High Speed Ethernet

Promoting openness in hybrid control

Eugenio F. da Silva Neto and Peter G. Berrie,
Endress+Hauser Process Solutions AG

Many tasks in Process Automation require a combination of continuous and sequential control. Develop-
ments in Ethernet-based backbones, however, are increasingly addressing the problems of high-speed, real-
time Factory Automation only. There is one exception: FOUNDATION Fieldbus High Speed Ethernet.
This paper shows, on the basis of practical examples, how High Speed Ethernet supports hybrid control
through standard and flexible function blocks, provides innovative and powerful solutions by bridging field-
bus networks, and allows the use of both FOUNDATION Fieldbus and PROFIBUS solutions when the applica-
tion demands it.

Flexible Function Block / FOUNDATION Fieldbus / High Speed Ethernet / Hybrid control / PROFIBUS

1. Introduction

It is a common misunderstanding that the High Speed Ether-
net specification, first published in 2002, is a communication
standard only, i.e. a way of getting control-relevant data
from A to B. Nothing could be farther from the truth. It is the
result of many years deliberation on the functions required
at the supervisory/control level to supplement the powerful
concept of the Function Block Application Process embed-
ded in the Fieldbus Foundation H1 specification. High Speed
Ethernet, as an open standard, contains a user layer that
provides everything required for decentralized process con-
trol. It is “Internet for Process Automation”.

As Internet users we just plug-in, call up our favourite
browser and look for the information we require. We use
search engines to find information, send and receive e-mails,
upload and download files, participate in interactive chat
sessions, pay bills, subscribe to publications, etc. As a site owner
we might also register the number of clicks, check the origin of visitors, keep statistics
and monitor trends. If we attempt to access a closed site,
an error message is displayed, but should it move from one
server to another, more often than not, we are automatically
rerouted. In fact, how we get from A to B does not concern
us at all. We just enjoy the benefits of having open, i.e. stan-
dardized and seamlessly integrated web applications.

If we look closely at the activities in a decentralized cont-
rol system, we see remarkable analogies to those performed
in Internet: data exchange, data acquisition, visualization,
trending, alarming, parametrization, asset management,
performance tuning and security management. How would
it be if we could just plug-in our host and see the whole plant
view and have access to every asset?

Would this be an advantage? Does a “broad interoperabi-
ity concept” bring any tangible savings and benefits to the
plant? In this paper the authors will examine HSE more clo-
sely, discuss the concept of the flexible function block used
as complementary technology and show how HSE can be
used for hybrid control on the basis of practical examples. In
addition, the benefits, acceptance and prospects for the
future will be briefly discussed.

2. High Speed Ethernet

HSE as plant backbone provides more than just a physical
path and control of media access. It is fully standardized up
to and beyond the application layer. This paper does not
describe HSE in detail, but restricts itself to a general over-
view of the features of interest to its use. More detailed infor-
mation is to be found in the specifications and any good
book on the subject [1, 2, 3].

2.1 Physical layer

Table 1 summarizes the main properties of the High Speed
Ethernet physical layer. Since they are Ethernet based, net-
works use a variety of commercial off-the-shelf (COTS) hard-

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>IEC 61158; Application Layer</td>
</tr>
<tr>
<td>Support</td>
<td>Fieldbus Foundation Organization</td>
</tr>
<tr>
<td>Physical layer</td>
<td>IEEE 802.3u; Ethernet 100BaseT, 100BaseF</td>
</tr>
<tr>
<td>Cable:</td>
<td>Copper: 2x shielded twisted pairs; Optics: fibre optic cable</td>
</tr>
<tr>
<td>Cable specification</td>
<td>Supported twisted pair cable category 5 or fibre optic components</td>
</tr>
<tr>
<td>Max. length</td>
<td>(UTP/STP)100m or (Multimode Fibre) 2000m, possible to expand with repeaters (switches)</td>
</tr>
<tr>
<td>Participants</td>
<td>256</td>
</tr>
<tr>
<td>Transmission rate</td>
<td>100 Mbps (fixed)</td>
</tr>
<tr>
<td>Bus access method</td>
<td>CSMA/CD: Carrier Sense Multiple Access/ Collision Detect</td>
</tr>
</tbody>
</table>
ware such as industrial connectors, cables, hubs, switches, routers, and firewalls. HSE is mainly used in a star topology but also supports dual LAN and Ring topologies if required.

