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Product Focus: Industrial Ethernet Communication

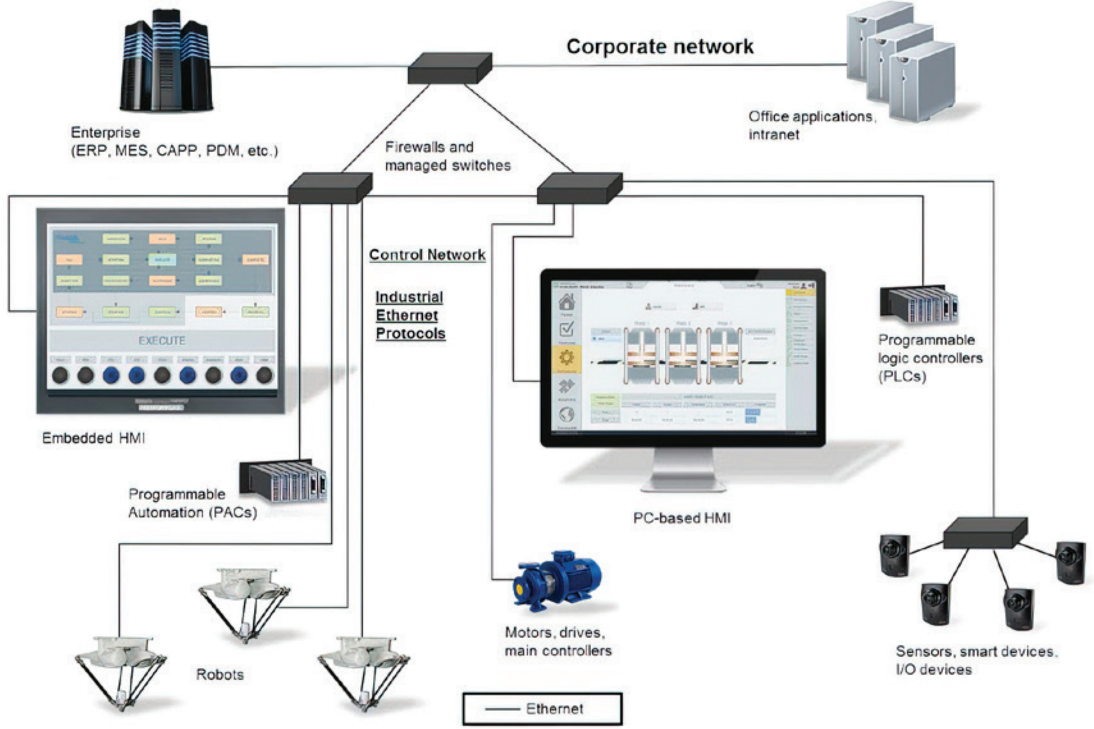
Ethernet's Evolution

Ethernet is the most widely used network in industrial plants and facilities, and was first conceived and deployed in a research setting in the 1970s. In the early 1980s, Ethernet was standardized under IEEE 802.3 which quickly led to commercial adoption in office environments. Since then, Ethernet has undergone many upgrades and improvements, making it the world's leading wired network technology not only in offices, but also in industrial applications.

Today, industrial sites commonly use Ethernet to connect PCs (that can host asset management, enterprise resource planning, production planning, and other applications), programmable logic controllers (PLCs), remote I/O, human machine interfaces (HMIs), smart instruments, motor drives, and many other intelligent automation components.

Exponential speed improvements have been a major component of Ethernet's evolution and there are several versions of Ethernet: 10BaseT, 100BaseTX (also known as Fast Ethernet), 1000BaseT (also known as Gigabit Ethernet because it transmits Ethernet frames at a rate of one gigabit per second), and most recently 10 Gigabit Ethernet or 10GBaseT. While some details vary among these versions, the most important differences are speed and cost, with cost increasing with speed. While consumer hardware and PCs typically operate at Gigabit speeds, many industrial Ethernet installations and components still use Fast Ethernet.

Over the years, many industrial Ethernet communication protocols have been created including EtherNet/IP, Ethernet TCP/IP, Modbus TCP/IP and Profinet. With Ethernet networking, all of these protocols can operate on the same network at the same time. However, in the U.S., EtherNet/IP and Modbus TCP are the most used Ethernet protocols and it is common for PLCs and other control devices to support one or both.



