Performance Testing and Analysis for a Stable Ethernet Communication Link

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Abstract: ***To make organizations more efficient and flexible, manufacturers are rapidly migrating to Industrial Ethernet technology to network their industrial automation and control systems and connect plant and business systems to achieve business objectives. Industrial Ethernet enables a more flexible, responsive system that encompasses both real-time data from the production floor. This end to-end networking architecture provides connectivity, collaboration, and integration from the device level to enterprise business systems. In this paper performance of an Ethernet link established is tested and analyzed based on latency for different amount of network load on development board having ARM Cortex A8 core and a Ethernet interface.***

Keywords: ARM Cortex A8, Ethernet, Latency, Load, PTS.

1. Introduction

Globalization, virtualization, and mobile computing drive a seemingly insatiable demand for bandwidth, and only Carrier Ethernet efficiently scales up to meet this demand. Using Ethernet instead of serial (RS232, RS422 or RS485) communications massively increases the flexibility of the installed network. A single cable can be used for video, voice and many different types of data. Traditional fieldbus systems were limited to one task with no scope for diversification [1].

Customers seeking high performance business Ethernet services can now easily purchase faster Ethernet connections at 100 Mbit/s to 1 Gbit/s and beyond. But sometimes users believe they are receiving lower throughput than they expected. This perception can be due to poor application performance which is caused by factors un-related to Ethernet service throughput.

TCP/IP over Ethernet is designed to establish a network of networks, each of which may be designed by different vendors. The architecture is very robust and can automatically restore connections between different network elements. However, the nature of automatic recovery means that network problems can go undiagnosed and uncorrected for long periods of time, regardless of the network speed.

The latency introduced by Ethernet transmission is therefore unpredictable and difficult to handle. Theoretically, it is not possible to control Ethernet latency. However, practical solutions have been developed. Unpredictable latency occurs when there are complex routing paths and a large number of Ethernet elements.

If controllers and devices are directly connected to each other, or if a private network is used, then the latency can be kept to within a specific range. A direct Ethernet link could be established between the SCADA system and the PLC or meter, with no other devices on the network.

In a 100 Mbps Ethernet environment, the transmission latency for 100 bytes of data could be calculated as follows:

$$\frac{1}{100 \times 10^6} \times 8 \text{ bits/byte} \times (100 \text{ bytes} + 54 \text{ bytes}) = 12.32\ \mu s$$

By using a dedicated high-speed Ethernet network for communication between two devices, transmission latency for a 100-byte message with a 54-byte header can be kept to about 12 microseconds. With more complex networks and additional devices such as switches and hubs, the transmission latency will increase [6].

In this paper first Ethernet link is implemented between development board TMDSICEAM3359 Industrial Communication Engine Version 2 (ICE V2) and a Personal Computer (PC).Further this Ethernet link is loaded with simultaneously running Webpage Application and an Echo_Sever application where Embedded Server ARM Cortex A8 on ICE V2 which responds to client request and serves the application as requested. Also Ethernet link is flooded with raw packets and ICMP packets and analyzed for stability.

2. Ethernet Parameters

Traffic Generation

An Ethernet service is a pipe offered to the customer to transmit traffic from one point to another. In order to confirm that the pipe is clean and will transmit the customer's traffic, the technician must generate traffic and confirm that all of the traffic traverses the network without being corrupted. When setting up a test set to generate traffic,

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Bit rate: The standard Industrial Ethernet operates at a bit rate of 100 Mbits/second• Maximum propagation delay: the maximum round trip delay between any two transmitters is defined to be 464 bit times.

Maximum jam time: a transmitter which detects a collision continues to transmit for 32-48 more bit times to insure that the other participants reliably detect the collision.

Slot time: an upper bound on the acquisition time of the network. It must be larger than the sum of the maximum round trip propagation time plus the maximum jam time. This is defined to be 512 bit times (51.2 microseconds)

Frame Size: Different frame sizes can affect Ethernet elements. Smaller frames cause elements to work harder than larger frames. The reason for this is that small frames have a smaller payload and less time for the element to process a frame before the next frame arrives. At high utilizations, the element may drop or corrupt frames.

Payload: The payload is the PDU portion of the frame. For the most part, this portion is irrelevant to the Ethernet service. From a customer standpoint, this is the most critical portion of the service. Therefore, the ability to edit the payload may be a requirement for some turn-ups.

