISE and FISCO, which have maximum intrinsically safe field device currents of I_0= 380 mA, the FF-H1 Entity concept specifies I_0= 250 mA.

A FISCO/2-WISE power supply can only be connected to an Entity certified FF-H1 field device using an additional device, limiting the current to I_0= 250mA.

2.3 Adaptions to be Made on the Host Level, Engineering Level, etc.

This chapter refers to the differences between hosts, controllers, Asset Management Systems (AMS) that are above the field device level. It also touches on the engineering that results from the differences in architecture and physical layers and cables that have been discussed in chapters 2.1.12.1 and 2.2.

2.3.1 Verification of the Cable

As stated in chapter 2.1.5, Ethernet-APL is intended to reuse FF-H1 Type A cable. However, the installed cable must be analyzed from two perspectives:

- Given the greater cable power losses under the Ethernet-APL segment load scenario, is the trunk cable length requirement still met? This is already addressed in chapter 2.2.2.
- Is the trunk cable length still met when performance degradation due to alteration effects is taken into account? The installed cable must be tested for Ethernet-APL compliance using the cable category listed in Table 2 (this refers to table 4.3 of the "Engineering Guideline Ethernet-APL"). The Engineering Guideline is available at www.ethernet-apl.org.

Table 4-3: Maximum allowed cable lengths and cable parameters according APL cable category

Parameter	APL cable category			
	I	II	III	IV
Maximum trunk cable length in m	250	500	750	1 000
Maximum spur cable length in m	50	100	150	200
Coupling attenuation in dB	≥ 60 (*f* is frequency in MHz; $0.1 \le f \le 20$)			
Cable return loss in dB	≥ 15 + 8 x *f* (*f* is frequency in MHz; $0.1 \le f \le 0.5$)			
	≥ 19 (*f* is frequency in MHz; $0.5 \le f \le 20$)			
Trunk cable insertion loss in dB	$\le 10 \times (1.23 \times \sqrt{f} + 0{,}01 \times f + 0.2/\sqrt{f})$ (*f* is frequency in MHz; $0.1 \le f \le 20$)			
Spur cable insertion loss in dB	$\le 2 \times (1.23 \times \sqrt{f} + 0{,}01 \times f + 0.2/\sqrt{f})$ (*f* is frequency in MHz; $0.1 \le f \le 20$)			
Cross talk in dB, (PSANEXT/PSAFEXT wire pair to wire pair) for multi core cables	≥ 60 (f is frequency in MHz; $0.1 \le f \le 20$)			

NOTE 1 The values in Table 4-3 apply to both single pair and multi pair cables.
NOTE 2 Insertion loss and return loss shall be measured with a reference cable length of 500 m.
NOTE 3 The AC link segment requirements may also be verified using TIA SP1-1000 and ISO/IEC T1-A-1000 channel definitions, which might exclude IEC 61158 type A fieldbus cables from being compliant to these definitions.
NOTE 4 Depending on the APL cable category, the maximum cable length is limited. This allows the use of higher insertion loss cables, which, therefore, can only support a lower maximum APL segment length, while still fulfilling all requirements of this table.
NOTE 5 The cable return loss limit curve is 6 dB above the IEEE802.3cg limit curve, taking into account multiple additive signal reflections occurring at short cable lengths.
NOTE 6 For powered APL segments, the voltage drop over the cable has to be additionally taken into account in order to determine the maximum supported cable length.

Table 2 – Ethernet-APL Cable Category System

2.3.2 AMS/Engineering Tool Connection

Difference of the location of AMS/Engineering are shown in Figure 3 below.

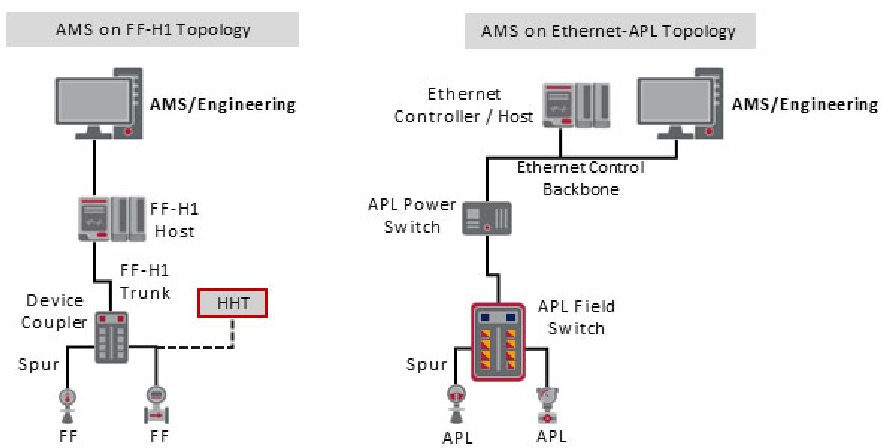


Figure 3 – Engineering Differences

In FF-H1 topology, the AMS/ Engineering tools are gathering device information from the FF-H1 host. Since it is an indirect connection, directly connecting a Hand-Held Terminal (HHT) closer to the field device is an alternative way to set parameters of the field device. However, in Ethernet-APL, AMS/Engineering tools can be connected in parallel to the Ethernet controller/ Host system with a direct connection to the APL field devices via the Ethernet control backbone. Since this connection is direct, there is no difference to connecting the HHT closer to the field device.

Further to say, a direct engineering tool connection offers adaption of conventional engineering tools widely used in the Ethernet world.

2.3.3 Redundancy

The point-to-point connection between devices is the fundamental nature of the Ethernet-based physical layer. Furthermore, Ethernet-APL supplies power, therefore the point-to-point connection always consists of a power supply (switch port) and a power load (field device). Fieldbus, as a shared network, may provide the network with more than one power source to power numerous power loads (field devices). This basic distinction specifies the primarily viable Ethernet-APL redundancy implementations.

Controller Redundancy
For both FF-H1 and Ethernet-based communication systems, controller redundancy is available.

Trunk Redundancy
The physical layer and the Ethernet protocol both influence the redundancy mechanism provided by Ethernet-APL. On the software level, Ethernet protocols implement redundancy as a ring redundancy or a parallel redundancy. Power and overlaid communication are provided by the two-wire Ethernet-APL physical layer. This necessitates particular hardware and software solutions to ensure the switch and field device availability in fault scenarios.

