COMPONET: INNOVATIONS FOR HIGH PERFORMANCE SENSOR-ACTUATOR APPLICATIONS

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Abstract

The purpose of this paper is to introduce CompoNet technology in depth. It contains not only explicit or implicit information from CompoNet specification, but also background not included in the specification. Detailed CompoNet protocol, data link, physical layer and network wiring are presented with special considerations and initial requirements while CompoNet was under development. The special data link of CompoNet has been developed to provide effective I/O data communication with high speed for a large numbers of nodes and special measures have been taken on physical layer to improve transmitting/receiving capabilities by cost-effective transformer-coupled signaling style. All of this technology backs CompoNet with advantages over its rival networks. Finally, the ways that CompoNet technology enhances CIP and applications are explored.

Keywords

CompoNet, DeviceNet, Field Networks, CIP, CIP Net works, ODVA

Definition of terms

SAN: Sensor and actuator network

MAC: Medium Access Control

PHY: Physical layer

CRC: Cyclic Redundancy Check

Introduction

CompoNet is a newly added field network to the ODVA family designed for sensor and actuator layers.

One of the reasons why CompoNet was developed is that field networks which contribute to reduce wiring effort have come to be recognized and the number of applications that have this requirement have increased in the industrial automation market.

In the market, advantages of field networks have been accepted and user requirements to field networks are focusing on its adaptation to sensor and actuator layers, reduction of wiring efforts, easy set-up, high maintainability and advanced machine performance.

CompoNet solves those problems. CompoNet provides wiring efficiency, data handling at bit-level, high-speed response and message communication that is required in, sensor and actuator networks (SAN). Adoption of flat cables and IDC connectors works for reduction of wiring efforts. As well, CIP messages are used to access Slave parameters and also allow access parameters via other CIP networks.

This paper introduces the development background and technology of CompoNet, adding some descriptions to the previously published paper, *"CompoNet™: NEW CIP NETWORK FOR SENSORS AND ACTUATORS. Toshiyuki Kojima" presented in 2006 CIP Networks Conference & 11th Annual Meeting, Technical Track: Technology & Innovations, Presented Papers.*

Overview

a. CompoNet application to target

CompoNet is a field network for connecting mainly to sensors and actuators. For that purpose, the following three factors are required, a. efficiency in bit data handling, b. large numbers of connection nodes and c. flexible wiring. CompoNet enjoys the advantages in all those factors.

Let us give some comparison between CompoNet and DeviceNet.
DeviceNet controls many more I/O points in a single network compared to CompoNet. CompoNet is faster than DeviceNet with its high-speed response, the number of nodes and wiring efforts.
Accordingly, DeviceNet is appropriate for the equipment with large amounts of data, and CompoNet is appropriate for networks which require lesser amounts of data and large numbers of nodes.
CompoNet fulfills the requirements of applications using large numbers of sensors and actuators.

b. CompoNet system configuration

CompoNet is a field network which transmits data for control and information system by cyclic or message communication between PLC (Master) and I/O terminal (Slave). CompoNet networks consist of the components shown below.

1. Master

   Controls the network and only 1 (one) Master is allowed in a single network.

2. Bit Unit

   Transmits bit ON and OFF information and allocates 2 to 4 bits per node. Maximum of 128 Bit IN Slave and 128 Bit OUT Slave (Bit OUT 256 bit max) are allowed in a network. (256 Bit Units in total.)

3. Word Unit

   Transmits bit ON and OFF information and allocates 16 to 256 bits per node. Maximum of 64 IN Slave (Word IN 1024 bit max) and 64 OUT Slave (Word OUT 1024 bit max) are allowed in a network. (128 Word Units in total.)

4. Repeater

   Extends or branches the communication cables, increases the number of nodes and allows the mixing of different cables. Maximum of 64 repeaters are allowed in a network.