Minimum packet length: The shortest packet must be no shorter than the slot time, so that if there is a collision it is detectable. This leads to a minimum length of 64 bytes, including a 14-byte header and a 4-byte ‘‘frame check sequence.’’

Maximum packet length: This limit, 1518 bytes, bounds the size of buffers that receivers must maintain, and also helps to limit the average access time.

Throughput: The throughput test identifies the maximum bandwidth that the circuit will operate at. This value should match or be slightly greater than the provisioned bandwidth rate.

Latency: The latency of the network can be a somewhat tricky result. There are two main factors that create latency – network architecture and network traffic.

Utilization: This is the most critical parameter. Depending on the service, the Ethernet pipe may transmit at a line rate of 1 Gbps or less. The carrier and type of network determines the maximum throughput. Therefore, generating traffic at the maximum line rate and confirming that the traffic is not corrupted is critical.

Traffic Rate – Constant Bandwidth

When setting utilization, there are several different units of measure. The two main units of measure are an actual bit rate (in Mbps or Gbps) or a percentage of the total available bandwidth. Stating bandwidth in terms of a percentage of the total available bandwidth is the most common. When turning up a circuit, generating traffic at the maximum rate is the only way to confirm that the circuit can transmit the customer data at the guaranteed rate without errors. Depending on how the carrier offers the Ethernet service, the maximum bandwidth available to the end user may vary.

Average delay: the average time it takes to send a packet, measured from the time the host first wishes to acquire the channel.

Channel capacity: the maximum achievable throughput for a given set of parameters. Capacity is a function of such parameters as packet length and network length.

Fairness: in a fair network, each host with pending traffic should have an equal probability of acquiring the channel (this is not an equal share of the bandwidth, since hosts use differing packet sizes).

Stability: if the throughput actually drops at high loads then the network is said to be unstable in that region.

3. Requirements

3.1 Hardware

The AM3359 Industrial Communications Engine (ICE) is a development platform targeted for systems that specifically focus on the industrial communications capabilities of the Sitara AM3359 ARM® Cortex™-A8 Processors. It enables low foot print designs with minimal external components and with best in class low power performance. Arm Am3359 is having 750 MHz core frequency. Here ARM drives Ethernet Media Access Controller EMAC for Ethernet usage in field of data acquisition, controlling devices and data networking. Since speed & reliability of Ethernet are dependent on the core frequency, communication link is tested for stability of Ethernet [3].

3.2 Protocol Test System

The Protocol test system (PTS) allows you to very easily test and analyze communication between systems that are based on the IEC 60870-5-101, -103 and -104 protocols.

3.3 Fping

Fping is a *ping* like program which uses the Internet Control Message Protocol (ICMP) echo request to determine if a host is up. Fping is different from ping in that you can specify any number of hosts on the command line, or specify a file containing the lists of hosts to ping. Instead of trying one host until it timeouts or replies, fping will send out a ping packet and move on to the next host in a round-robin fashion. If a host replies, it is noted and removed from the list of hosts to check. If a host does not respond within a certain time limit and/or retry limit it will be considered unreachable.

3.4 Ping Plotter Pro

Ping Plotter Pro offers users the unique ability to see their network, and pinpoint the problem - and allows network professionals fast and easy access to routing and performance information on their networks. Using a combination of easy-to-understand graphs, coupled with its features designed to aid in network troubleshooting. Ping Plotter Pro is a tool that can notify you the moment network conditions change, and then give you the information to help solve the problem [4].

3.5 Comm Operator

Comm Operator is professional communication software for serial port, TCP/IP, UDP, HTTP and FTDI. Comm Operator makes it more efficient for development of hardware-software application, client-server application as well as internet application.

3.6 Code Composer Studio

Code Composer Studio is an integrated development environment (IDE) that supports TI's Microcontroller and Embedded Processors portfolio. Code Composer Studio comprises a suite of tools used to develop and debug embedded applications. It includes an optimizing C/C++ compiler, source code editor, project build environment, debugger, profiler, and many other features. The intuitive IDE provides a single user interface taking you through each step of the application development flow. Familiar tools and interfaces allow users to get started faster than ever before. Code Composer Studio combines the advantages of the Eclipse software framework with advanced embedded debug capabilities from TI resulting in a compelling feature-rich development environment for embedded developers [5].