The Ethernet-APL specification currently does not provide a powered ring or a parallel redundancy with multiple field switches. Two power switches with one field switch can be utilized in migration scenarios when one coupler is connected to an FF-H1 trunk, and the field switch implements two load ports (see Figure 4). This arrangement is compatible with either a ring or a parallel redundancy software mechanism. Because the trunk cable is redundant, the availability is higher than FF-H1.

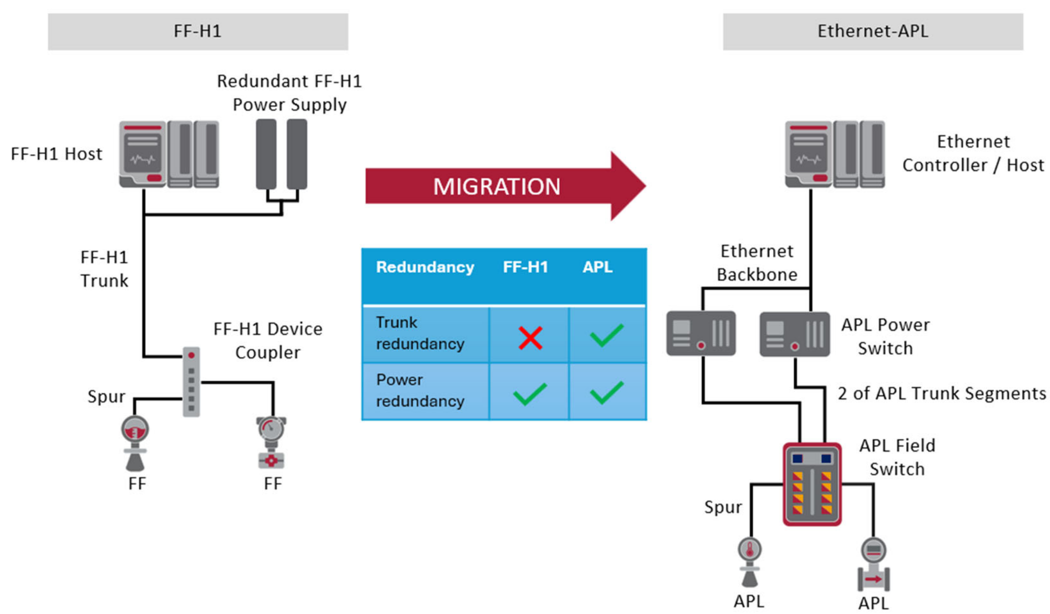


Figure 4 – Migration Scenario for Trunk and Power Redundancy

Power Redundancy
FF-H1 supports power supply redundancy with two power supplies feeding into one trunk. The equivalent solution is two power switches feeding into two power independent trunk segments to which one field switch is connected (see **Error! Reference source not found.**). The power and field switch need to support Ethernet protocol redundancy implementations such as ring or parallel redundancy (see paragraph above "Trunk redundancy").

Coupler/Field Switch Redundancy
Redundancy is not provided for the FF-H1 device coupler, as it is for the Ethernet-APL field switch.

Spur Redundancy
The STC project charter requests that redundancy be investigated for the connection between the Ethernet-APL field switch and the field device. Redundancy at this level necessitates considerations for the physical layer of Ethernet-APL that goes above and beyond what the current specification provides. Redundancy at this level is also non-existent with FF-H1.

3 Migration Concepts

The term migration is widely used, but it can have a different meaning for end users depending on the specific situation in their installation. The term migration can refer to an update in software and/or hardware for control systems, an upgrade in field equipment, etc.

The title of the project charter provided by FCG Strategic Technology Committee (STC) "FF-H1 Migration to Ethernet-APL" is misleading in the sense that not only is the physical layer included in the migration, but the focus is how to migrate the application layer of FF-H1 to the application layer of an industrial Ethernet-based protocol. A major use case is to replace the FF-H1 field devices with devices that support an industrial Ethernet protocol with Ethernet-APL connectivity over time. Accordingly, the user has chosen a control system that implements a specific Ethernet protocol with a corresponding tool chain, implementing specific communication services and application layers. Ethernet protocols provide specific services for deterministic communication, alarm, client/server access, redundancy, and security concepts.

Hence any FF-H1 migration concept must focus on the seamless integration of FF-H1 ensuring compatibility to the Ethernet protocol specification and provide a user experience like the Ethernet protocol.

The migration concepts consider a collection of user stories from the perspective of different stakeholders (see ANNEX A).

3.1 Proposed Migration Concepts

To manage the wide range of migration scenarios, one focus was set on the reuse of existing FF-H1 software assets, such as control applications, field device engineering, network engineering, and visualization through faceplates. Reusing existing software is one of the key costs for migrating FF-H1 to Ethernet (see user stories EU-0070, EU-0080, EU-0090, EU-0120, EU-0150, EU-0160, EU-0170, EU0200).

For smaller installations the main driver for migration to Ethernet may be modernization, to leverage new technologies like edge access, NOA, MTP, etc. (see user stories EUM-0001, EUM-0060) or simply because the installation requires modernization using the latest technology (see user stories EUM-0030, EUM-0070).
Furthermore, the end user faces difficulties maintaining the FF-H1 installation due to operating issues related to the physical layer or that no qualified maintenance staff is available anymore (see user stories EUM-0015, EUM-0040, EUM-0050).

Ethernet-APL based communications systems in 2024 are starting to get momentum, because new equipment such as field devices, infrastructure components like switches, or the support of Ethernet communication in control systems are announced to be available (see September issue ATP magazine article "No excuses: APL is available now “). Nevertheless, it will still take years before the choice of required field devices will be available to cover all possible applications in the process industries. Therefore, green field applications have been considered with a mix of Ethernet-APL field devices as well as FF-H1 field devices for which no equivalent Ethernet-APL field device is yet available.

Further user stories and requirements are valid for all migration concepts as well as for greenfield installations. These user stories/requirements define the boundaries of the following aspects:

– Physical network architecture (see user stories EU-0160, EU-0210, IS-0010)
– Simplification (see user stories UGO-0001, EUM-0040, EU-0130, IS-0010)
– PROXY field switch design (see user stories EU-0050, EU-0100, EU-0130, EU-0140, EU-0165, EU-0230, EU-0235, IS-0001, IS-0010, IS0020)

The key component for all migration concepts is a standard Ethernet-APL field switch enhanced with a PROXY software instance to additionally provide connectivity for FF-H1 field devices (see chapter 3.3).

