

Fieldbus specification

Part 1. System architecture

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Foreword

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This publication contains the following parts:

Part 1	System architecture	FF-94-800	Revision 1.0
Part 2	Network management	FF-94-801	Revision 1.0
Part 3	Data link layer services subset	FF-94-821	Revision 1.0
Part 4	Data link protocol specification	FF-94-822	Revision 1.0
Part 5	Fieldbus message specification	FF-94-870	Revision 1.0
Part 6	Fieldbus access sublayer (services and protocol)	FF-94-875	Revision 1.0

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According to the replies received the responsible BSI Committee will judge whether the Draft for Development can be converted into a British Standard or what other action should be taken.

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Fieldbus Foundation Fieldbus Specification System Architecture

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Foreword

This document describes the architecture and features of Fieldbus Foundation systems.

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1. Scope

This document specifies the architecture of Fieldbus Foundation systems. It describes how the components specified in the other Fieldbus Foundation specifications may be related and configured to construct and support Fieldbus Foundation devices, networks, and systems.

2. Overview

A fieldbus system can be characterized as a distributed system composed of digital devices and control/monitoring equipment. They are integrated into the physical environment of a plant or factory where they work together to provide I/O and control for automated processes and operations.

The Fieldbus Foundation system architecture provides a framework for describing these systems. It represents a fieldbus system as a collection of physical devices interconnected by a fieldbus network.

Each physical device performs a portion of the total system operation by implementing one or more application processes. Application processes perform one or more time-critical functions, such as providing sensor readings or implementing one or more control algorithms. These elementary field device functions are modeled by function blocks, and their activities are coordinated through configuration of their external communications, execution schedules, and operating parameters. Their applications are referred to as function block applications.

Physical devices in a fieldbus system are interconnected by a fieldbus network. Fieldbus networks may be composed of one or more link segments interconnected by bridges. Communication between physical devices is provided by physical layer and data link layer protocols. Intervening bridges forward messages transparently between links.

Communications between application processes in these physical devices occurs through application layer protocols. The intervening layers, as defined by the ISO OSI Reference Model (ISO 7498), are not present in the Fieldbus Foundation system architecture.

Field devices may operate in manufacturing and process control environments that include intrinsic safety requirements. This creates a need for devices that operate with limited memory and processing power, and buses that provide very low bandwidth.

2.1 Key Components of FF Systems

As a result of these factors, the Fieldbus Foundation System Architecture is *simple* and *open*. It has been designed to be simple to meet the functional, environmental, and technology needs of distributed manufacturing and control systems. It is open so that distributed automation systems can be constructed from control and measurement devices manufactured by different vendors.

This architecture represents a departure from vendor specific control systems architectures that have dominated the marketplace in the past. In these architectures, proprietary interfaces defined how devices communicated with each other. Devices that worked in one vendor's control system, therefore, would not work in that of another. Furthermore, because of these proprietary interfaces, the upgrade and evolution of a system was controlled more by its vendor, than by what the industry as a whole had to offer.

The Fieldbus Foundation System Architecture has been designed to change this. Its purpose is to open the interface definitions to promote interoperability of devices, regardless of vendor. It addresses application and communications interfaces, and provides for network and system management. The key components of this architecture are illustrated in figure 1.