4. Embedded Applications

A. Connection:

To develop application on the board connect ICE V2 to PC via USB debugger running CCS. Application code is written in C language. IP of the board is configured as 172.16.0.21. Once the application is programmed, flash the program on SPI flash memory. Connect Ethernet cable to Ethernet port on ICE V2 and PC.

B. Application design:

Embedded web server serves webpage static or dynamic to client on request. In this example webpage is made to refresh every 1 second and also cache memory is cleared so as to loading of application takes from server only. This application is designed at TCP/IP socket at port 80 and webpage is fully in C coded [2].

In Echo_Server application client sends data to server, and same data is echoed back to client. This application is implemented at TCP/IP socket at port 23. Using Comm Operator terminal software continuous data to server is sent at interval of 1 second [2].

5. Analysis Of Ethernet Link For Stability

1) Experimental setup & Configuration:

- Connect the ICE V2 board through Ethernet cable to PC.
- Implement the TCP client /server Echo application along with Embedded Web Server application explained on board simultaneously.
- Configure Comm Operator application to open Echo server application at port 23 and send data" hello" continuously to server at a rate of 1second.
- Run embedded web server application at socket 80.
- Execute fping file for ping at 5ms & packet size of 1460 resulting in 200 packets /second.
- Run PTS for various delays between packets.
- Run the ping plotter which sends ICMP 25 packets/second and trace the graph.

Experimental setup is shown in figure 1.

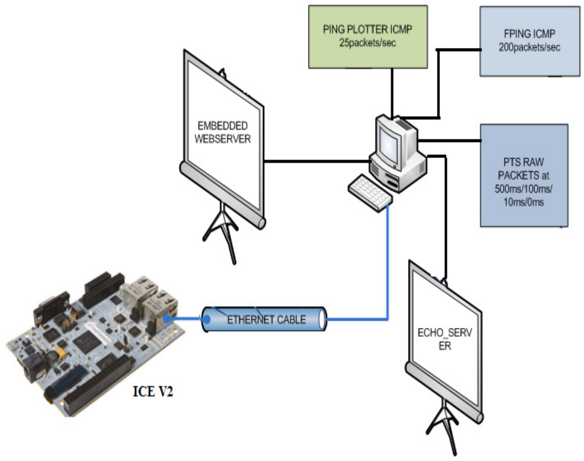
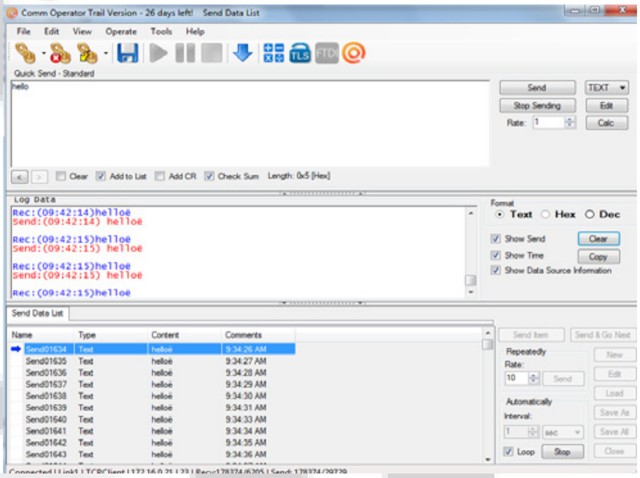


Figure 1: Experimental Setup

2) Results

The maximum core frequency at which these applications are running is 600 MHz. The output of Echo_Server application seen in Comm Operator is shown in figure 2 and Webpage served by server to client on request at every 1 second shown in figure 3. Also figure 4 shows the configuration of PTS software to load packets at 0ms delay between them and figure 5 shows fping configuration.



hello

Rate: 1

☐ Clear ☑ Add to List ☐ Add CR ☑ Check Sum Length: 0x5 [Hex]

Log Data

```
Rec:(09:42:14)helloé
send:(09:42:14) helloé

Rec:(09:42:15)helloé
send:(09:42:15) helloé

Rec:(09:42:15)helloé
send:(09:42:15) helloé

Rec:(09:42:15)helloé
```