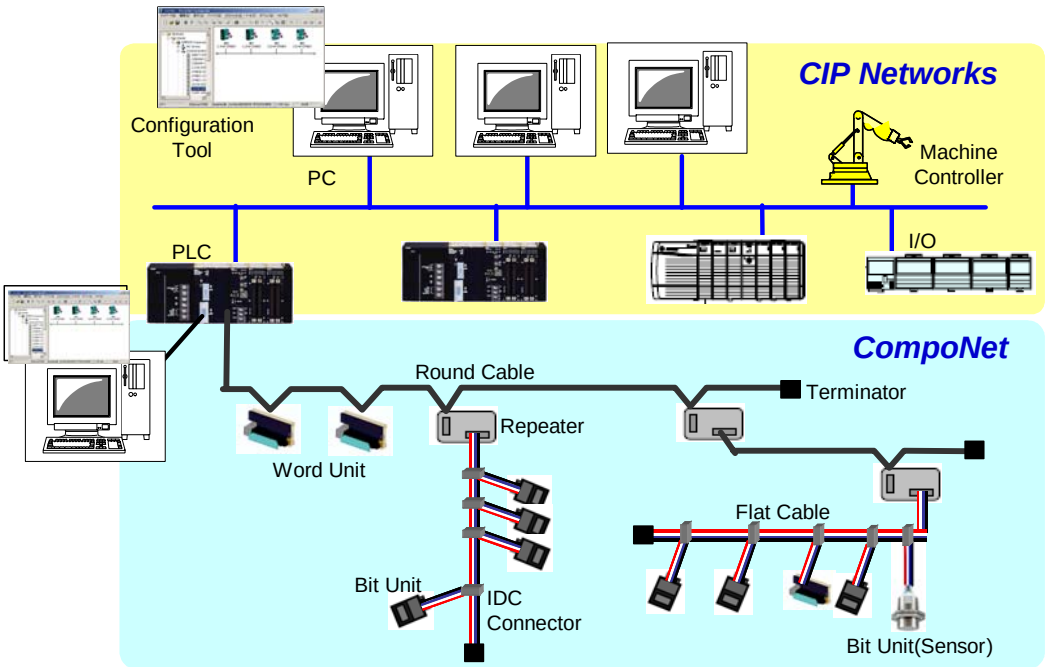
5. Communication cables

   Transmits information as the media for electric signals. Unshielded communication cables are allowed in CompoNet network and 4 types of cables are defined, Round Cable I, Round Cable II, FLAT Cable I and FLAT Cable II.

6. Configuration tool

   Allows the setting for Master, Slave or Repeater on network and information gathering at emergency, using message communication. Monitoring the error information helps users to specify and promptly access the location where troubles occur, and enable timely on-site recovery. In addition, message communication is based on the CIP protocol and supports CIP routing. CompoNet supports routing from EtherNet/IP or DeviceNet, and other CIP networks to and from CompoNet nodes.

Figure 1 - CompoNet system configuration



c. CompoNet Characteristics

High-speed response and variety of topologies

CompoNet accomplishes a 1ms communication cycle time while supporting both 1000 points of I/O data communication and message communication. In communication networks, extra time for message communication is required to accomplish high-speed response and punctuality of data for I/O control when messaging-type data transmission occurs. Extra time causes the degradation of the communications cycle time. CompoNet protocol helps to overcome this problem by supporting high-speed response of I/O data up to 4Mbit/s.

Typically, the improvement of data rate is not compatible with the improvement of wiring performance such as various types of communication cables, transmission distance, the number of nodes, and branches – which tend to degrade its wiring performance. CompoNet minimizes the wiring degradation by the advanced physical layer with pulse transformer, preamble and receive mask developed for CompoNet. In addition, the wiring performance can be improved by using Repeaters. CompoNet's Repeaters are designed to minimize the transmission delay and to improve the maximum allowable distances.

Maintainability

Requirements for less wiring, reduced efforts at setup and quick troubleshooting for the fault nodes can be solved by CompoNet.

Large numbers of nodes are required to be connected to a network for Sensors and Actuators, thus required efforts during its installation or replacement cannot be disregarded. CompoNet system supports the crimping of flat cables to accomplish less wiring. Furthermore, to meet the requirement for topology that depends on each user, CompoNet allows T-branch and multi-drop topologies, and flat cables and round cables for communication cables. If the user intends to use different cables, CompoNet Repeater allows the mixing of different cables.

Data Rate Auto-Detection, CIP messaging, configuration tool and duplicate MAC ID detection realizes the requirement of quick troubleshooting.

Data Rate Auto-Detection enables easy setup so that nodes can automatically recognize the baud rate set in the Master. This function simplifies the baud rate setting and prevents any setting mistakes. CIP messaging enables the user to monitor and control the network communication or settings remotely. Configuration tools help to specify the location where trouble occurs and troubleshoot using “network configuration window”. Duplicate MAC ID detection enables detecting errors if MAC IDs are duplicated.

d. CompoNet technology

The following are the CompoNet technologies that enable CompoNet characteristics, high-speed response, variety of topologies and high maintainability.

Pulse transformer

a. Variety of topologies: Circuit configuration using a transformer to improve the communication performance. Insulation of communication path simplifies the designing of the power supply.

Preamble

a. High-speed response: Transmission is enabled with no gaps between frames (There is no idle time on the communication line)
b. Variety of topologies: Prevents the drop in wiring performance by data arrays that minimize the signal degradation.

Receive Mask

a. Variety of topologies: Prevents the drop in wiring performance by measures for reduction in amplitude and deformation of waveform. Branches at megabit data rate level enabled by antireflection.

High-speed Repeater

a. High-speed response: Minimizes the response delay caused by Repeater connection.
b. Variety of topologies: Expands the installation field and the number of nodes, and allows the mixing of different cables.

Cable and connector

a. Variety of topologies: Reduces the installation efforts with the use of flat cables and IDC connectors.

Protocol

a. High-speed response: 1000 points per millisecond is accomplished by the efficient protocols
b. High maintainability: Information-oriented system by CIP messages. Segment separation, node error notice by alarm, duplicate MAC ID detection and data rate auto-detection to prevent setting error and to shorten the time for specifying the location where trouble occurs.

These technologies shall be explained in the following section.

CompoNet technologies

Pulse transformer on transmitting line

In CompoNet system, the transmitting line shall be isolated by pulse transformer. Use of a pulse transformer helps the user to isolate each node to meet the requirements on applications whose power supplies are separate.