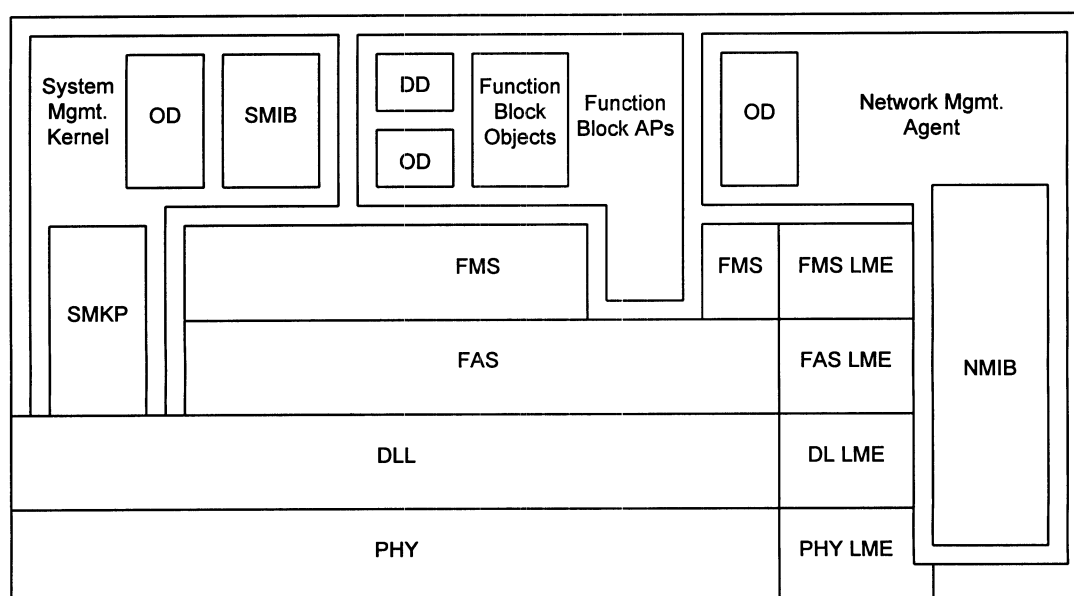


Figure 1 – Key Components of Fieldbus Foundation System Architecture

2.1.1 Function Block Application Processes

Automated manufacturing and process control systems perform a variety of functions. Because each system is different, the mix and configuration of functions is different. Therefore, the Fieldbus Foundation System Architecture has been designed to support a range of functional models, each addressing a different need.

One of these models, the “function block” model has been designed to support low level functions found in manufacturing and process control. Function blocks model elementary field device functions, such as analog input (AI) functions and proportional integral derivative (PID) functions. Additional models, such as “exchange blocks” are defined for distributed input/output and programmable devices.

The function block model provides a common structure for defining function block inputs, outputs, algorithms and control parameters. This structure simplifies the identification and standardization of characteristics that are common to function blocks.

The Fieldbus Foundation has taken a first step in the standardization of function blocks by defining a small set of parameters used in all function blocks called “universal parameters”. A second level of standardization has occurred through the definition of a base set of function block classes, such as input, output, control, and calculation blocks. Each of these classes also has a small set of parameters standardized for it.

This classification scheme provides a third level of parameter standardization by allowing user groups to define subclasses of the base classes. Vendors may also add their own parameters by further subclassing user group defined classes. This approach provides for the extensibility of function block definitions as new requirements are discovered and as technology advances.

2.1.2 Object Dictionary (OD) and Device Descriptions (DD)

Associated with the function block model are standardized tool definitions used to support function blocks. Two of these tools are the Object Dictionary (OD) and the Device Description Language (DDL). They support APs in the definition and description of their network visible objects, such as function blocks and their parameters.

Application processes (APs) provide access to these objects by remote users. To promote consistency of definition and understanding of these objects, they also provide descriptive information about them, such as data type and length. This descriptive information is maintained by the AP in an Object Dictionary (OD). Function block, network management, and system management APs all represent their network visible objects using an OD.

The OD is a schema-based approach for defining dictionary and directory information about devices and their function blocks. OD descriptions of device applications can be supplemented by Device Descriptions (DD) generated by the Device Description Language (DDL). DDL is an interpretative language designed for describing the *behavioral* aspects of AP objects and the operator interface to them.

The function block model is used in conjunction with the OD and DDL to simplify the process of achieving interoperability. Parameter transfers between function blocks can be easily verified because all parameters are defined using a common model and described using the OD and DDL. Likewise, checks can be made to ensure that the function block selected to supply data to another uses the appropriate algorithm to process and output its data.

2.1.3 Network Communications

To support the transfer of information between devices, the Fieldbus Foundation System Architecture defines a three layer communications architecture. This architecture contains a physical layer that specifies how signals are sent, a data link layer that specifies how the network is shared and scheduled among devices, and an application layer that defines the message formats available to applications for the exchange of commands and responses, data, and event messages.

The application layer is divided into two sublayers, an upper sublayer that supplies application layer services to APs, and a lower Fieldbus Access Sublayer (FAS) that provides different models of interaction by mapping these services onto different capabilities of the underlying data link layer.