3.2 Description of the Migration Concepts

G1, Greenfield
The primary focus for greenfield installations is the use of Ethernet from the controller down to field device. Field devices dominantly will support Ethernet-APL as the physical layer. To fill the gap for field devices which are not yet available with Ethernet-APL connectivity, FF-H1 field devices may be used. The control application, field device engineering and visualization software will be newly generated.

B1, Brownfield
The focus of migration concept B1 is the reuse of all existing FF-H1 software assets such as the control application, FF-H1 network engineering, field device configuration and visualization (e.g. faceplates). The FF-H1 infrastructure will be replaced by the Ethernet-APL infrastructure. The control system may be reused if the FF-H1 interface card can be changed out for an Ethernet card. The FF-H1 field devices may be reused or exchanged against Ethernet-APL field devices where appropriate.

Depending on whether trunk cables can be reused see chapter 2.2.3, the Ethernet-APL trunk-spur topology can be applied. If the trunk cable is not adequate for an existing installation, the trunk cable may be exchanged for a suitable fieldbus type A cable, or the Ethernet-APL spur topology can be applied instead of the trunk-spur topology using an Ethernet copper or fiber optic connection to the control backbone. Additionally, cables for auxiliary power for the field switch need to be installed.

To be able to reuse existing FF-H1 software assets, the control system and related tools require the support of FF-H1 field device data tunneling through the Ethernet protocol. A concept which fulfills this requirement is proposed in chapter 5.

Once the migrated installation is up and running, a replacement of an FF-H1 field devices to an Ethernet-APL field device requires:

– Ethernet network reconfiguration
– Adaption of the control application
– Field device configuration
– PROXY reconfiguration
– Visualization reconfiguration

Further information for migration concept B1 can be found in chapter 5.

B2, Brownfield
The focus of brownfield migration concept B2 is the redesign of most of the FF-H1 software assets. The physical network aspects for migration are identical to brownfield migration concept B1.

B2 concept will be most probably applied when the Ethernet based control system is not compatible with the existing FF-H1 control system. FF-H1 field device configuration can be reused if the principles in chapter 3.1 are applied.

In consequence an important aspect is the simplification of application and network layers to reduce the configuration effort caused by the migration. Generally, the same software architecture can be applied as for concept G1 and B1 (see chapter 4).

3.3 Physical Network Architecture

The physical network architecture is generally identical for migration concepts G1, B1 and B2. The STC guidance to follow a simple point-to-point architecture between the FF-H1 field device and the PROXY field switch (see user stories EU-0050, UGO-0001) defines the connectivity between the FF-H1 field device and the Ethernet network. This results in simplified engineering compared to the bus architecture of an FF-H1 network (see user stories EUM-0040, EPCM-0020).

A PROXY Field switch spur port shall be configurable to work either with an FF-H1 field device or an Ethernet-APL field device. The intention is to use existing, standard Ethernet-APL Field switches provided with a PROXY software extension.

From the network architecture point of view, Ethernet does provide several redundancy concepts (e.g. ring-redundancy or parallel redundancy) which are complemented by software, specific for each Ethernet protocol such as MRP for PROFINET and DLR for Ethernet/IP (see user story EU-0075, UGO-0010).

FF-H1 networks are exclusively designed using the trunk-spur concept with a limit of 16 field devices, connected to a simplex or redundant FF-H1 card and fieldbus power supplies. Ethernet-APL provides a comparable network structure where the coupler is replaced by a field switch and the fieldbus power supply by a power switch. The power switch is connected to one or a pair of redundant controllers via a control network, which could use any Ethernet physical layer such as copper 100Mbit/s or fiber optic. As the number of supported IP-devices on such a control network is much higher (e.g. 512 for PROFINET) several FF-H1 segments could be connected to one control network.

For simplification, some customers may migrate the physical FF-H1 network to a correspondent physical Ethernet-APL network. To reduce the overall cost for the network, it is expected that most of the customers will be connecting several FF-H1 segments to one Ethernet segment. Also, the installed trunk cable might not be suitable for migration because of its communication performance, load condition or length, see chapter 2.2.3. The Coupler could be replaced by PROXY field switches supporting direct physical connectivity to the control network. In installations where couplers for two or more segments are installed in one junction box or the junction boxes are installed nearby, one field switch may replace multiple couplers. In consequence, the FF-H1 trunk cable needs to be replaced by Ethernet copper or fiber optic cable. Also, additional auxiliary power is required for the power switch.

Assuming that the PROXY switch will be installed at the physical location where the coupler was installed the spur cable can be reused (see user stories EU-0010, EU-0020).

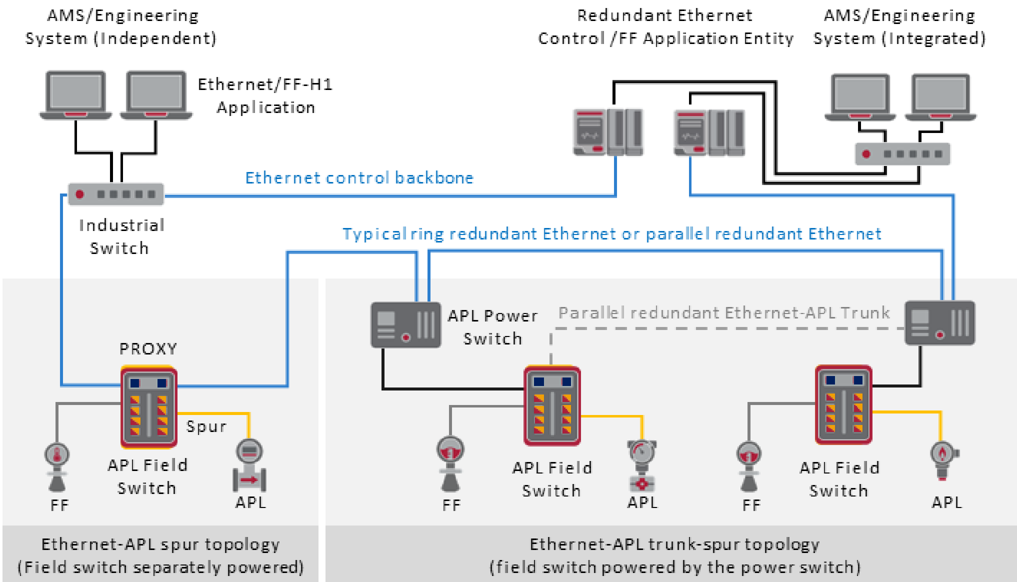


Figure 5 – Network Architecture for Migration Concepts G1, B1, B2

4 Software Architecture

For the integration of FF-H1 devices into Ethernet protocol networks, the PROXY field switch plays a central part. The PROXY acts as a gateway between the FF-H1 devices and the Ethernet based field control network.
To give full access to the FF-H1 field device data, the PROXY manages the mapping between the FF-H1 communication services and the Ethernet protocol communication services.