Channels are coded by Manchester coding. Manchester coding prevents the bias voltage that occurs as a result of 0 or 1-biased energy storage, since Manchester coding specifies the duty of “0” and “1” as 50/50. Moreover, the midpoint of the pulse transformer is connected to GND to improve the wiring performance while to maintain impedance consistency of the physical layer.

For the circuit configuration, refer to [2].

Preamble

Preamble has two functions.

- Synchronization
- Indicates that it is the header of frame

Flexible wiring, long wiring distance and high-speed communication cycle time are all required in applications such as electronics manufacturing system or sorters for logistics.

A slower baud rate is appropriate for flexible wiring and long wiring distance, conversely, a faster baud rate is appropriate for high-speed communication cycle time. Baud rate shall be temporarily determined by the length or wiring and branch methods. A new preamble data arrays that accomplishes no gaps between frames is realized to accelerate the communication cycle time at all baud rates.

To send frames with no gaps on a physical layer (PHY) in which pulse transformers are used, the preamble part consists of 10 marks:

“0011100110”. The duty of “0” and “1” in data transmitted on channels is 50% each.

A CompoNet typical frame consists of 4 parts: Preamble, Command Code, Command-dependent block and CRC. CompoNet frame blocks other than the preamble use Manchester encoding to send Manchester-encoded data on channels. Therefore, the duty of “0” and “1” shall be 50/50 each in data between Command Code and CRC.

Figure 2 - Frame block

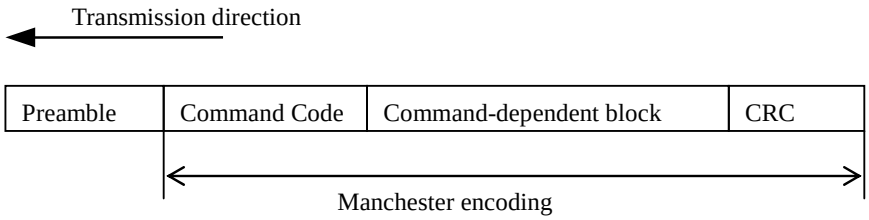
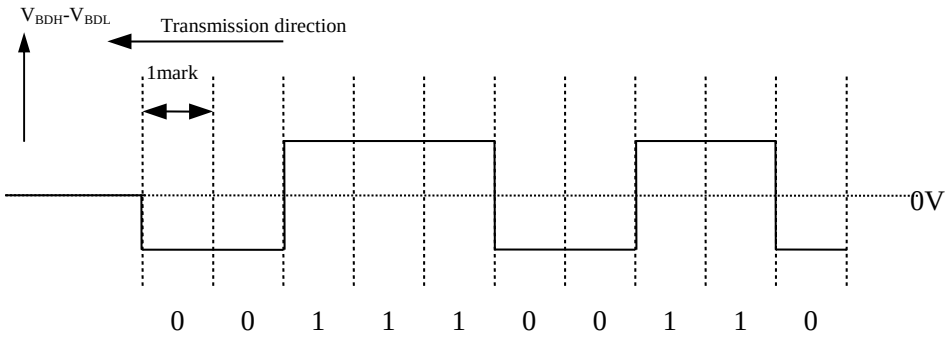


Figure 3 - Preamble Waveform on Transmitting Line



Data arrays that are resistant to signal degradation is adopted for preamble. Preamble indicates that it is the header of frame if the data array includes “111”, which is unapparent on data arrays of Manchester encoding. Thus, 4 marks of “1110” is the shortest data arrays. Additionally, “0” is added right before “1110” for “111” to be certainly recognized, while allowing the receiver input threshold voltage fluctuation for transceiver IC.

In the verification process of wiring performance, it became clear that “0” right after “111”, 3 marks in a row, is between “1” and “1”, it will be hard to be received because of signal degradation on transmission line.
e.g. Preamble: “01110” and Command Code: “10”
Consider the data packet“0111010” for the above example. If this packet is degraded during transmission, it will be difficult to be received. To prevent that phenomenon, add 1 mark of “0” to be “011100”. Then, the duty of “0” and “1” shall be 50/50 each in such a way as to allowing the uninterrupted transmission and prevent the drop of “0” of “0111” affected by the last frame to be “00111001”.

Finally, add “10” to the end of preamble to reduce the influences by the reflection for communication frame waveform.

Examples of waveform are indicated in “Figure 4 - Waveform before improving Preamble” and “Figure 5 - Waveform after improving Preamble”. The waveforms are observed with the same wiring, measured at the same point but with different data packets.