2.1.3.1 Application Layer Services

Application Layer services in the Fieldbus Foundation are defined by Fieldbus Messaging Specification (FMS). FMS specifies services and message formats for accessing AP objects as well as the OD descriptions for those objects. FMS, in combination with OD descriptions, specify the functional interface for field device applications.

FMS messages are transferred between devices over application layer communications channels called Virtual Communication Relationships (VCRs). A VCR represents a binding between two or more APs, with a single context shared by FMS, FAS, and the Data Link Layer. Different types of VCRs are defined to support three different models of AP interaction: data publisher/subscriber, report distribution, and client/server requests and responses. FMS provides the services to APs to open and close its VCRs, but is itself not aware of the model of interaction. It, instead, relies on the Fieldbus Access Sublayer to select and manage the specific characteristics of a particular type of VCR.

2.1.3.2 Fieldbus Access Sublayer

The Fieldbus Access Sublayer defines and provides the three types of VCRs. Each type is defined by packaging a specific set of data link layer capabilities together to support a particular model of AP interaction.

FAS maintains a set of data link mapping attributes that specify the data link support for the VCR type. These attributes indicate whether the VCR is queued or buffered, cyclic or acyclic, unidirectional or bidirectional, and connection-oriented or connectionless. If buffered, it indicates whether timeliness is to be supported. These attributes also include the data link addresses necessary to convey messages between FAS entities. A summary of the VCR types and their mapping to the data link layer is shown below:

DL Mapping Attribute	VCR Type		
	Publisher/Subscriber	Report Distribution	Client/Server
Queue/Buffer	Buffer	Queue	Queue
Cyclic/Acyclic	Either	Acyclic	Acyclic
Unidirectional/Bidirectional	Unidirectional	Unidirectional	Bidirectional
Connection-oriented/Connectionless	Connection-oriented	Connectionless	Connection-oriented

Table 1 – VCR Type Summary

2.1.3.3 Fieldbus Data Link Layer

The fieldbus data link layer is a subset of that defined by the IEC. The subset was selected used to support the VCR types defined by FAS.

Queued VCR types permit applications to transfer messages to each other using a FIFO (first-in-first-out) queue maintained within the data link layer.

Buffered VCR types, on the other hand, permit applications to transfer messages to each other using buffers in the sending and receiving data link layer entities. Buffered transfers are specified such that:

- 1) sending a new message overwrites the old message in the buffer, and
- 2) reading from the buffer does not destroy its contents.

Cyclic VCR types have their messages transferred according to a data link layer schedule maintained and enforced by a special device on each link segment known as the Link Active Scheduler (LAS). Within the Fieldbus Foundation subset, only publisher/subscriber data can be transmitted cyclically. The LAS uses the schedule to know when to instruct a device to send data. Each entry in the schedule contains the data link address of the publisher and indicates when the data is to be transmitted. Subscribers of the data listen for the publisher's address to know whether they are to receive the data.

To publish data through a bridge, the bridge and the LAS on the bridge's outbound link must be configured to republish the data. The LAS on the inbound link triggers the publisher to transmit the data. The bridge receives the data, and if configured for republishing, buffers the data for transmission on its outbound link. The bridge then waits for the LAS on its outbound link to instruct it to transmit the data.

When the LAS has nothing scheduled, it gives the devices on its link the right to transmit acyclic, or unscheduled data. Report distribution and client/server exchanges are transferred during unscheduled periods, according to their priority. In special cases, it is possible to define an acyclic publisher/subscriber VCR. In these cases, the data to be published is only sent when the data is *compelled* from the buffer by the publisher or the subscriber. The compel is a special service provided by the data link layer to allow a local or remote DLL user to request an acyclic transfer of data.

To forward acyclic data through a bridge, only the bridge has to be configured for forwarding. When a bridge receives acyclic data for forwarding, it queues the data on its outbound link. When receiving the right to transmit, the bridge transmits from its queue in first-in-first-out (FIFO) priority order. In this case, the bridge only needs to know which addresses it will forward.

Unidirectional VCR types are used to transfer unconfirmed services to one or more recipients. They are used to support the transfer of published data and for the distribution of event messages. Bidirectional VCR types are used to transfer confirmed service requests and response between two APs. Only the client/server VCR type is bidirectional.