Publisher/Subscriber
Publisher/subscriber services are used to deterministically communicate the field device function block I/O data.

Client/Server
Acyclic read/write of management and application data of an FF-H1 field device.

Alerts, Alarms, Event Report Distribution
Notification, communication, confirmation and acknowledgement of alerts.

Figure 6 shows how FF-H1 communication services are applied within the Ethernet network and where mapping between the FF-H1 communication and Ethernet protocol services is needed.

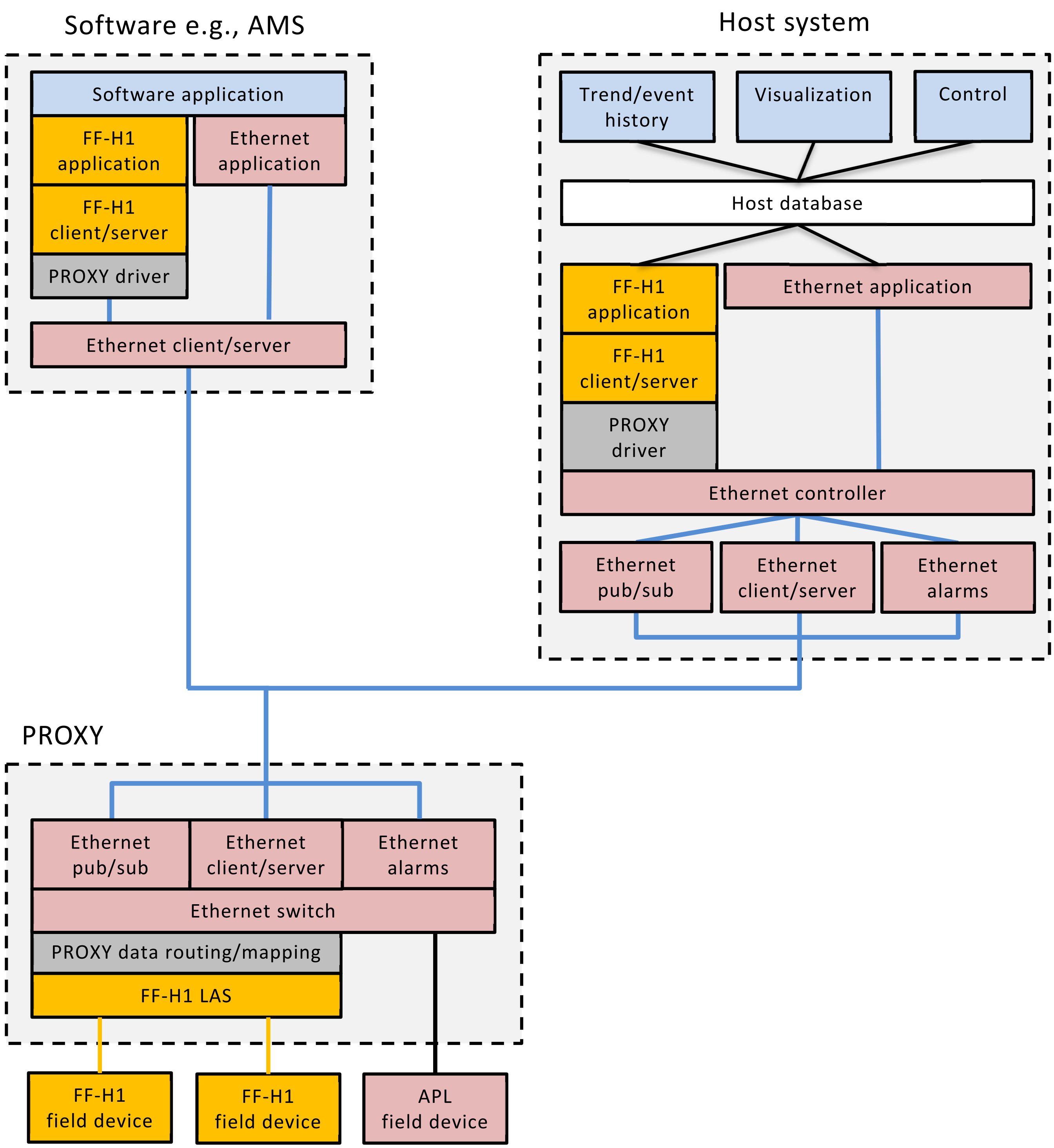


Figure 6 – Mapping of FF-H1 Communication Services

4.1.1 Publisher/Subscriber

Each Ethernet based communication protocol provides its own mechanism to transport process data in a deterministic way. This necessitates the decoupling of process data communication between the Ethernet network and FF-H1.

The FCG issued a specification “Standardized Connection Points SCP”, FCG_TS30916-1.0 in July 2018, which focuses on some of the aspects, particularly simplifications, which are of importance for migration.

The Standardized Connection Point (SCP) concept is a simplified scheme that allows a control system to use the I/O functionality of a field device without first having to configure function block schedules or communication connections.

In consequence, several FF-H1 features are simplified or disabled, including:

– Control elements in the field device; CIF features such as LAS and control blocks in the field device are not supported
– Block instantiation in the field device is not allowed
– Many network management functions are auto configured by the field device, including VCRs, links, and communication addresses
– Block execution is performed without an explicit schedule from the host (unsynchronized)

The STC user story FDS-0010 does exclude the use of SCP since field devices that support SCP are uncommon.
The plan is to leverage the core principles of SCP for the FF-H1 migration concept, although no changes to field devices are required.