2.1 HSE network

Fig. 1 shows a schematic diagram of a HSE Foundation Fieldbus network. It comprises one or more interconnected HSE subnets and/or one or more H1 fieldbus segments (also called links). A HSE subnet comprises one or more HSE devices connected via Ethernet, with HSE subnets being interconnected by standard routers or switches. A H1 link interconnects one or more H1 devices.

2.1.1 HSE network

Fig. 1 shows a schematic diagram of a HSE Foundation Fieldbus network. It comprises one or more interconnected HSE subnets and/or one or more H1 fieldbus segments (also called links). A HSE subnet comprises one or more HSE devices connected via Ethernet, with HSE subnets being interconnected by standard routers or switches. A H1 link interconnects one or more H1 devices.

2.1.2 Device types

The network in Fig. 1 has four HSE “device” types connected to it:

- **HSE Host Application**: A host application is e.g. a configuration application, which may be connected to the network permanently or temporarily, according to function.
- **HSE Field Device**: The HSE Field Device is the HSE equivalent of the H1 Field Device.
- **HSE I/O Gateway**: An I/O Gateway provides UDP/TCP access to networks and devices that do not support the FF protocol.
- **HSE Linking Device**: The HSE Linking Device interconnects one or more H1 links to an HSE subnet, providing UDP/TCP access to FF H1 field devices. A HSE linking device is sometimes called a bridge when it has the ability to forward and republish data, see Section 2.3.1.

A single HSE device may function as a HSE Field Device, a HSE Linking Device and/or an I/O Gateway device.

2.2 Data link layer

Like FOUNDATION Fieldbus H1, High Speed Ethernet transfers data in three different ways, using the features provided by the Ethernet TCP and UDP protocols:

- **Publisher–Subscriber**: A publisher multicasts its data when it is requested. One or more subscribers to the data receive the data to update their local copies. There is no direct confirmation of receipt, but transfers can be scheduled. Subscribers can get data from one or more publishers.
- **Client–Server**: A client issues a request and sends it to its server communication partner. When a requested action is executed and its confirmation is necessary, the server issues response to the client.
- **Report Distribution (Source–Sink)**: When a source detects a necessity to report an event, it multicasts the event. One or more sinks receive and detect the event. One of the sinks is responsible for acknowledging the event via a separate Client-Server application relationship.

Table 2 summarizes the way in which the three methods are used by HSE.

2.3 Application layer

2.3.1 Bridging

Bridging is the ability to forward and republish plant, process and device information (value and status) among multiple devices plant-wide. This means that two or more devices can exchange (and interlock) data via an Ethernet backbone to realise process control tasks within a time schedule defined and managed by a process automation system.

Fig. 2 illustrates the three bridging mechanisms available on an HSE network:

- **H1-H1 bridging**: Process control information can be exchanged between devices in different H1 segments but connected to the same linking device.
- **HSE-H1 bridging**: Information is exchanged between HSE and H1 devices by using the so-called HSE–H1 forwarding mechanism.
- **H1-HSE-H1 bridging**: This allows devices connected to different
HSE linking devices to exchange data across the HSE network, and is essentially an extension of the HSE–H1 forwarding mechanism.

### 2.3.2 Redundancy

A HSE network is expected to be used for the control and monitoring of an industrial plant. This demands a higher availability of the automation system than a non-fault tolerant system can provide. The solution is to provide a means of redundancy. In order to ensure operational transparency, the redundancy may not be visible to the communicating applications. HSE provides redundancy at two levels:

- **Local Area Network (LAN) redundancy** utilizes multiple network interfaces at the HSE devices to maximize their ability to communicate with the other devices on the HSE network.
- **Device redundancy** allows one or more backup devices (secondaries) to take over the function of a primary device in the event of its failure.

The HSE specification foresees three distinct types of HSE device redundancy:

- **Uncoupled**: these devices can be assigned to take over the role of a failed device by a configuration application.
- **Loosely coupled**: these devices maintain the same PD Tag and configuration information as their correspondent primaries to allow for more rapid response to failures than uncoupled devices.
- **Tightly coupled**: these devices have full independent redundancy but behave operationally as a single device.

### 2.3.3 Sense of time

Each HSE device has a clock that provides time values for use in function block scheduling or time stamping within the device or any H1 segment connected to it. When necessary, the clocks can be synchronized to a remote time server.

Where a function block application process is operating at the HSE level, block execution is triggered at fixed offsets from the so-called current time in the HSE device. To this end, the function block application triggers execution after receiving a time event signal from the device system management. In the presence of function block scheduling, the value resulting from the execution of the function block is published immediately. Since each device has its own clock, time synchronisation must be used where the application is spread across the HSE network, i.e. a time server must be present in the network. Local clock times are then synchronised at regular intervals and current times corrected accordingly. Function block scheduling is then consistent across the network (HSE and H1).