Format: ● Text ○ Hex ○ Dec

☑ Show Send
☑ Show Time
☑ Show Data Source Information

Send Data List

Name	Type	Content	Comments
Send01634	Text	helloé	9:34:26 AM
Send01635	Text	helloé	9:34:27 AM
Send01636	Text	helloé	9:34:28 AM
Send01637	Text	helloé	9:34:29 AM
Send01638	Text	helloé	9:34:30 AM
Send01639	Text	helloé	9:34:31 AM
Send01640	Text	helloé	9:34:33 AM
Send01641	Text	helloé	9:34:34 AM
Send01642	Text	helloé	9:34:35 AM
Send01643	Text	helloé	9:34:36 AM

Repeatedly
Rate: 10

Automatically
Interval: 1 sec
☑ Loop

Connected | Link1 | TCPClient | 172.16.0.21 | 23 | Recv:178374/6205 | Send: 178374/29729

Figure 2: Echo_Server output

Implementation of Static Webpage on TMDSICEAM3359 ICE V2 Board having arm Cortex A8 32bit RISC - Windows Internet Explor

http://172.16.0.21/

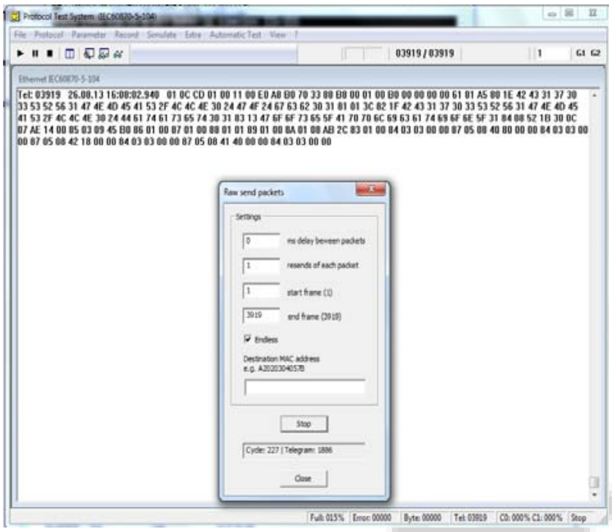
Implementation of Static Webpage on TMDSICE...

webpage implementation

Webpage on TMDSICEAM3359 ICE V2 Board having arm Cortex A8 32bit RISC running at 750MHz

This webpage auto refreshes in 1 second.

Figure 3: Webpage output



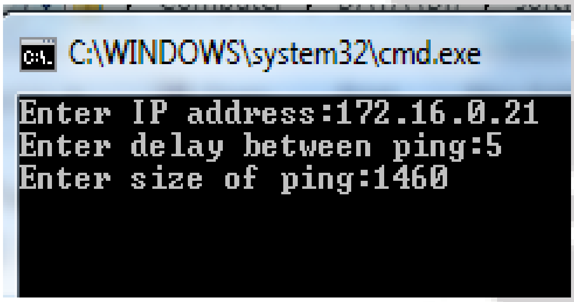
```
Tel: 03919   26.08.13 16:08:02.940   01 0C CD 01 00 11 00 E0 A8 B0 70 33 88 B8 00 01 00 B0 00 00 00 00 61 81 A5 80 1E 42 43 31 37 30
33 53 52 56 31 47 4E 4D 45 41 53 2F 4C 4C 4E 30 24 47 4F 24 67 63 62 30 31 81 01 3C 82 1F 42 43 31 37 30 33 53 52 56 31 47 4E 4D 45
41 53 2F 4C 4C 4E 30 24 44 61 74 61 73 65 74 30 31 83 13 47 6F 6F 73 65 5F 41 70 70 6C 69 63 61 74 69 6F 6E 5F 31 84 08 52 1B 30 0C
07 AE 14 00 85 03 09 45 B0 86 01 00 87 01 00 88 01 01 89 01 00 8A 01 08 AB 2C 83 01 00 84 03 03 00 00 87 05 08 40 80 00 00 84 03 03 00
00 87 05 08 42 18 00 00 84 03 03 00 00 87 05 08 41 40 00 00 84 03 03 00 00
```

0 ms delay between packets
1 resends of each packet
1 start frame (1)
3919 end frame (3919)
☑ Endless
Destination MAC address e.g. A2020304057B