Connection-oriented VCRs use data link connections. These connections must be established before data can be sent. However, after they are established, only a single address is required to accompany transmitted data. In the case of publisher/subscriber VCRs, the address of the publisher is used. For client/server VCRs, the address of the destination endpoint is used.

Connection-less VCRs do not use data link connections. Instead, their data is transferred using a single connectionless transfer service. No setup is required in this case. However, both the source and destination address accompanies the data. This type of transfer is used for event message distribution, because it permits the senders of event messages to send their messages to group addresses. Receivers, then can listen to all messages transmitted to a single group, regardless of who the sender is. If a publisher/subscriber approach had been used instead, each receiver would have to listen to a set of addresses, one for each event message source.

2.1.3.4 Fieldbus Physical Layer

The Fieldbus physical layer is composed of the physical medium and signaling protocol used to transmit data. Three types of media are defined, twisted wire pair, optical fiber, and radio. When the twisted wire pair medium is used, two power options are defined, a bus powered option in which devices draw their power directly from the bus. This option provides the ability to implement low power devices for use in intrinsically safe environments. The second power option is referred to as self-powered, or also line-powered. Self powered devices draw their power from an external source, and not from the bus.

Three transmission speeds may be used in fieldbus networks, 31.25 kbps, 1 Mbps, and 2.5 Mbps. The 31.25 kbps speed has been specified to support intrinsically safe environments.

2.1.4 Network Management

To provide a means for integrating the protocols of a communication stack within a device, and for controlling and monitoring their operation, the Fieldbus Foundation System Architecture includes a network management agent for each device. The network management agent provides capabilities that support configuration management, performance management, and fault management. The capabilities are accessed through the same communication protocols used to access other device applications, instead of requiring the use of specialized network management protocols.

Using configuration management capabilities, parameters are set within the communication stack to support data exchanges with other devices in the system. This process normally involves linking the inputs and outputs of a device's applications with those of other devices in the system and then selecting the desired communications characteristics for each of the transfers. These characteristics are then loaded into the device using the configuration management capabilities of the network management agent.

As part of this configuration, the network management agent can be configured to collect performance and fault related information for selected transfers. This information is accessible during run-time, making it possible to view and analyze the behavior of device communications. If problems are detected, performance is to be optimized, or device communications are to be changed, reconfiguration can be performed while the device is operating. Whether or not communications with other devices is interrupted during reconfiguration depends on the nature of the reconfiguration.

This configuration, performance, and fault information is represented by the network management agent to the network as the Network Management Information Base (NMIB), although much of it actually resides within the communication stack itself. Like function block application information, the NMIB is described by an OD. The NMIB also represents other protocol specific information that may not be configurable. For example, protocol version numbers are accessible from the NMIB, but they cannot be changed without modification of the communication stack.

2.1.5 System Management

To provide a basic level of integrated operation across devices, above which function blocks and other applications execute, the Fieldbus Foundation System Architecture includes a system management kernel for each device. System management kernels in all devices maintain information and a level of coordination that provides a distributed platform for the execution and interoperation of device applications. The information maintained by the system management kernel is defined as the System Management Information Base (SMIB) and is described in its OD.

One responsibility of the system management kernel is to provide for the configuration of basic system information into its SMIB prior to device operation. A system management kernel startup procedure takes a device through a set of predefined phases as it prepares the device for operation.

During this procedure, a special system configuration device, such as a handheld, may pass system information to the SMIB through its standard fieldbus port. This permits the device to be configured in an off-line workbench network or on the operational network, depending on the particular needs of the system.

Once configured, system management defines procedures for assigning a device a permanent address and bringing it to an operational state without affecting the operation of other devices on the network. A similar procedure permits temporary devices, such as handheld terminals or portable workstations, to join and leave the network for short periods of time as needed.

After a device has been added to the network, its applications may find it necessary to locate remote devices and function blocks. To meet this need, the system management kernel provides a directory service to its applications. This capability may be used by an application to obtain information necessary to complete the configuration of or to alter existing communications characteristics maintained for it by its local network management agent.

To become fully operational, the activities of devices and their function blocks may have to be synchronized with those of the other devices on the network. Two mechanisms are defined by system management to support this. First, system management provides for the synchronization of device clocks to a common time reference so that each device shares a common sense of time. Second, and related to the first, system management defines scheduling objects that control when function blocks execute. This ensures that each function block executes at the appropriate time in relationship to other function blocks in the system.