Applying the SCP principles to the PROXY results in the requirements given in chapter 4.2.1.

4.1.2 Client/Server

To provide access to FF-H1 field device data for control system embedded or control system independent client application like asset management systems, engineering or visualization tools, FF-H1 client/server communication services shall be tunneled through Ethernet communication from the client application to the FF-H1 field device. The PROXY routes the received client services to the addressed FF-H1 field device and routes back the response to the client application.

The PROXY shall support multiple parallel client/server accesses for each connected FF-H1 field device.

The client application needs to support the FF-H1 client/server tunneling by means of communication drivers. These communication drivers are specific for a field device tool based on e.g., FDI or FDT. Today only FDT provides a specification for the tunneling of communication which is called “nested communication”.

Therefore, the PROXY requires a so-called gateway DTM which allows configuration of the PROXY but also implements the tunneling mechanism between FF-H1 client/server and Ethernet.

For FDI, the nested communication is not yet available, but specification development is ongoing. For configuration of the PROXY in an FDI based application an FDI-package needs to be provided.

In addition to the driver for nested communication, the field device tools include a standard Ethernet protocol specific communication driver, called communication server for FDI or communication DTM for FDT. To be able to reuse these communication drivers, the FF-H1 client/server communication must be tunneled through Ethernet protocol specific data objects by means of a mailbox.

Summary requirements for Client/server communication:

- The FF-H1 client/server services shall be tunneled via the Ethernet protocol client/server services from the client application to the FF-H1 field device and backwards.
- Tunneling principles are already specified in some Ethernet protocols. The Ethernet protocol tunneling specification shall be used if it is specified.
- Some of the Ethernet protocols have already specified tunneling concepts. If available, the Ethernet protocols tunneling concept shall be applied.
- The PROXY shall support an Ethernet protocol specific device instance, represented as a gateway between one or more FF-H1 segments, for integration into FDI and/or FDT based engineering tools.

4.1.3 Alerts, Alarms, Event Report Distribution

Each Ethernet protocol specifies its own alert services, alarm and event types which are incompatible with FF-H1. To maintain the FF-H1 alert principles, FF-H1 alert notification shall be mapped to an Ethernet protocol specific service to inform the alarm/alert application that an alarm or event occurred. An alarm/alert application reads the alert objects and manages alert confirmation and acknowledgement by using the tunneled FF-H1 client/server services.

Some Ethernet protocols require the mandatory support of specific alarm and event types transported through their services. The PROXY shall support a mapping of the FF-H1 alarms and events to the semantically equal alarms and events specified by the Ethernet protocol.

4.2 The PROXY Field Switch

The proposed PROXY field switch design approach may be used with any migration concept.

4.2.1 Requirements Derived from the SCP Principles

The following requirements must be met when applying the SCP principles to the PROXY:

- The PROXY shall implement IO-endpoint interfaces to each of the connected FF-H1 field devices providing function block I/O data.
- The PROXY shall implement an Ethernet protocol specific I/O object interface to the Ethernet based control system and map the FF-H1 I/O endpoint data to the Ethernet specific I/O objects.
- The PROXY shall map the I/O endpoint data to the Ethernet protocol specific I/O object data.
- The Control application shall be exclusively executed in the control system.
- Block execution in the field device shall be managed by the PROXY without an explicit schedule from the control host (unsynchronized).
- Control in the field device (CIF) features such as LAS and control blocks in the field device shall not be supported.
- Block instantiation in the field device shall not be allowed. This requirement has been thoroughly examined and determined not to be a problem with existing field devices.
- Network management functions in the field device may be auto-configured by the PROXY or may be configured in the PROXY including VCRs, links, and communication addresses such that the field device I/O data is published to the PROXY or subscribed from the PROXY. This leads to simplification for engineering depending on the PROXY implementation in use.

4.2.2 LAS Implementation

A PROXY field switch implements several spurs to which FF-H1 field devices are connected. It represents an I/O device on the Ethernet and one or more LAS providing publisher/subscriber I/O endpoints to publish or subscribe function block data on the FF-H1 side.

The PROXY provides for each FF-H1 spur, I/O endpoint resources for the function block data of one field device see Figure 7. This resource is implemented PROXY vendor specific, but shall support function block I/O data for both:

– A minimum of 8x identical function blocks of types of AI, AO, DI, DO.

– A minimum of 1x function blocks of types of MAI, MAO, MDI, MDO.