Figure 4 - Waveform before improving Preamble

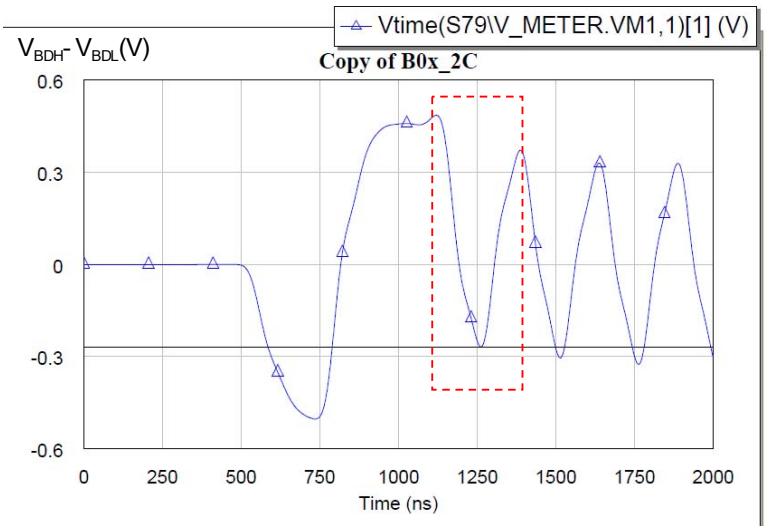
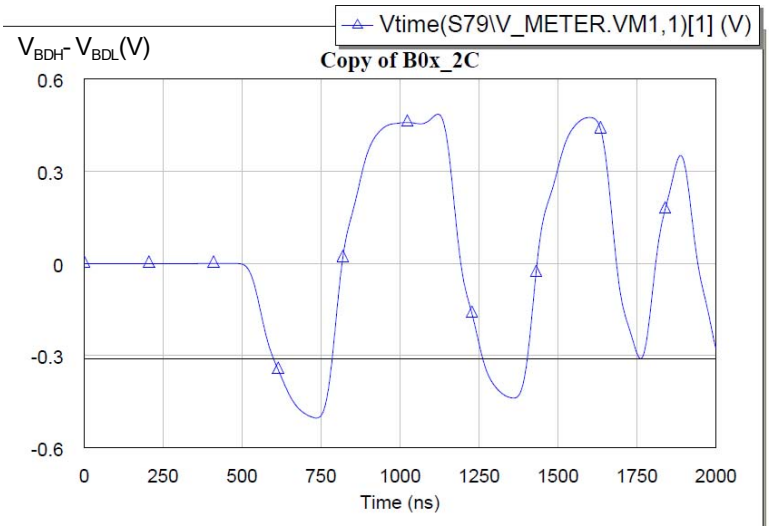


Figure 5 - Waveform after improving Preamble



Receive Mask

The definition of Receive Mask is described here.

In CompoNet system, unshielded cables with electrical characteristics that are different can be used to meet user requirements for easy and cost-effective wiring. Besides, it can also achieve network topology that allows branches at 3Mbit/s and 1.5Mbit/s.

The Receive Mask is the key technology for allowing the use of several types of cables.

a) Cables with different electrical characteristics

I/O characteristics for Master port and Slave port cannot be changed nor can the characteristics for terminators. Those characteristics are in conjunction with that of transmission line; therefore, communication waveform shall be changed if their electrical characteristics do not match.

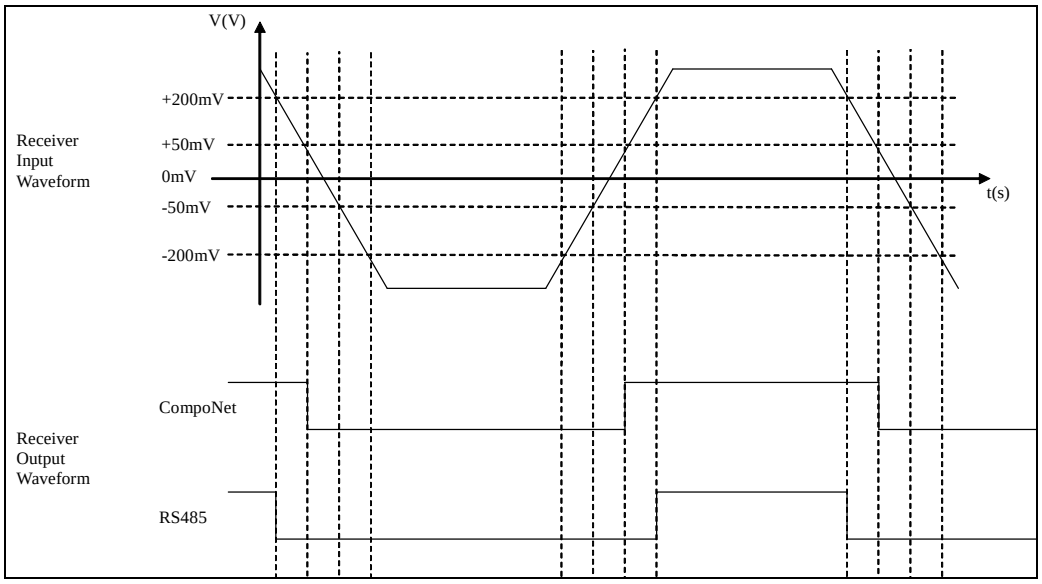
A transceiver IC with RS485-based receiver that has a narrow range of input threshold voltage is adopted in CompoNet system to receive waveforms with deformation or attenuation.

Receiver input of RS485 communication transceiver is between -200 and +200mV, meanwhile, that of CompoNet is between -50mV and +50mV. Consequently, when allowing for the attenuation of the waveform caused by components located between the interface connector and the receiver input pin into consideration, the input threshold voltage for Receive Mask shall be between -60mV and +60mV,.