In an industrial environment, Ethernet is used to network PCs, controllers, and other intelligent industrial automation components.

The Ethernet Framework - OSI 7-Layer Model

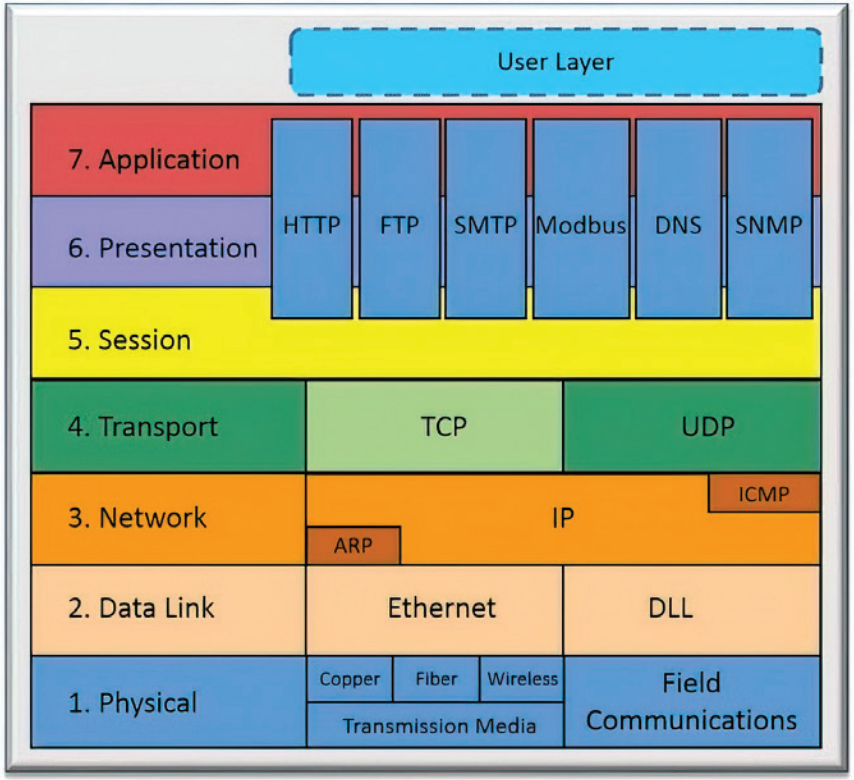
The Ethernet communciation structure is defined by the Open System Interconnection (OSI) model. The 7 layers of the Ethernet networking framework help define the needed components in an Ethernet transmission. The goal for protocols adhering to this model is for any network-connected device to be able to transmit a data packet or message to any other device.

Ethernet messages initiate at a device connected to Physical Layer 1, which defines the required electrical signals and cabling. The Data Link Layer 2 is the next one up, acting as a traffic cop in the form of Ethernet switches and other Layer 2 devices. These devices use the media access control (MAC) address of each component or device to figure out which packets go to which ports. The MAC address is the hard, physical address of a component or device. Although there are exceptions, this address is set during manufacturing and should never change.

Similarly, network layer 3 uses the Internet Protocol (IP) address to route the data packets. The IP address is the logical address of a component or device, used to identify its address and network Finally, transport layer 4 delivers the data payload, for example, the actual Modbus message for Modbus TCP, up to layer 7.

Layer 7 is the Application Layer and this is where a common language is important. Although industrial Ethernet protocols may be identical in their use of layers 1-4, and can thus use the same network, they won't be able to communicate with each other if their application layer 7 is different.

Most of the lower layers such as physical medium, data link with MAC address, and network with IP address are often common among devices and well established. However, upper layers such as session, presentation, and applications are where things change. For example, a Modbus TCP device can't talk directly to an EtherNet/IP device, and neither can talk to a Profinet device.



Addresses and Message Types

MAC Address

As previously mentioned, the media access control (MAC) address is the hard, physical address of a device and is configured during manufacturing. An Ethernet packet cannot enter a device without this address. However, it's rare that a communication setup or configuration will require entry of this address because another protocol, called address resolution protocol (ARP), usually automatically retrieves it and correlates it to an Internet Protocol (IP) address.