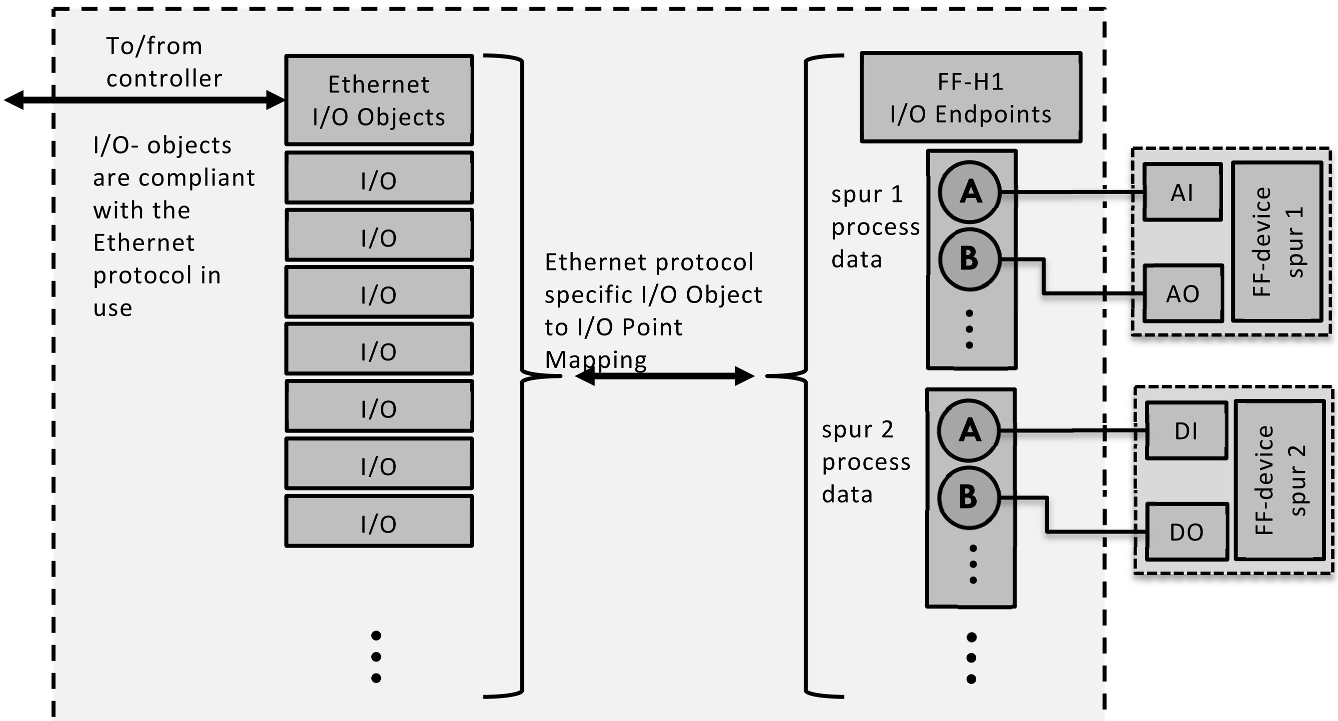


Figure 7 – PROXY I/O Endpoint to Ethernet Object Mapping

The PROXY may include one LAS per spur, or one or more LAS may share numerous spurs see Figure 8.

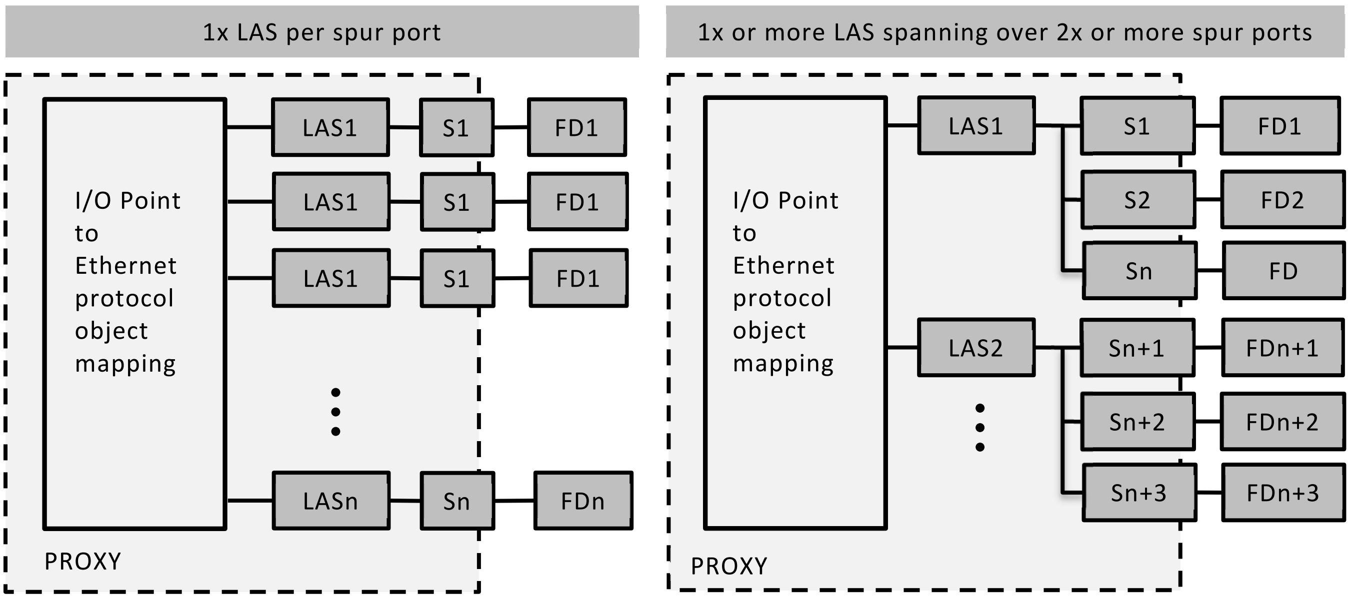


Figure 8 – PROXY LAS Structure

4.2.3 PROXY Configuration

The PROXY requires configuration for:

- The FF-H1 function block I/O data must be published/subscribed for each field device and mapped to the Ethernet protocol's deterministic communication service. This setting is part of the Ethernet controller configuration.
- The FF-H1 network management parameters. The achieved simplicity in the LAS architecture may allow for standardization on a set of parameters, making configuration superfluous.

In addition to the PROXY, the field switch must be configured for Ethernet network management services such as port disabling, password management, redundancy, system time management, and so on. FDI Package and DTM drivers are required for Ethernet-APL switches to integrate into field device management systems, supporting the network management configuration.

Additionally, the PROXY device driver shall support FF-H1 field device search services, or if supported, the detection of multiple LAS.

5 Special Consideration for Migration Concept B1

The main user stories for migration concept B1 focus on the reuse of the existing FF-H1 software assets to minimize cost and time for execution (see EU-0070, EU-0080, EU-0090, EU-0160).

Since FF-H1 and any industrial Ethernet protocol use different application models and communication services, routing of FF-H1 data to the software applications database is always required. All control systems maintain a database that contains all publisher and subscriber data, client and server data, and alert information. In the case of FF-H1, this data is communicated via the FF-H1 interface card. Data from the database is used by different software assets. To map and tunnel the FF-H1 data to an Ethernet protocol, the FF-H1 data must be routed and mapped to the control system database. If the control data is mapped from the Ethernet protocol deterministic services to the control system database the control application can be reused, see Figure 6.

If the control system or other software applications allows tunneling of FF-H1 client/server data over the Ethernet protocol, the following FF-H1 software assets can be reused:

– Visualization, such as faceplates for FF-H1 client/server or alert data.
– Trend and event history management.
– Field device configuration data.
– FF-H1 network management configuration data, for PROXY implementations which require FF-H1 network management.

Additional engineering is necessary to configure the Ethernet interface card in the AMS to establish and configure the PROXY field switch.

The following adjustments to current software assets are necessary when migrating an FF-H1 field device to an Ethernet-APL field device:

– Ethernet communication must be reconfigured since the Ethernet-APL field device is now an IP-device in and of itself and is no longer represented by the PROXY field switch.
– To remove the FF-H1 field device, the PROXY field switch must be reconfigured.
– The control application must be reconfigured since the FF-H1 function blocks must be replaced with Ethernet protocol specific function blocks.
– The Ethernet-APL field device must be added to the AMS, and the FF-H1 field device must be removed.
– The Ethernet-APL field device needs to be configured.
– Visualization faceplates need to be updated.