Setting the voltage of the above transceiver contributes to the improvement of receiving performance, In brief, it improves the receiving performance for signals whose wave height is low or skewed signals.

Example of data arrays as “01” is shown in “Figure 6 - Difference of output signal deformation caused by receiver input threshold”. In this case, data arrays with 50/50 duty of “0” and “1” are easier to be received. Setting for the input threshold voltage as according to CompoNet specifications brings the data arrays to closer to 50/50 duty even if with skewed waveform.

Figure 6 - Difference of output signal deformation caused by receiver input threshold voltage



b) Branches

Branches on transmission line might cause large reflections to invert the logic of receiving waveform. The Receive Mask to receive those waveforms is defined in “CIP Networks Library, Volume6, Chapter 8, Figure 8-2.15 Receive Mask 3”.

Circuit block that implement the aforesaid Receive Mask 3 are be shown in “Figure 7 - Receiving circuit block and waveform” Waveforms that cause the inversion of logic are reformed by a Digital Filter circuit in the MAC. The effects of reforming by the Digital Filter circuit are shown in “Figure 8 - Reformed waveform with 1/8 of a mark inverted” and “Figure 9 - Reformed waveform with 2/8 of a mark inverted”.

A MAC layer that accomplishes the CompoNet-specific Receive Mask that receives spike waveform samples waveforms after reforming (Dfil_OUT) in decode circuit block.

Figure 7 - Receiving circuit block and waveform

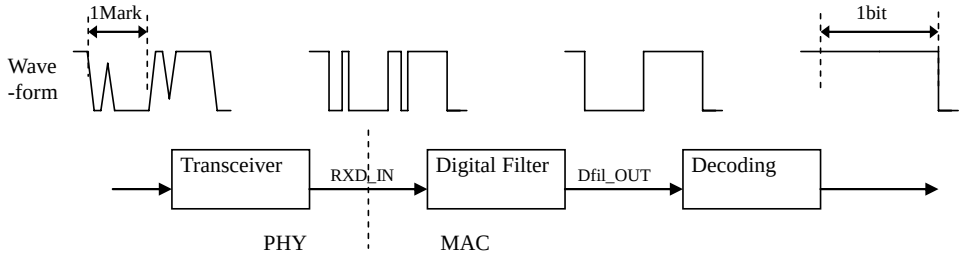


Figure 8 - Reformed waveform with 1/8 of a mark inverted

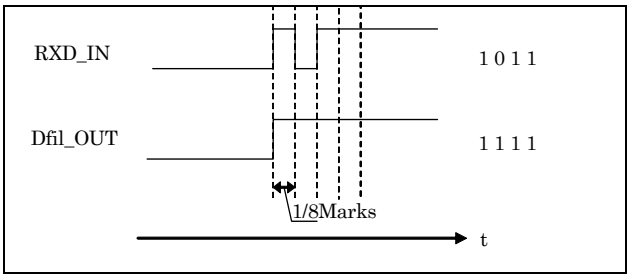
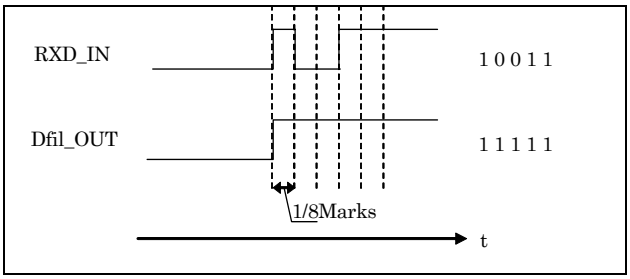


Figure 9 - Reformed waveform with 2/8 of a mark inverted



High-speed Repeater

In CompoNet systems, the Repeater is developed as a waveform repeater to allow the extension of the maximum trunk line length and the expansion of installation area, and for the connection of many nodes. A common repeater sends the noise waveforms that should not be sent or frames that are not required on protocols. A CompoNet Repeater filters the waveforms and frames that should not be sent. As well, CompoNet Repeater has its own MAC ID to easily recognize that there is a repeater connected on the network.

A CompoNet Repeater and time division accomplish the minimizing of the delay of communication cycle time caused by a typical Repeater connection and network segmentation. It promotes the efficiency in CompoNet communication and high maintainability. For the details on the minimization of the delay of communication cycle time by CompoNet Repeater, refer to [2].

Cables and Connectors

CompoNet allows various types of cables or connectors such as flat cables and IDC connectors that help easy installation, 2-Conductor Round Cable that is easily-available, cost-effective and allows power to be supplied to Slaves, and 4-Conductor Round Cable suitable for IP67.
For the details of easy installation realized by Flat cables and IDC connectors, refer to [2].

Protocol

CompoNet protocol is highly efficient and with high maintainability. Its efficiency is realized by the strict arbitration of high-speed Repeater and the CompoNet frames specially developed for SAN. In addition, the protocol helps to quickly assess the network status and specify the location where trouble occurs with its detecting functions such as Data Rate Auto-detection, duplicate MAC ID detection, segment configuration control.

a. Highly-efficient flame blocks

In CompoNet systems, intelligent frames are used to prevent sending useless data on the communication line; specifically, minimum but complete frames are provided for each Command.