IP Address

The IP address is defined by the user and identifies the device's address and network. An IP address, such as 192.168.070.001, includes two identifiers: the network address and the host address. The network address helps switches and routers determine where to send messages. The host address identifies the specific device on that network. The subnet mask determines which part of an IP address is the network address and which part is the host address.

The default gateway address and a router enable connections to other networks. A device can only send and receive Ethernet messages to other devices on its network as determined by the IP address and subnet mask. If a device needs to communicate with a device on another network, a router is required. In order to get the message to the other network, the device will send its message to the default gateway address, which is the IP address of the router.

LAN/WAN

Local area network (LAN) and wide area network (WAN) definitions vary greatly, but in general LANs are smaller, more localized networks encompassing switches and hubs while WANs offer more widespread connectivity. Once a network is divided into separate groups using a router, these separate networks are considered to be encompassed within a WAN.

Unicasting, Broadcasting, and Multicasting

Unicast messages are sent from one specific device or component to another. Broadcast messages are sent from one device to all components or devices in a group. Multicast messages are sent to many different receivers at once, typically all components or devices on an Ethernet network.

A router is needed to make sure a broadcast message only goes to members of a group, but managed switches can intelligently route multicast messages to the correct ports of all components or devices on a network. A managed switch will learn which ports should be receiving multicast messages, using a feature called IGMP Join, and only send messages to those ports, resulting in significant performance improvement.

Ethernet Cabling

The first point to consider when deploying an Ethernet network is the type of cabling. Cat5e cable supports Gigabit speeds and is often the minimum specification recommended. Also available is Cat6, providing better performance at a higher cost, and also providing a degree of future-proofing as Ethernet moves toward 10 Gigabit speeds in coming years. Although commercial installations use unshielded cables, shielded cable should be used in industrial environments to protect communications from electrical noise generated by motors, motor drives, welding, and other electrical equipment.

In years past, it was important to define whether cables should use straight-through patch or crossover connections. Crossover cabling was typically required when directly connecting components to each other, and patch cabling was used when connecting components to Ethernet IT devices such as switches and routers. However, most devices today support Auto MDI/MDIX which will accept either configuration, so most installations use patch cabling throughout.

Another point to consider for both performance and compatibility is communication speed, and half or full duplex capability. While duplex compatibility can be overcome by using a managed switch or router, performance is limited to the slowest device. As previously mentioned, Fast Ethernet is used in most industrial automation applications because its raw speed is more than sufficient, but this can be affected by the selection of half or full duplex. With half duplex, a device can only transmit or receive, but can't do both simultaneously. This reduces performance, and in the worst case half duplex devices drop packets under heavy load due to data collisions. Most devices used in Fast and Gigabit Ethernet installations use full duplex, meaning the node can transmit and receive simultaneously.

Cabling Dos and Don'ts

- In new or retrofit industrial Ethernet network installations, do specify Ethernet cable rated for Gigabit network speeds. Most quality Category 5e cable (CAT5e) will work well. CAT6 cable can handle 10 Gigabit speeds, which might be overkill for your application, but will future-proof the installation.
- Do use stranded copper Ethernet patch cables for connections in a control panel or field devices. They are available in lengths up to about 50 feet. Longer cable runs often use bulk cable and RJ45 connectors that are manually assembled.
- Do run plenum-rated Ethernet cable in recirculating or air-handling ceilings.
- Patch cables should include an overall metal foil shield to reduce the effects of electrical noise often present in industrial applications. This will help eliminate data loss in transmission and possible intermittent problems.
- Since patch cables come in many different colors, do consider differentiating network applications using different color cables. Red for critical, blue for information only, orange for office, etc. While colors are not necessary, do label the cable ends to simplify troubleshooting and future changes.
- Don't run these CAT5 or CAT6 Ethernet cables over 100 meters. For longer runs, do use an unmanaged or managed switch or Ethernet extender every 100 meters. For longer distances susceptible to electromagnetic interference, do use fiber optic cables.

Hubs, Switches, and Topologies

There are a variety of Ethernet network topologies including bus, ring, and star. Bus and ring are similar to a daisy-chain connection, with a single cable hopping between each device. Bus topology is a bit obsolete, while the newer ring topology adds fault tolerance. However, most industrial Ethernet installations use star topology, with some ring connections to reduce cable run distances or improve resilience.