The time event signal sent by the function block scheduling application corresponds to the compel data command sent by the link active scheduler to force the publication of a H1 process value. Function block scheduling on HSE is optional, however, and in its absence the HSE device will queue its messages in the transmission buffer and hold them until the transmit delay timer for the HSE device expires or the buffer is full. Despite this and the fact that medium access is regulated by the CSMA/CD mechanism, the process can still be considered deterministic. Firstly, the time synchronisation and H1 function block application process within a HSE device regulate part of the traffic on the bus. Secondly, the publication can be considered as instantaneous for traffic loads up to 50%, which even for extensive networks is seldom exceeded [2].

### 2.3.4 Multivariable Container

In time critical applications involving several process values, the use of the Multivariable Container (MVC) services also provides an optimized solution called multivariable optimization. A device publishing several process values to the network is engineered or automatically configured during operation to pack all its information in a “container”. The complete device information can then be published at once, either as a report or in a publisher-subscriber relationship. This ensures a complete process image of the current device status. The subscribing devices then filter out the process values they require, see Fig. 3.

### 3. Flexible function block

#### 3.1 Function block application process

One of the major differences between FOUNDATION Fieldbus and other fieldbuses is the ability of field devices and other intelligent equipment to execute tasks beyond simply measuring process values or positioning valves in response...
From the desk to manufacturer

Flexible Function Block technology has extended standard function block definitions still further, by allowing device vendors to encapsulate and embed “custom” algorithms within function blocks. These are fully interoperable with standard FOUNDATION Fieldbus function blocks. This has opened up unlimited opportunities for device manufacturers to provide unique solutions for specific applications by utilizing more intelligence within field devices.

As High Speed Ethernet also supports the function block application process, including flexible function blocks, it is the ideal backbone for decentralized hybrid control. “Field controllers” running flexible function blocks for sequential, logic and discrete control can supplement device continuous control capabilities by “bridging” existing embedded intelligence and extending distributed control capability beyond the local fieldbus domain.

3.2 Flexible function blocks

A flexible function block is nothing else but, for example, an executable sequence written in one of the IEC 61131-3 programming languages, well known to PLC programmers, wrapped up in a standard FOUNDATION Fieldbus function block shell. Four types of Flexible Function Blocks are defined by the Function Block Application Process [1c]. For practical purposes these can be reduced to the following combinations:

- Fixed or freely configurable wrapper, i.e. inputs and outputs
- Fixed or freely configurable programming.

An example of a fixed/fixed combination would be a pre-configured flexible function block provided by a manufacturer to solve a particular measurement or control task. A fixed/free combination would provide a programmer with a defined set of inputs and outputs, to which the user could tailor his own algorithm. Fig. 4 shows a Flexible Function Block of the latter type created in a FOUNDATION Fieldbus configuration environment.

The possibility of “wrapping” custom hybrid control algorithms with open and interoperable interfaces of a function block and linking its input/output over a high performance backbone is very powerful. As the “PLC” origin of the blocks suggests, flexible function blocks extend FOUNDATION Fieldbus capabilities beyond continuous control, allowing interlocking, emergency shutdown or just on-off motor and valve control. Their possibilities are not just limited to control, however, and many measurement applications, e.g. snap control, multivariable matrix control, variable speed drive control, discrete valve control, are possible candidates for a customized flexible function block.

Their application, however, is limited by restrictions placed on them by the FOUNDATION Fieldbus protocol itself. The blocks are executed within the function block application process, which means that on a FF H1 segment, they will normally operate within a macrocycle of 100 ms to 500 ms. Their scope of application in HSE is considerably greater, but they are never going to be suitable for tasks requiring time-critical, jitter-free control, e.g. in factory automation applications such as motion control or anti-surge in process automation, at least for a long time. Here the old adage “horses for courses” applies, whereby the course for the flexible function block is still not clearly defined. The technology is already available, however, so customers and vendors have a unique opportunity to take advantage of technology to innovate their business.
4. High Speed Ethernet in reality

High Speed Ethernet with the associated function block application process provides an open standard for process control that applies from the field through to the host application. The standardized plant application layer makes the system and all subsystems truly interoperable. So where does it stand today?