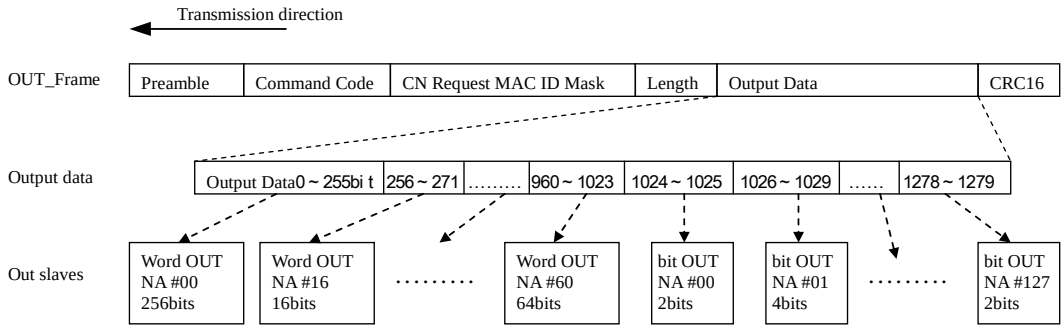
Networks that handle the data length in Byte (8 bits) or Word (16 bits) formats have data frames in Bytes or Words in its frame format. Thus, when handling 2 bits of IN data in the network, 2 bits in the data format shall be used as valid data and the remaining 14 bits shall not be used and treated as invalid (empty) data to be sent as a frame. If multiple nodes of 2 bits are connected on such network, a large quantity of useless data is sent – which would be very inefficient.
CompoNet frame solves such problem to increase the network efficiency.
IN frame has multiple data length such as 2, 4, 8, 16, 32, 48 … up to 256, allowing the selecting of the most appropriate data length for each I/O data.

OUT data shall be delivered in a multicast message that 1 (one) frame transmits all data on 1 (one) network, however, the OUT frame has no destination MAC ID. In this case, OUT Slave cannot recognize which OUT data to use. This problem is solved by the Master specifying the location where

OUT data stored to Slave using OutBlockPointer in STW. The slave is notified the location of OUT data to use by STW.

Thus, efficiency in CompoNet communication frame is improved against unicast message. As well, OUT frame is flexible to shorten its data length to reduce the invalid data transmission.

Figure 10 - Relationship between OUT_Frame and OUT Slave data acquisition



b. High maintainability

In CompoNet systems, the installation area is designed to cover a wide area since the total length can be extended by a Repeater. However, it takes much time to confirm if the logical wiring diagram matches the actual wiring. CompoNet user can confirm the configuration easily by accessing Master since the Master controls the configuration information for each segment..

Figure 11 - CompoNet Actual Wiring

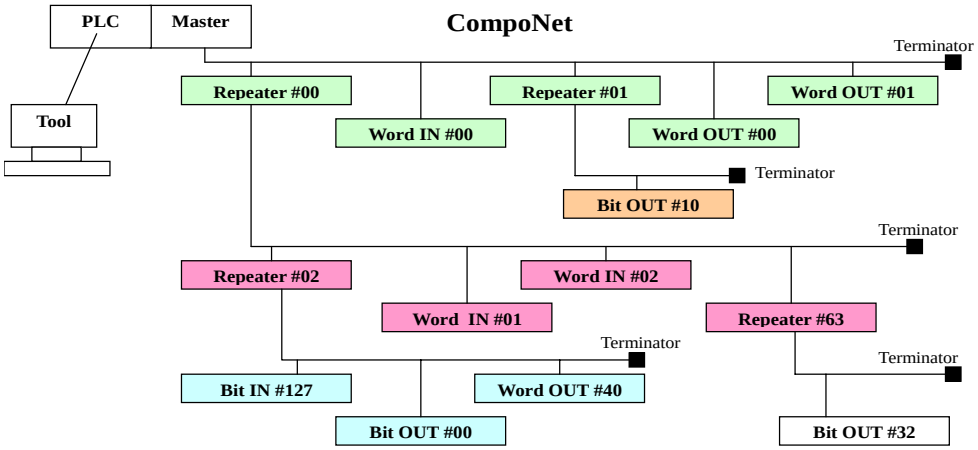
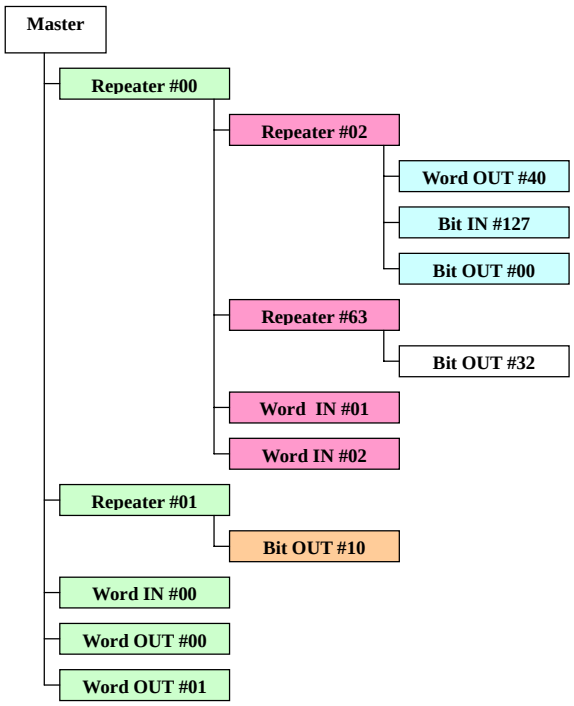


Figure 12 - Logical wiring example



The logical Network configuration is controlled by the Beacon frame and STR.