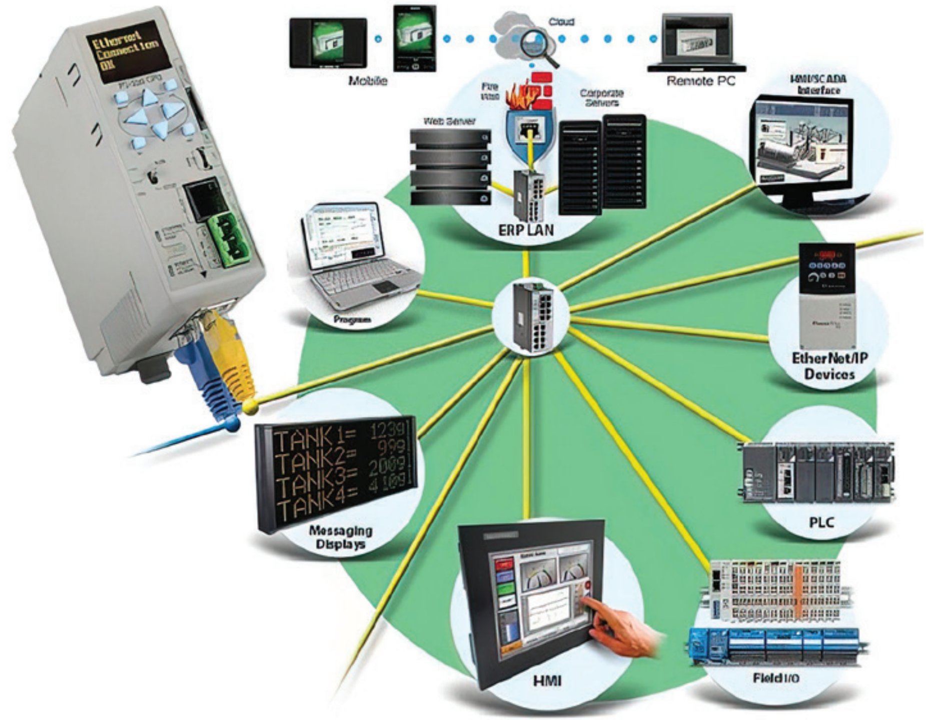
With the star topology, many devices connect to the central access point, the switch. Ethernet switches come in both unmanaged and managed configurations. There are applications and situations that make sense for unmanaged switches, and there are others where a managed switch is a better choice.

An Ethernet hub simply connects Ethernet devices together with no regard for MAC addresses, so all messages are sent to all devices. An unmanaged switch is a little smarter, using the MAC addresses to determine what devices are connected to each of its ports, and then routing messages targeted to those devices out the appropriate port, preventing the collisions often occurring with an Ethernet hub.

A managed switch adds features to those offered by an unmanaged switch, with one of the most important being selection of speed and duplex mode. When connecting a device to a switch, it must auto negotiate to an agreed-upon speed and duplex mode. Auto negotiation is common in commercial environments but can fail for industrial situations. In these applications, it is often better to turn off auto negotiation, and use a managed switch to set the speed and duplex mode to a known working setting for both sides. This can be particularly helpful when connecting components from different manufacturers.

For a simple network with five or fewer components in a relatively small area, an unmanaged switch will usually work, and it will always be less expensive than its managed equivalent. For larger applications with more components, a managed switch should be strongly considered. The benefits of a managed switch's configuration and other features will easily outweigh the cost premium over an unmanaged switch in most complex applications.

A router is a more powerful version of a managed switch, with the ability to create different groups of devices within an Ethernet network. Creating groups allows one part of a network to be separated from another, a useful feature for managing network traffic. A virtual private network (VPN) router should be used when connecting a network via the Internet to provide the required degree of cybersecurity.



Example of a star topology with an industrial switch as the central access point.

Ethernet Protocols

The physical or hardware aspects of industrial Ethernet is only half the story, with the other half being the many different software protocols used in industrial Ethernet installations. In short, a protocol allows every device on the network to use a common language for communication. Most industrial Ethernet protocols can run on standard Ethernet hardware, but some require modified and proprietary versions of hardware to operate. This is usually done to improve performance in highly specialized applications. Although different industrial Ethernet protocols can all use the same network, only devices that support the same protocol can communicate with one other.