4.1 HSE devices

4.1.1 HSE transmitters and actuators

Starting on the negative side, three years after publication of the HSE specification there is still no HSE transmitter or “actuator” on the market. There are persistent rumours that devices will be introduced in the near future, but candidates are not forthcoming. Within the author’s company, High Speed Ethernet is at a great disadvantage as a possible interface for flowmeters, because “control auxiliaries”, e.g. frequency converters, motor starters, low-voltage switchgear, simply do not exist. Here PROFIBUS DP, Modbus and ControlNet/DeviceNet offer more profitable alternatives and choices at the current time.

4.1.2 Linking devices

In contrast to the situation with HSE transmitters and actuators, there are a few systems on the market that offer linking devices with bridging capability. Several major manufacturers have moved from Proprietary/H1 to HSE/H1 links. This, however, is more to do with having flexible access to the field than producing an open Ethernet backbone based on HSE standards.

The interoperability level provided by today’s linking devices does not give the absolute freedom of choice that allows customers to choose a single host to connect components from different vendors, configure their H1 devices through them and to download control strategies. Although, FOUNDATION Fieldbus has been demonstrated as an “open, integrated FOUNDATION fieldbus architecture” e.g. at the “Lima plant” [5], the reality is that “openness” is still limited to “field-based control systems” only.

This situation is being addressed by the Fieldbus Foundation, though, and steps are being taken on the standardizing of vital fieldbus system elements such as gateways and linking devices.

4.1.3 HSE I/O gateways

Perhaps the greatest development has been made in HSE I/O gateways. This has been driven partly by the need to integrate legacy devices into FOUNDATION Fieldbus systems and partly because of the lack of auxiliary control equipment with a FOUNDATION Fieldbus interface. At the moment HSE/Modbus and HSE/PROFIBUS DP gateways are on the market. These are available as simple gateways or equipped with a local controller for the connected network. Remote I/O in the sense of HSE/HART point-to-point or HSE/analog and digital is not on the market at the time of writing, but will probably be available in the near future.

4.2 HSE as system backbone

Fig. 5 shows a system using HSE as backbone and connecting to FOUNDATION Fieldbus, PROFIBUS DP/PA and HART devices. Both the HSE/FF H1 linking device and the HSE/PROFIBUS I/O gateway have control capability, use the same Function Block library and can be equipped with local I/O. The connection to PROFIBUS DP allows the integration of legacy HART devices through PROFIBUS DP/HART Remote I/O, whilst also providing a means of integrating the auxiliary control equipment necessary for hybrid control via PROFIBUS DP. An alternative, not shown here, would be the use of a HSE/Modbus gateway to connect to Modbus TCP or a direct connection to a Modbus controller with an HSE interface. HSE/DeviceNet is a similar option.

Data are visualized from a single (redundant) HSE OPC server, which collects information from both sides of the network. Similarly the configuration application provides a uniform environment for engineering the entire network: control strategies can be created and flexible function blocks programmed with the same Engineering tool. Of note here is the fact that the PROFIBUS controller has a CommDTM. By choosing appropriate components, the entire PROFIBUS assets, including auxiliary control equipment, can also be managed from a single tool. FOUNDATION Fieldbus devices are currently configured in the FF engineering environment, but here too a FDT solution is in view.

Connecting a foreign bus (in this case, PROFIBUS DP) to a backbone, is not new, nor is it an enabling solution. Translating PROFIBUS DP/PA cyclic data information into FOUNDATION Fieldbus function blocks is. By placing the PROFIBUS cyclic data in an FF wrapper and mapping process parameters, a “standard” FOUNDATION Fieldbus function block can be emulated. The input/output parameters can be linked in the standard manner to other function blocks within the gateway/field controller, to decentralized to various controllers in the HSE network and to distributed function blocks within H1 segments. Each link contains a ‘value’ and ‘status’,...
From the desk to manufacturer

44

5. Benefits of a HSE solution

It is probably true to say, that most end-users are not fully aware of the true potential of FOUNDATION Fieldbus, perhaps because most are familiar with field devices only. Interoperability, of particular importance to the FF concept, is conceived to apply to H1 field devices only, whereas the specification applies it to all equipment: linking devices, controllers, gateways and other network components. The result is an open system in which any component conforming to the HSE or H1 specifications can operate with any other component of the same ilk. This broad interoperability concept can, if it enough pressure is applied by the end-user, break down the last great bastion of proprietary enterprise, the control system backbone. The benefits to be had are many:

