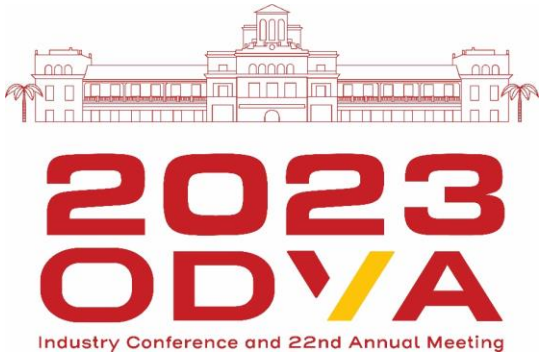


Evaluating EtherNet/IP and CIP Safety Communication over 5G

Shinji Kobayashi

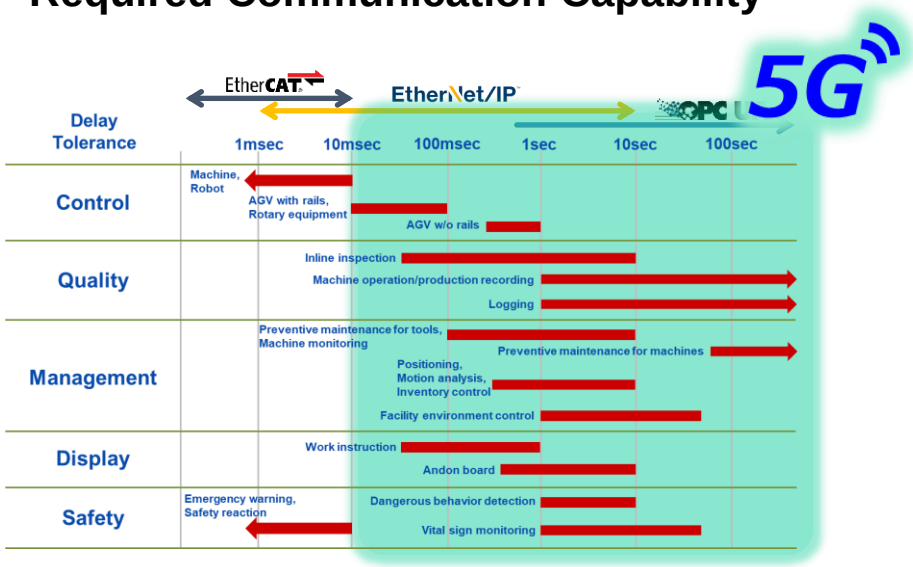
OMRON Corporation

Agenda

1. Introduction
2. Private 5G in Japan
3. EtherNet/IP Evaluation
4. CIP Safety Evaluation
5. Conclusion

Permissible Latencies of Representative Wireless Use Cases

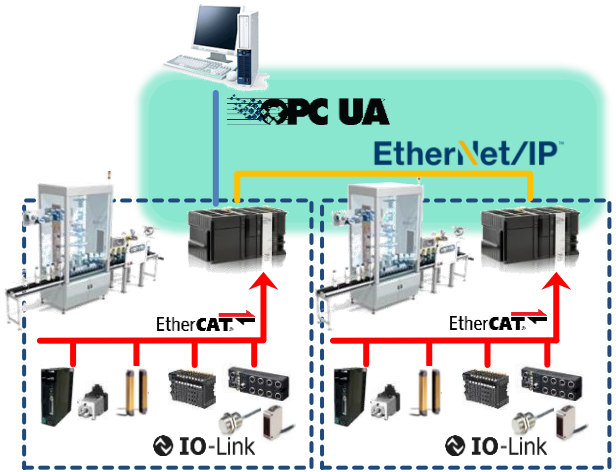
Required Communication Capability



Reference :

- NICT (National Institute of Information and Communications Technology) "Wireless use cases and communication requirements in factories" https://www2.nict.go.jp/wireless/en/ffpj-wp.html