There are several industrial Ethernet protocls in use today, including:

- EtherNet/IP
- Profinet
- Modbus TCP
- EtherCAT
- SERCOS

Most of these protocols were originally created by a single vendor and worked only with their products. But now, each of these protocols is administered by its own independent foundation, and each will work with components from many different vendors if they support it.

In the U.S., EtherNet/IP and Modbus TCP are the most used Ethernet protocols and it's common for PLCs to support one or both protocols. Both of these protocols run on standard Ethernet hardware, further promoting their widespread use.

Often the best Ethernet protocol to use is vendor specific, but the application sometimes drives the decision. With EtherNet/IP, a scheduling mechanism, called requested packet interval (RPI), helps optimize data transfer for high-speed applications. On the other hand, Modbus TCP, with its wide support and simplicity, is a great choice for multi-vendor applications.

Modbus TCP/IP

The Modbus protocol was created in 1979 by Modicon Inc. specifically for communication between Modicon programmable controllers and other proprietary devices. Since then, Modbus has become an industry standard for transmitting data between industrial control systems and components. Modbus TCP/IP or Modbus TCP is basically the original Modbus RTU protocol, which was a serial communication method, combined with a TCP interface that runs on Ethernet.

To break it down futher, Modbus refers to the application protocol that defines how to configure and interpret the data being transmitted (seen in layer 7 of the OSI model discussed previously). TCP/IP refers to the Transmission Control Protocol and Internet Protocol; these two work together to ensure the data is received correctly and properly routed. The TCP/IP combination is just a transport protocol (layers 3 and 4 of the OSI model) and has nothing to do with how the data is configured or interpreted. Therefore, Modbus TCP combines an Ethernet transmission standard (TCP/IP) with a well known application protocol (Modbus) that defines how the data is presented.

Modbus devices communicate using a master-slave or client-server method in which the master/client must initiate the communication. The slaves/servers respond only when prompted and will supply the requested data to the master, or take the requested action. Slaves/servers can be any peripheral device (sensors, drives, valves, etc.) which will processes information and deliver it to the master using Modbus.

EtherNet/IP™

ODVA

EtherNet/IP

EtherNet/IP development began in the 1990s and today is controlled and managed by the ODVA standards organization. EtherNet/IP is a popular industrial Ethernet communication protocol that supports traditional Ethernet, the Internet Protocol (IP), and TCP or UDP.

TCP/IP is the transport and network layer protocol of the Internet and provides a set of services that any two devices can use to share data. The UDP/IP (User Datagram Protocol) provides the fast, efficient data transport necessary for real-time data exchange. The Common Industrial Protocol (CIP) has been added on top of TCP/UDP/IP to provide a common application layer. Therefore, when you choose an EtherNet/IP product, you are choosing a product with TCP/IP and CIP capabilities. This combination allows seamless continuity between numerous devices and allows you to control and configure your devices while collecting data at the same time.

Other EtherNet/IP highlights:

1. EtherNet/IP is a certified standard for Ethernet communication. Being such, any manufacturer wanting to implement this technology must meet consistency and quality standards for their devices.
2. Using CIP, which is defined using the OSI 7-layer model as its base, EtherNet/IP can work with a variety of industrial automation components from a host of manufacturers.
3. EtherNet/IP is a widely used communication method and is supported and used by numerous vendors in their products, from simple sensors to complex controllers.
4. EtherNet/IP provides very fast I/O data transmission speeds. Since EtherNet/IP is compliant with IEEE Ethernet standards, users can take advantage of speeds of up to 1 Gigabits per second (Gbps) or more.
5. Various topology options, including conventional star, ring, or daisy chain (linear).
6. EtherNet/IP is designed to handle large amounts of messaging data – up to 1500 bytes per packet.
7. EtherNet/IP provides both implicit (time-critical data including I/O values) and explicit messaging (data like parameters, setpoints, programs, and recipes).