When Master sends the Beacon frame, Last Repeater Node Address in Beacon frame shall be overwritten for the node address of passed Repeater. Nodes that have received Beacon frame shall hold the data of Last Repeater Node Address. When the Master requests STR, Slave sends the STR frame with the Last Repeater Node Address. The Master receives the information that indicates which nodes are connected to which repeaters. Consequently, the Master adds to the Slave detailed information by STR providing EDS file for its configuration tools.

The Gate Count in a Beacon frame increases by 1 after a BEACON finds a repeater from master port. Nodes (Slaves or Repeaters) recognize the number of repeaters between themselves and the Master. CompoNet allows up to 3rd segment layer using Repeaters. If the slave port of Repeater is connected to 3rd segment layer, the operation of Repeater shall be faulted as invalid, to prevent the unstable network behavior caused by unsupported Repeater connection.

The CN frame has various functions not only to control node configuration per segment and prevent unsupported installations but also to notify the status of each node to Master. This notification function

comes from Alarm bit and Warning bit in CN frame. This function is used to detect errors without message from Master.

Application

Expected applications for CompoNet are described here.

a) Electronics Manufacturing System

CompoNet network with data rate at 4Mbit/s is appropriate for the Electronics Manufacturing System or Assembly System of semiconductors.

For the use of CompoNet in these systems, there have been several requirements such as;

- I/O 1000 points at 1ms for the improvement of takt time
- In most systems, the maximum length is 20 meters, Word Units used
- High maintainability since the equipment is used for 24 hours

These requirements shall be solved by CompoNet communication specifications at 4Mbit/s (Communication cycle time for 1000 points at 1ms and the maximum trunk length for 30m) and CIP messages adaptation to improve its maintainability.

b) Automated warehouses

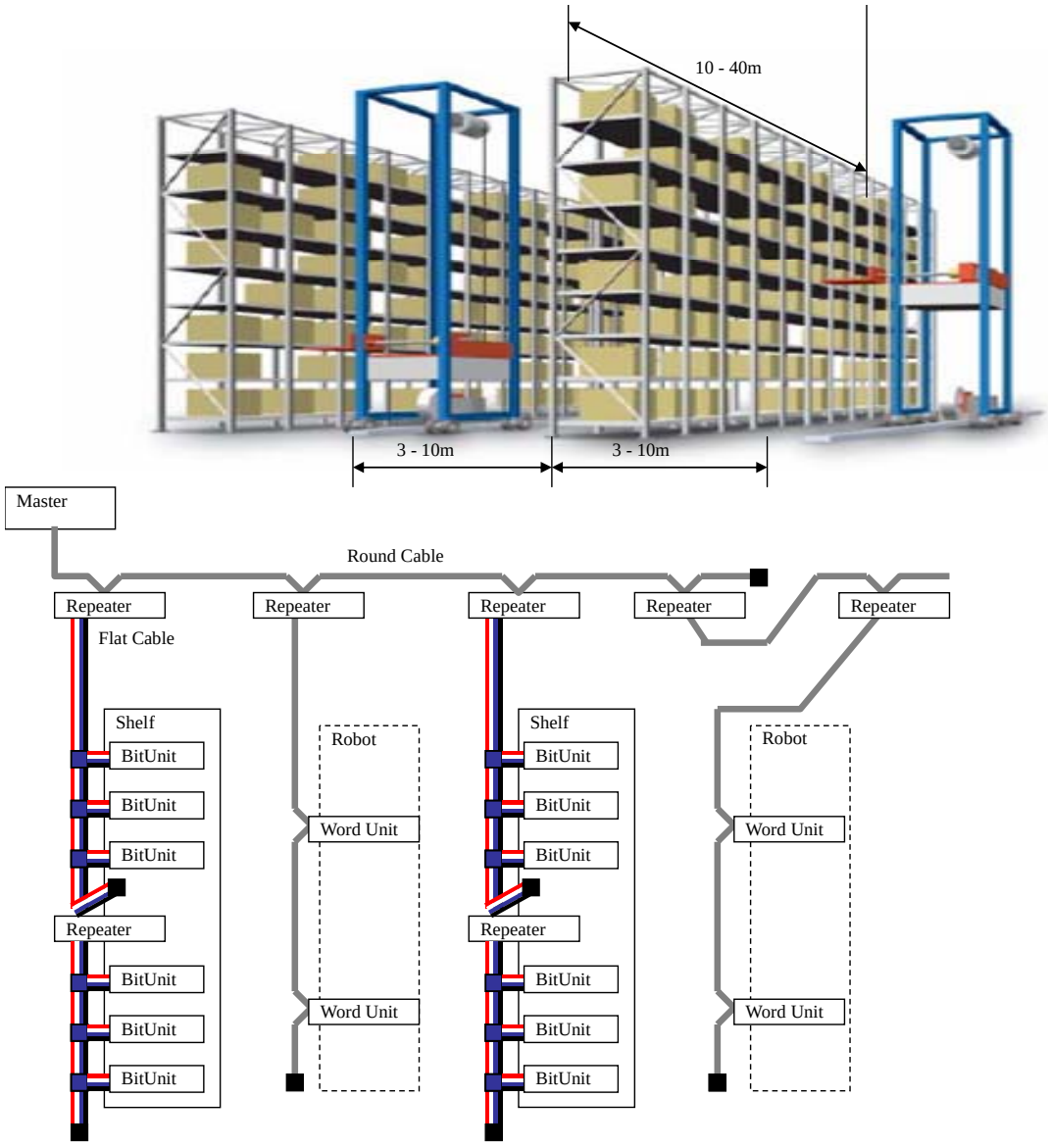
CompoNet network with data rate at 1.5Mbit/s is appropriate for the automated warehouses that consist of several tens of meters.