6 Conclusion

Migration of an existing FF-H1 installation to an Ethernet-based control system is doable by reusing most of the software assets, given the communication service mapping outlined in the preceding chapters. The host suppliers must implement the required software interfaces as a prerequisite.

Changing an FF-H1 field device to an Ethernet-APL field device always necessitates software reengineering.

Annex A
User Stories

Collected user stories are collected from the perspective of:

- The end user
- Control system vendor
- Field device vendor
- Infrastructure vendor (Ethernet-APL switches)
- EPC
- FCG (user group organization)

The user stories are categorized according to their importance for the migration concepts of Greenfield G1, Brownfield B1 and Brownfield B2, and prioritized accordingly.

Priority Ranking for User Stories
Prioritization of user stories to assure the acceptance of users for one or more migration concepts.

- P1: Critical
- P2: Important
- P3: Desirable

Several user stories do not directly impact technical requirements for this migration concept, but give guidance for additional deliveries once a technical specification is released such as:

- Engineering guidelines, including step by step evaluation and implementation procedures for different migration scenarios.
- Support of conformance testing for the PROXY switches.

Motivation for Migration

Id	Cat.	Prio	Story	Comment
EUM-0001	all	P2	to introduce IIoT, DX in my plant for efficient operation. ▪ Utilization of unrevealed information only used inside of the field devices that could not be transmitted because of slow data rate of fieldbus or small power of 2-wire device ▪ Integration of field level and enterprise level network ▪ Access information on field devices directly from edge or cloud computing enabling remote engineering/operation or, diagnosis of the plant or, etc...	mostly important for green field introducing new host systems

EUM-0010	B1, B2, B3	P1	to replace my broken or aged FF-H1 components (field devices, infrastructure device, system interfaces) with Ethernet-APL component because the same or alternative FF-H1 component is no longer available for purchasing or has long delivery times, increased prices, end of life info etc.	Leads to general system and infrastructure upgrade. FF-H1 field devices are kept where appropriate.
EUM-0015	all	P1	Declining support of FF-H1 on the system side e.g., systems do not support an FF-H1 interface	
EUM-0030	B1, B2, B3	P2	My plant is 20 years old, and I need to modernize it for at least the next 20 years – so the latest technology is required.	Leads to general system and infrastructure upgrade. FF-H1 field devices are kept where appropriate.
EUM-0040	B1, B2, B3	P3	I am not happy with my existing FF H1 installation, difficult handling (network management), problems in operation (installation), cannot do what I wanted to do and want to change it step by step (or on an opportunity base)	
EUM-0050	B1, B2, B3	P2	I don't get any trained personal for my installation and on the vendor side for support any more (technical specialist for planning & trouble shooting)	Growing issue due to aging installations and aging staff
EUM-0060	all	P2	I want to expand my installation for modern automation topologies, and this is not supported by FF H1 (NOA, modular automation, vertical & horizontal integration, data storage on cloud or servers)	Ethernet-APL is the enabler technology for the listed use cases
EUM-0070	all	P1	It allows me to standardize on one common network to connect my different IO-solutions to process systems.	Harmonization to one common Ethernet communication protocol specific for one end user
EUM-0090	all	P1	my management has strategically decided on Ethernet-APL as the global company standard => I cannot effort to update all my equipment immediately / not all equipment is available with APL yet - so I have to migrate step by step my FF-H1 installation	
EPC Motivation				
EPCM-0010	all	P1	I want to handle as few as possible technologies (manpower, training requirements, experience)	Set focus on Ethernet-APL based system and reduce legacy technologies
EPCM-0020	all	P3	Ethernet-APL seems to be easier to handle/to learn as FF H1 network planning	Reduced complexity of Ethernet-APL compared to FF-H1
EPCM-0030	all	P3	I do have IT experts that know industrial Ethernet networks (e.g., PROFINET, Ethernet IP) but no/few experts on FF H1	
Field device supplier motivation				

FDSM-0020	all	P1	I want to implement new features into my products that require higher bandwidth/higher functionality	
FDSM-0030	all	P3	I expect lower product costs due to Ethernet technology (mass market for electronics) compared to proprietary fieldbus components (no. of suppliers; variety of components; development tools)	Cost and complexity hurdles for smaller suppliers are lower compared to FF-H1
FDSM-0040	all	P2	I expect better sales with modern/innovative technology and expect my customers to pay better prices for it.	From marketing perspective

User stories:
As an end user (I want ...

Id	Cat.	Prio	Story	Comments
Infrastructure				
EU-0001	all	P1	to migrate an existing FF-plant to Ethernet-APL based infrastructure by re-using installed FF-field devices so time and cost are minimized	
EU-0010	B1, B2, B3	P1	When migrating existing FF plant to Ethernet-APL based infrastructure, minimize changes in topology and physical location of network components to minimize time and cost	
EU-0020	B1, B2, B3	P1	To re-use existing trunk and spur cables so that time and effort for revamping is minimized	Depending on segment load conditions trunk cable might not be reusable
EU-0030	all	P1	To use Ethernet-APL for intrinsically safe and non-intrinsically installations to cover all process conditions in my plant	
EU-0040	G1	P2	to install a new plant with a mixture of FF-field devices and Ethernet-APL field devices to maximize my choice of field devices	Also, expansion projects
EU-0050	all	P1	To use the same proxy switch port to connect either one FF-H1 or one Ethernet-APL field device that in case of the exchange of an FF-H1 field device to an Ethernet-APL field device the infrastructure is kept unchanged	
EU-0060	all	P1	To migrate one FF-H1 field device to an Ethernet-APL field device at the time of its failure to minimize initial cost for plant migration	
EU-0070	B1	P1	To migrate one FF-H1 field device to an Ethernet-APL field device at the time of its failure with reuse and no change of existing FF software assets for plant migration. So that initial costs for hardware changes (all switches incl. junction boxes) and necessary software preparation for the	