System management kernels communicate using two application layer protocols over a dedicated management channel for each. FMS is used for access to the SMIB, and a special purpose management protocol, the System Management Kernel Protocol (SMKP), is used to support the various functions of the system management kernel, such as clock synchronization and the directory service. This protocol is integrated into the system management kernel, and is separate from the normal communication stack protocols.

2.2 Relationship to the OSI Reference Model

The ISO OSI Reference Model defines a general seven layer communications architecture for the interconnection of open systems. This general architecture has been optimized for the fieldbus environment by removing the middle layers, which are normally associated with general purpose, non-time critical applications such as file transfer and electronic mail. This three-layer architecture, and its relationship to the ISO OSI seven layer architecture is shown in the following figure.

In the figure above, the Application Layer for the fieldbus is composed of two sublayers. The Messaging Sublayer provides communication services to fieldbus applications, system management applications, and to network management applications.

The Fieldbus Access Sublayer provides different types of communication relationships (channels) between applications which it maps onto the underlying network. This mapping insulates application processes from changes in the network technology.

As shown in Figure 2, the middle layers of the OSI architecture are not present in the system architecture, while the Fieldbus Data Link and Physical Layer definitions conform to the OSI definitions for these layers.

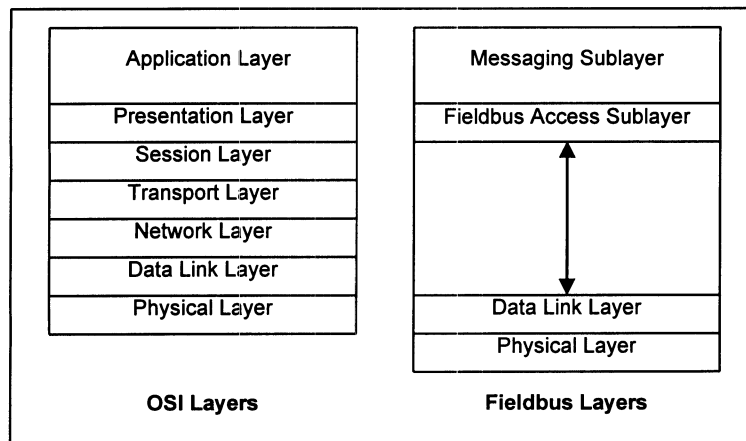


Figure 2 – Relationship of the Fieldbus Foundation Communication Architecture to the ISO OSI Reference Model

2.3 Relationship to the IEC and ISA Fieldbus Standards

The Fieldbus Foundation system architecture is the same as that proposed in IEC SC65C WG6/ISA SP50. The Fieldbus Foundation Application Layer Protocols are based on IEC SC65C WG6 committee documents. The Data Link Layer is a subset of the committee specifications. The Fieldbus Foundation Physical Layer is the IEC Physical Layer standard.

2.4 Fieldbus Foundation Documents

The Fieldbus Foundation Specifications are provided in a multi-part document set. This part, the System Architecture Specification, is the first part of the set.

The other parts of the Fieldbus Foundation Specifications define standards for user applications, network protocols, and system and network management. A summary of each of the documents in the Fieldbus Foundation Specifications is provided below.

System Architecture - provides an overview of the Fieldbus specifications. It describes the Architectural Model for Fieldbus Systems, Fieldbus Devices, and Fieldbus Communications, including the rules for naming and addressing.

Function Block Application Process - describes function blocks and the application processes that contain them.

Device Description Language - defines the language used to specify fieldbus applications and their interactions. This is one of the tools used within the Fieldbus Foundation to achieve interoperability.

System Management - specifies the data, procedures, and protocols used to manage basic fieldbus device capabilities.

Network Management - specifies data and procedures used to manage the communications stack of a fieldbus device.

Fieldbus Messaging Specification - defines the Fieldbus Foundation application layer services and protocols used by fieldbus applications. This protocol supports both client-server and publisher-subscriber (distributed data base services) models for direct control of applications and for distribution of data and events.

Fieldbus Access Sublayer - defines the services, protocols, and application layer communication relationship types used to convey application layer protocol data units. It also specifies the mapping of communication relationships to the data link layer.