EtherNet/IP: Implicit vs. Explicit Messaging

Explicit Messaging

Within EtherNet/IP, the client, such as a PLC, asks or requests the information from a server, such as a VFD field device, and the server sends the requested information back to the controller. Because the client requests the information from the server via TCP/IP services, the request has all the information needed for the server to respond to the message exactly as requested. This configuring and monitoring ability, common to explicit messaging, works well for non-real-time messaging as the client (controller) can send a message request anytime, and the server (field device) can respond when it's available. Explicit messaging is typically used for communication which isn't time critical.

Implicit Messaging

EtherNet/IP uses implicit messaging, sometimes called I/O messaging, for time-critical applications such as real-time control. It's a much more efficient communication connection than explicit messaging as both the client and server ends are pre-configured to know implicitly or exactly what to expect in terms of communication. Real-time, implicit messaging basically copies data with minimal additional information built into the message. There is no extra baggage because both ends already know exactly what each bit and byte mean.

Which Messaging Mode is Best For You?

If your application requires large amounts of data, explicit messaging is the preferred choice because bandwidth is saved, as data is only requested when necessary. For high-speed, real-time applications, implicit messaging is the way to go. Think of the "i" in implicit as the "I" in I/O messaging, which of course requires high speed as I/O is generally used for real-time control.

Explicit messaging requires programming in the controller for setup. You need to request the data, add handshaking, acknowledge the data, and move the data where it's needed in the controller. Real-time implicit messaging can be quickly configured, just set the controller up as a scanner to receive data and configure the connection to a remote EtherNet/IP device.

AutomationDirect.com offers these components for your communications needs:

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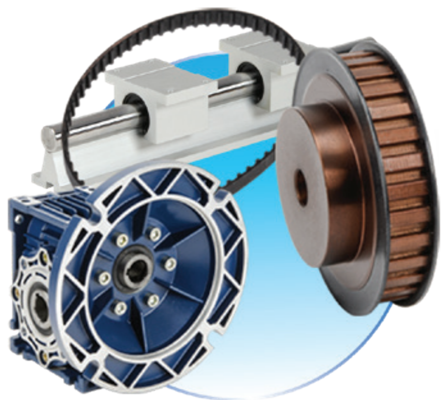

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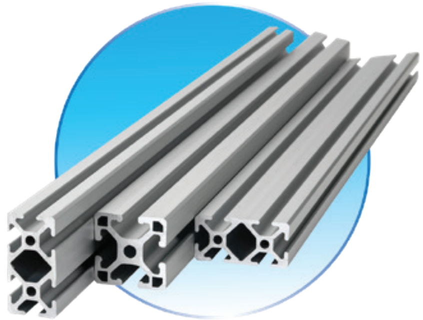

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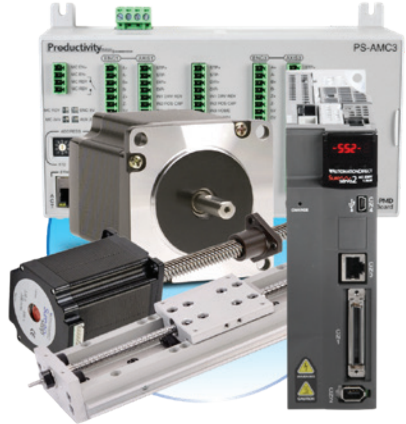

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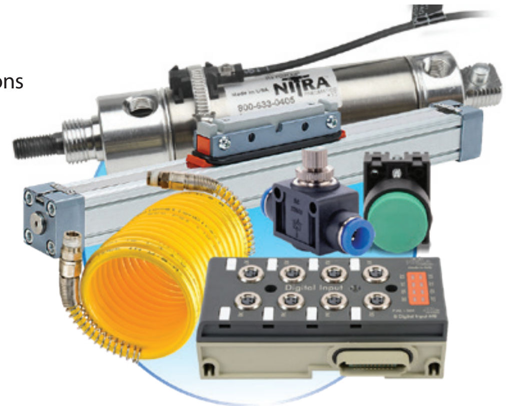

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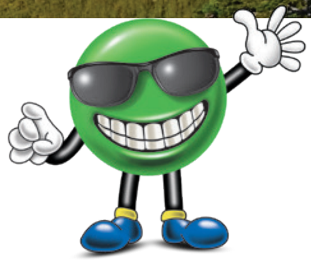

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