			APL migrated system will be allowed to be incurred as needed. FF Software assets: control application, engineering information for FF segment etc.	
EU-0075	all	P1	Support high availability as with FF-trunks	Don´t change the Ethernet-APL physical layer
EU-0076	all	P1	to keep my field enclosures and just replace the field device couplers by field switches to save time and cost for the enclosure replacement	Has limits to size and hazardous area certification for the enclosure and the Field Switches
EU-0077	all	P1	to know, if my existing H1 cabling is suitable for the migration of an installed plant	Quality, degradation might impact the cable performance
Control				
EU-0080	B1	P1	Want to reuse control strategy, graphics and alarming to minimize migration cost	
EU-0090	B1	P1	That the integration concept permits access to FF-H1 devices without modifying the control logic of existing applications.	
EU-0100	all	P3	That the integration concept from FF-H1 to Ethernet-APL leads to better performance by e.g., faster loop times to increase the quality of my processes	
EU-0110	B1, B2, B3	P1	Control system suppliers provides a clear migration path for my control modules and strategies to move from FF to eAPL I/Os.	
Engineering for Network and Field Device				
EU-0120	B1, B3	P1	That I don´t need to change the FF-H1 field device configuration when converted to an Ethernet-APL network to minimize time and cost for migration	Transducer high requirement, maybe some automation is required
EU-0130	G1, B2	P2	Want to have a simplified FF application and network layer to reduce migration complexity and network engineering	Needs to be narrowed down for clarification
EU-0140	all	P1	That the integration concept should not make Foundation Fieldbus more difficult to deploy to minimize time and cost for retraining	
EU-0150	B1, B2, B3	P1	That the integration concept permits the transfer the engineering data from the previous FF-H1 system, and additional changes are possible.	Proxy or engineering system should handle the engineering data as it is but may change, skip or add details
EU-0160	B1	P1	I want to completely reuse control applications, graphics, and alarms, without migration costs. Background: Even a small cost will be a rejecting factor for migration in case of large system. So, the ideal goal should be "zero" rather than "minimal”.	
EU-0165	all	P2	to that the spur outputs of a field switch support besides 2-WISE also Entity and FISCO certification to be able to use existing FF field devices in an intrinsic safe loop.	2-WISE and FISCO are technically feasible. FF-Entity might require an additional barrier between the switch and the field device

Asset Management				
EU-0170	all	P1	to integrate field devices and proxies into the AMS using existing DD´s to minimize time and cost for engineering	
EU-0180	all	P1	An open integration concept that allows the data to be visible to other systems. This will allow me to decouple my AMS solution from my control system supplier.	
EU-190	all	P1	A solution that is compatible with existing FDT/DTM applications and the FDT3 standard.	Solution should be independent from the technology
EU-0200	all	P1	FF devices connected to an Ethernet-APL switch can be accessed via DTMs, because I want to reuse my FDT based AMS system.	
EU-0210	B1	P1	FF device annunciation of diagnostics (i.e., block errors, FF912) are maintained when connected to an Ethernet-APL switch.	
EU-0220	B1	P2	Unlike Device replacement of ITK 5.0/6.0 FF devices connected to an Ethernet-APL switch is straightforward or if possible simpler than it currently is. Block instantiation is maintained.	Needs more discussion with David about intension
EU-0230	all	P1	Continue having access to physical layer diagnostics for FF devices connected via an Ethernet-APL switch. Ditto for communication diagnostics (e.g., device offsets).	Requires new FF specifications. Implementation is today vendor specific
EU-0235	all	P1	to get FDI packages for field devices and field switches to integrate into modern/latest asset management tools	
Standardization/Documentation				
EU-0240	all	P1	When migrating existing FF plant to Ethernet-APL based infrastructure, documentation (engineering guideline) should be provided to easily decide the extent of diversion. (e.g., relationship between cable diameter and cable length)	
EU-0250	all	P2	A standard solution with no room for interpretation so that it can be applied consistently by all control system suppliers.	Might be difficult to achieve in all details

As a control system supplier, I want …

Id	Cat.	Prio	Story	Comments
CSS-0001	B3	P1	That the open integration concept doesn´t prevent me to provide a proprietary integration concept that end users can leverage from a tight integration of Ethernet-APL based networks into my control system and into my field switch	

CSS-0010	all	P1	That the integrated concept permits the use of FF-H1 application services (system management service) using the same procedures as the FF-H1 protocol. This will allow the use of device search services, such as those used for plug-and-play.	Application services may not be identical but provide same functionality

As an infrastructure supplier I want …

Id	Cat.	Prio	Story	Comments
IS-0001	G1, B1, B2	P1	to use the same standardized integration concept for different communication protocols to minimize development time and cost	
IS-0010	G1, B1, B2	P1	Want to minimize design complexity of Ethernet-APL proxy switches by supporting a simplified FF application and network layer	See concepts provided in TS-30916 (standardized connection points)
IS-0020	G1, B1, B2	P2	a technical requirement specification that is as open as possible to have sufficient freedom in field switch development and the possibility of incorporating own innovative features	Focus on interoperability but provide flexibility on implementation e.g., network timing and address depending on the migration concepts B1 and B2
IS-0030	G1, B1, B2	P1	a SDO conformance test specification and registration-mark to prove interoperability between the control system, APL switches and FF field devices	

As a field device supplier, I want …

Id	Cat.	Prio	Story	Comments
FDS-0001	all	P1	To sell my existing FF-H1 field devices without the need to change its design to be avoiding additional investment	
FDS-0010	all	P1	That the integration concept does not require an update of my device firmware to support Standard Connection Points (SCP) functionality to avoid additional investment	

As user group organization we want …

Id	Cat.	Prio	Story	Comments
UGO-0001	all	P1	the point-to-point architecture as a basis for Ethernet-APL integration, so that end users and manufacturers can leverage from the architectural simplicity and reduced engineering effort	
UGO-0010	all	P2	To explore redundancy concepts on the media and field devices connection level to provide the highest possible level of availability to end users	Do not prohibit the use of existing redundancy concepts for Ethernet-APL. Provide

				guidance on the application level
UGO-0020	all	P1	That the integration concept relies on existing technologies e.g., FDI, PA-DIM etc. to leverage from existing, future proven technologies	
UGO-0030	all	P2	That the concept does not prevent the application of any Ethernet based communication protocol, including those providing functional safety, to increase the solution space for end users	Do not prohibit the use of existing safety concepts. Provide guidance on the application level