Cycle: 227 | Telegram: 1886

Full: 015% | Error: 00000 | Byte: 00000 | Tel: 03919 | C0: 00% C1: 00% | Stop

Figure 4: PTS Configuration

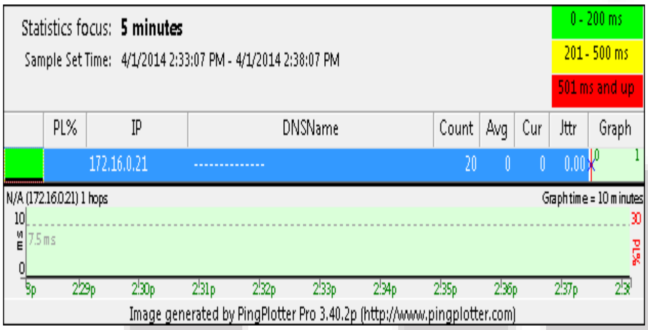


```
Enter IP address:172.16.0.21
Enter delay between ping:5
Enter size of ping:1460
```

Figure 5: Fping configuration

For PTS load with 500ms delay between packets:

By loading the link with PTS load of raw packets with delay between the packets 500ms resulting in 2 packets /sec is tested for around 10 minutes. It is observed that link behaves normal with no jitter and packet loss shown in figure 6.



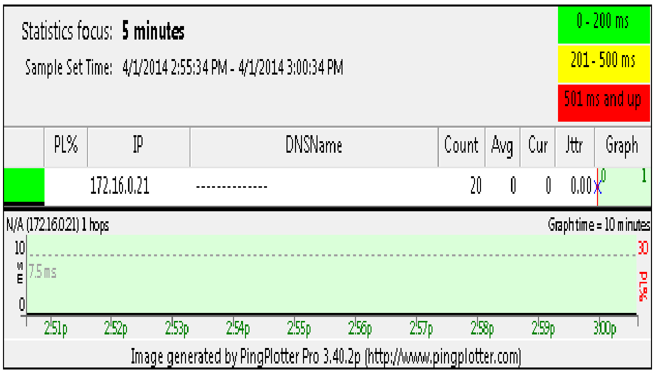
Statistics focus: **5 minutes**
Sample Set Time: 4/1/2014 2:33:07 PM - 4/1/2014 2:38:07 PM

PL%	IP	DNSName	Count	Avg	Cur	Jttr	Graph
	172.16.0.21	-------------	20	0	0	0.00	

Figure 6: PTS load with 500ms delay between packets

For PTS load with 100ms delay between packets:

The link is loaded with PTS load of raw packets with delay between the packets 100ms resulting in 10 packets /sec is tested for around 10 minutes. It is observed that link behaves normal with no jitter and no packet loss shown in figure 7.



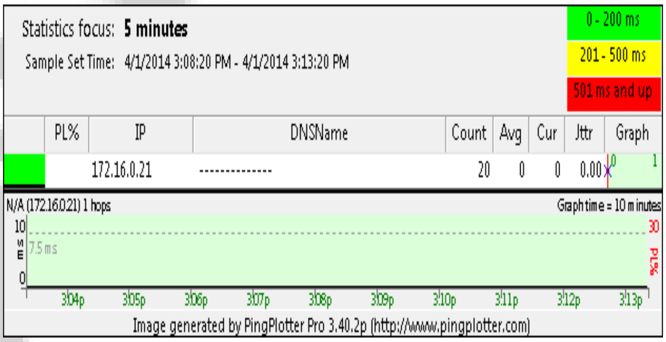
Statistics focus: **5 minutes**
Sample Set Time: 4/1/2014 2:55:34 PM - 4/1/2014 3:00:34 PM

PL%	IP	DNSName	Count	Avg	Cur	Jttr	Graph
	172.16.0.21	-------------	20	0	0	0.00	

Figure 7: PTS load with 100ms delay between packets

For PTS load with 10ms delay between packets:

The PTS load of raw packets with delay between the packets 10ms resulting in 100 packets /sec is tested for around 10 minutes. It is observed that link behaves normal with no jitter and no packet loss shown in figure 8.