- **Freedom of choice**: All components in the system, from field devices through controllers to HMI, can be chosen for their suitability for the application rather than the control system. Eliminating dependency on a single manufacturer always brings cost and operational benefits.
- **Seamless integration into any system platform**: Components can be quickly and easily integrated into open systems. This not only brings savings in engineering, commissioning and operational expenditure (OPEX), it also means that all plant information is available on a “common backbone”, plant-wide, via HSE. It includes information integration with Plant Asset Management (sub-system integration) and business applications such as ERP, MIS, etc (data server integration).
- **Comfort, reliability**: The installed base of open components is potentially much larger than those “tweaked” to work in a semi-proprietary system. The end-user has the comfort of a well-proven IT solution. So-called off-the-shelf components are more reliable because they have been tested in many business applications.
- **Greater flexibility**: FOUNDATION Fieldbus interoperability ensures that all components work together. This means that there can be a much more flexible approach to planning, designing, extending and incorporating fieldbus networks for plant automation. This translates to more economy, more freedom and more transparency in plant management.
- **Increased scope**: Flexible function blocks add sequential, logical and batch control to FOUNDATION Fieldbus. There are a tremendous number of applications that require just a little more than continuous control. The end-user will benefit from solutions based on open standards, bringing savings in engineering and commissioning as well as better operation.
- **Improved plant asset management**: Built to provide open communication at all levels of the system, FOUNDATION Fieldbus already provides all the information required for plant asset management. Ultimately the end-user will have a choice between EDD-based and FDT-based systems. He will be able to select a system that is sized to the application and additionally see all the devices in the plant. The benefits are efficient maintenance and improved plant availability. This also means that “Asset Management” best practices will take advantage of open architectures and Internet standards.
- **Coordinated migration**: Improvements to specifications, enhanced functionality etc. are the responsibility of the Fieldbus Foundation. Revision control policy ensures backward compatibility of system components and devices. End-users are ensured of a well coordinated migration from one version to another.

6. Conclusion

A recent ARC Report stated that “many of the benefits of fieldbus are still being discovered as users gain more experience with these technologies in real world plant settings” [6]. The proposition of using a decentralized HSE-based platform to connect best-in-class devices in a best-for-purpose solution could be counted as one. It will only be cost-effective if:
- Customers and vendors have autonomy to take what is available in the market and install it in the plant without the hurdles and perils of integrating competing technologies.
There is no risk of putting in place a system platform that does not satisfy completely the plant’s requirement today and in the future.

The authors recognize that flexibility can also bring complexity, but by following the concepts of interoperability and openness to their full extent (from devices to backbone) the risk is much lower than that of having a proprietary solution, no matter how simple.

FOUNDATION Fieldbus High Speed Ethernet offers an open solution for continuous control, for hybrid control in the processing industries and for the integration of foreign bus systems into an overall process management system. It remains to be seen, whether end-users embrace this technology – the authors sincerely hope that they will and innovation will prevail.

Acknowledgements
This article is based on papers given at the Fieldbus FOUNDATION End-user Conference Jump Aboard initiative in Australia 2005 and the DCS XI conference in Budapest, Hungary in 2005. It is published with kind permission of the Fieldbus FOUNDATION and University of Miskolc - Research Institute of Applied Chemistry (Dept. of Research Instrumentation and Informatics) in Budapest.

References + Links

Received: February 2nd, 2006.

Eugenio F. da Silva Neto (BSc (EEEng), 41) works as ControlCare Product Manager for Endress+Hauser Process Solutions AG, Reinach, Switzerland. An Electrical Engineering graduate of University of Sao Paulo, Brazil, he spent 15 years working in Fieldbus technologies, conceiving and designing field devices based on the HART, PROFIBUS PA and FOUNDATION Fieldbus protocols. During this time, he worked in the technical committees and working groups for the standardization of these protocols. Eugenio F. da Silva Neto arrived at Endress+Hauser in 2001.

Address: Endress+Hauser Process Solutions AG, Christoph Merian-Ring 23, 4153 Reinach/BL, Switzerland, phone +41 61 715-7371, fax -7301, e-mail: eugenio.silva@solutions.endress.com

Peter G. Berrie (BSc (Eng), Ph. Dr., 57) works as Marketing Communication Manager for Endress+Hauser Process Solutions AG, Reinach, Switzerland. A graduate of Imperial College, London, he spent five years in research in Germany and England, before turning to technical communication in 1978. Peter Berrie arrived at Endress+Hauser GmbH+Co, Maulburg, Germany in 1990, as a technical author responsible for digital communication, level and pressure products. In 2000, he moved to his current position, where he is concerned with fieldbus technologies and process solutions that include instruments, monitoring, asset management and control.

Address: see above, phone +41 61 715-7340, fax -7301, e-mail:peter.berrie@solutions.endress.com