Fieldbus Data Link Layer Services Subset - defines the subset of the IEC Data Link Layer Service Specification selected for Fieldbus Foundation Data Link Layer services and protocol. They contain a functional superset of the IEC 65C/92 services.

Fieldbus Data Link Layer Protocol Subset - defines the Fieldbus Foundation Data Link Layer services and protocol. They contain a functional superset of the IEC 65C/92 services.

Fieldbus Physical Layer Specification - is the same as the ISA-S50.02-1992 Part 2 Physical Layer Specification and Service Definition. It is also known as IEC 1158-2.

Fieldbus Communications Profile Specifications - Separate Communications Profiles are defined for different operating environments. Each profile selects the communications capabilities required for a given environment and specifies values for selected communications parameters for the environment.

3. Network Topology

Fieldbus Foundation networks are composed of one or more link segments interconnected by data link layer bridges. Each link contains two or more devices. The figure below illustrates a simple single link fieldbus network. Links with two devices are typical of offline configuration networks containing only a configuration device, such as a handheld, and the device to be configured.

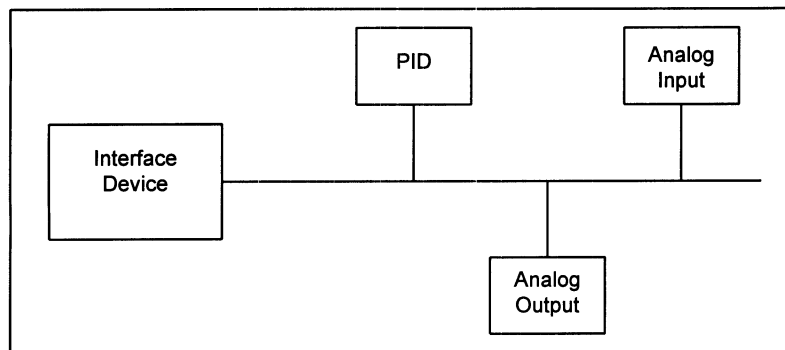


Figure 3 – Simple, Single-Link Fieldbus Network

All links are required to have a Link Active Scheduler (LAS). The LAS operates at the data link layer as the bus arbiter for the link. In the role of the LAS, a device:

- recognizes and adds new devices to the link.
- removes non-responsive devices from the link.
- distributes data link time on the link (which is adjusted to system time by system management).
- polls devices for buffered data at scheduled transmission times.
- gives devices the right to transmit between scheduled transmissions.

Any device on the link may become the LAS, as long as it is capable. Those devices that are capable of becoming the LAS are called *link master* devices. When the link first starts up, or upon failure of the existing LAS, the link master devices on the link bid to become the LAS. The link master that wins the bid begins operating as the LAS immediately upon completion of the bidding process.

In certain cases, it may be desirable to have the LAS role assigned to a specific link master. In these cases, one link master may be designated as the *primary* link master. If the primary link master fails to win the bid, it will direct the winning link master to transfer the LAS role to it. Once it becomes the LAS the link becomes operational.

3.1 Link Active Scheduler (LAS)

The LAS is a special data link layer capability responsible for adding devices to a link segment, distributing data link time to them, granting them the right to transmit, and removing them from the network. Each link segment has only one LAS, although the capability may exist in more than one device.

Devices that are capable of becoming the LAS are known as *link masters*. A special procedure defined in the data link layer specification provides for link masters to bid for the LAS role should a failure of the existing LAS be detected. A separate procedure permits a designated link master to request the LAS role to be transferred to it from the existing LAS. This permit systems designers to identify which device is to be the LAS and which are to be backups for it.

3.2 Bridged Networks

Links of different speeds and media types may be bridged together to form multi-segment, or *bridged*, networks. Data link layer bridges are used in these networks to interconnect link segments. In all Fieldbus Foundation bridged networks, there is only one data path between any two devices. To ensure this, routing tables within bridges are coordinated with each other to form a *spanning tree*.

The spanning tree represents a configuration of bridges, such that there are only two directions of data flow, either towards the root of the tree, or away from it. There are no loops and no parallel routes. That is, for each link there must be one and only one active bridge leading to the root.

Each bridge in the spanning tree has a single root port and one or more downstream ports. Each bridge port represents a connection to one link segment. Root ports lead toward the root and the downstream ports lead away from the root.