For the use of CompoNet in these systems, there have been several requirements such as;

- Network connection to bit Slave
- Up to 200m for the maximum length and branches
- I/O 2000 points at 10ms maximum
- Network segmentation and control of configuration to change the specifications appropriate for each user

These requirements shall be solved by CompoNet communication specifications at 1.5Mbit/s (Communication cycle time for 2000 points at 10ms and the maximum trunk length for 100m, 300m at maximum with Repeater), CIP messages adaptation, and network segmentation by Repeater.

Figure 13 Image of CompoNet used in the automated warehouse

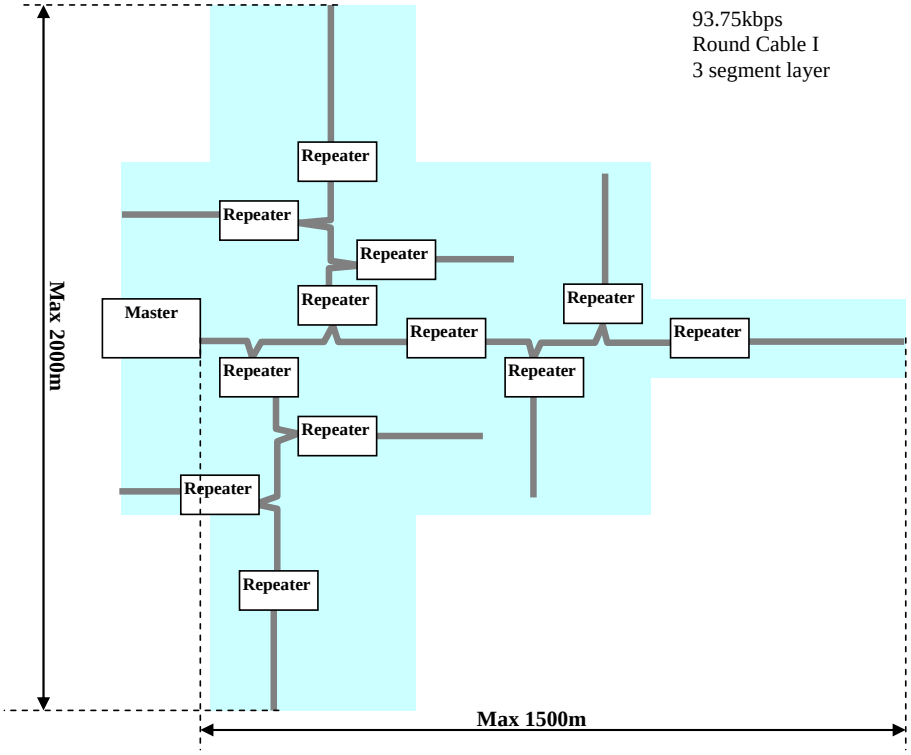


c) Applications in future

CompoNet supports the communication with 93.75kbit/s and 3Mbit/s to expect its capability for various types of applications.

Especially at 93.75Kbit/s, the maximum wiring method shall be 1500m with Repeater to be applied in Building Automation field.

Figure 14 Image of installation at 93.75kbit/s



Conclusion

CompoNet, a field network designed for sensor and actuator applications has accomplished the key requirements of high-speed response, varied and flexible topologies and high maintainability. Moreover, seamless CIP messaging enables communication through multiple layers of networks such as EtherNet/IP, DeviceNet and CompoNet.

CompoNet, with its key advantages, has been used in the electronics manufacturing system and conveyers. It is expected to be applied in Building Automation by the installation area with Repeater.

CompoNet is expected to be used as standard network such as EtherNet/IP, DeviceNet in CIP family.

References

*1. *CIP NETWORKS LIBRARY, Volume6*

*2. *"CompoNetTM: NEW CIP NETWORK FOR SENSORS AND ACTUATORS. Toshiyuki Kojima" presented in 2006 CIP Networks Conference & 11th Annual Meeting, Technical Track: Technology & Innovations, Presented Papers.*

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