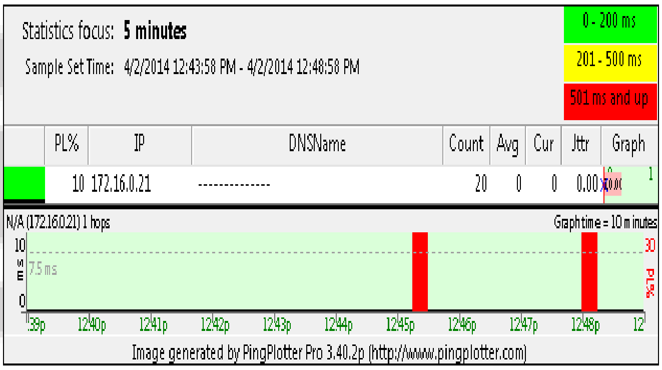
Statistics focus: **5 minutes**
Sample Set Time: 4/1/2014 3:08:20 PM - 4/1/2014 3:13:20 PM

PL%	IP	DNSName	Count	Avg	Cur	Jttr	Graph
	172.16.0.21	-------------	20	0	0	0.00	

Figure 8: PTS load with 10ms delay between packets

For PTS load with 0 ms delay between packets:

When the link is loaded with PTS load of raw packets with delay between the packets 0ms resulting in 1000 packets /sec is tested for around one hour. It is observed that there is packet loss randomly amounting to around 30% shown in figure 9.



Statistics focus: **5 minutes**
Sample Set Time: 4/2/2014 12:43:58 PM - 4/2/2014 12:48:58 PM

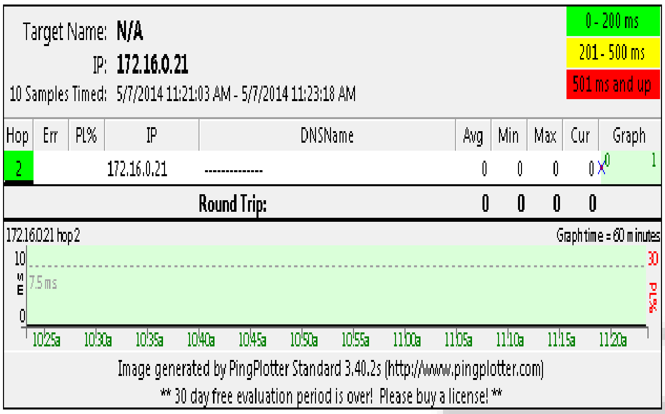
PL%	IP	DNSName	Count	Avg	Cur	Jttr	Graph
10	172.16.0.21	-------------	20	0	0	0.00	

Figure 9: PTS load with 0ms delay between packets

For PTS load with 0 ms delay between packets and scheduling task on priority basis:

Below figure10 depicts the result with scheduling of tasks on priority basis is performed. PTS loads raw packets with delay between the packets 0ms resulting in 1000 packets /sec for around one hour. It is seen that there is no packet loss.

With the scheduling of tasks on priority basis, so as to enable controller to handle tasks more efficiently results in no packet loss. It can be inferred that packets processing ability of processor increases when scheduling of tasks is proper.



Target Name: N/A
IP: 172.16.0.21
10 Samples Timed: 5/7/2014 11:21:03 AM - 5/7/2014 11:23:18 AM

Hop	Err	PL%	IP	DNSName	Avg	Min	Max	Cur	Graph
2			172.16.0.21	--------------	0	0	0	0	
				Round Trip:	0	0	0	0	

Image generated by PingPlotter Standard 3.40.2s (http://www.pingplotter.com)
** 30 day free evaluation period is over! Please buy a license! **

Figure 10: PTS load with 0ms delay between packets & scheduling

6. Conclusion

With ICE V2, the analysis of Ethernet communication link with simultaneously embedded applications running at a high rate along with delay between the packets 0ms /10ms/ 100ms /500ms and 5ms is successfully tested and analyzed. It is observed that the ARM with Ethernet communication link behaves normal with no latency and almost a stable graph. Loss in packets is noticed with 0 ms delay between the packets. Hence as there is increase in load, there are chances of link failure. By proper scheduling of the task using Real Time Operating System there is no packet loss and hence Stable Ethernet communication link is developed.

Future work: The same implemented link can be further tested with real time heavy load so as to check suitability of the communication link over Ethernet in field.

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