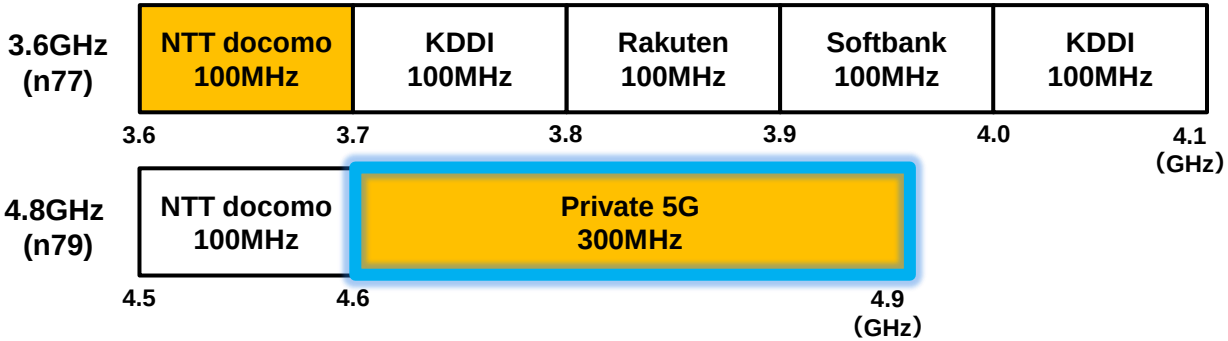
Omron's Adopted Communication Hierarchy



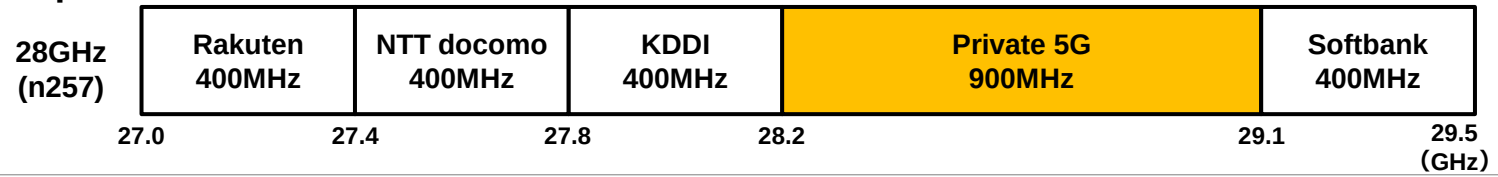
Private 5G Frequencies used in Japan

Evaluation of communication using Sub6 (n79, 4.8GHz Band, 100 MHz BW) with increasing adoption in factories

- **Sub 6 : Less susceptible to obstacles' influence.**



- **mmWave: Capable of high-speed and high-capacity communication, susceptible to obstacles' influence.**

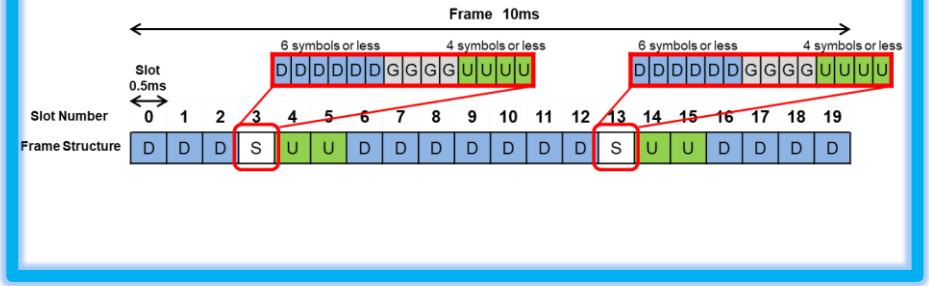


5G TDD Configuration in Japan

Carrier band synchronization method used in Japan

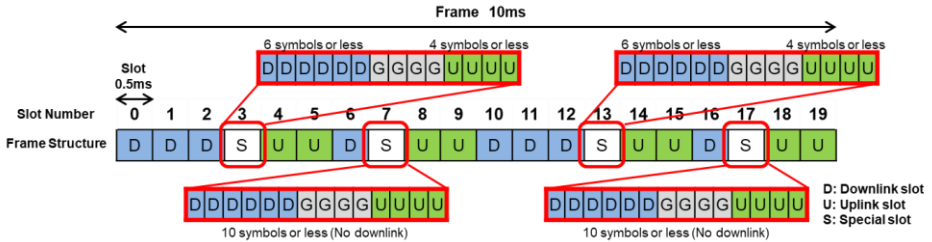
Synchronization pattern

DL : UL = 3.25 : 1



Semi-Synchronization pattern

DL : UL = 5 : 4



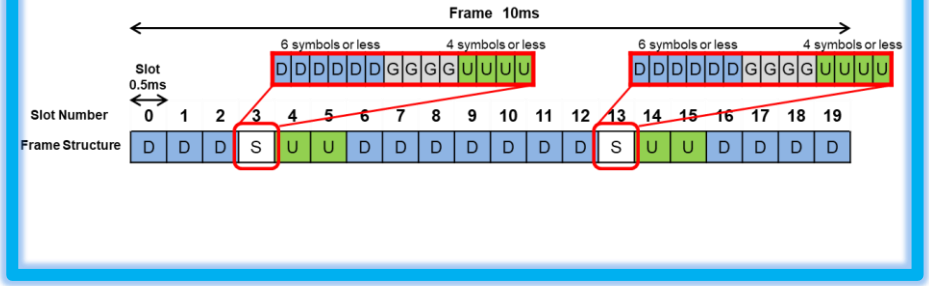
TDD - Time Division Duplex

5G TDD Configuration in Japan

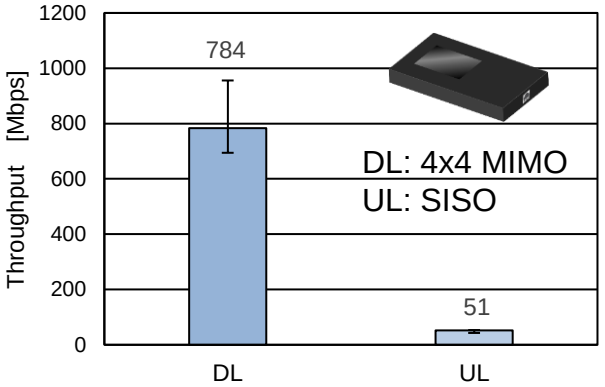
Carrier band synchronization method used in Japan

Synchronization pattern

DL : UL = 3.25 : 1



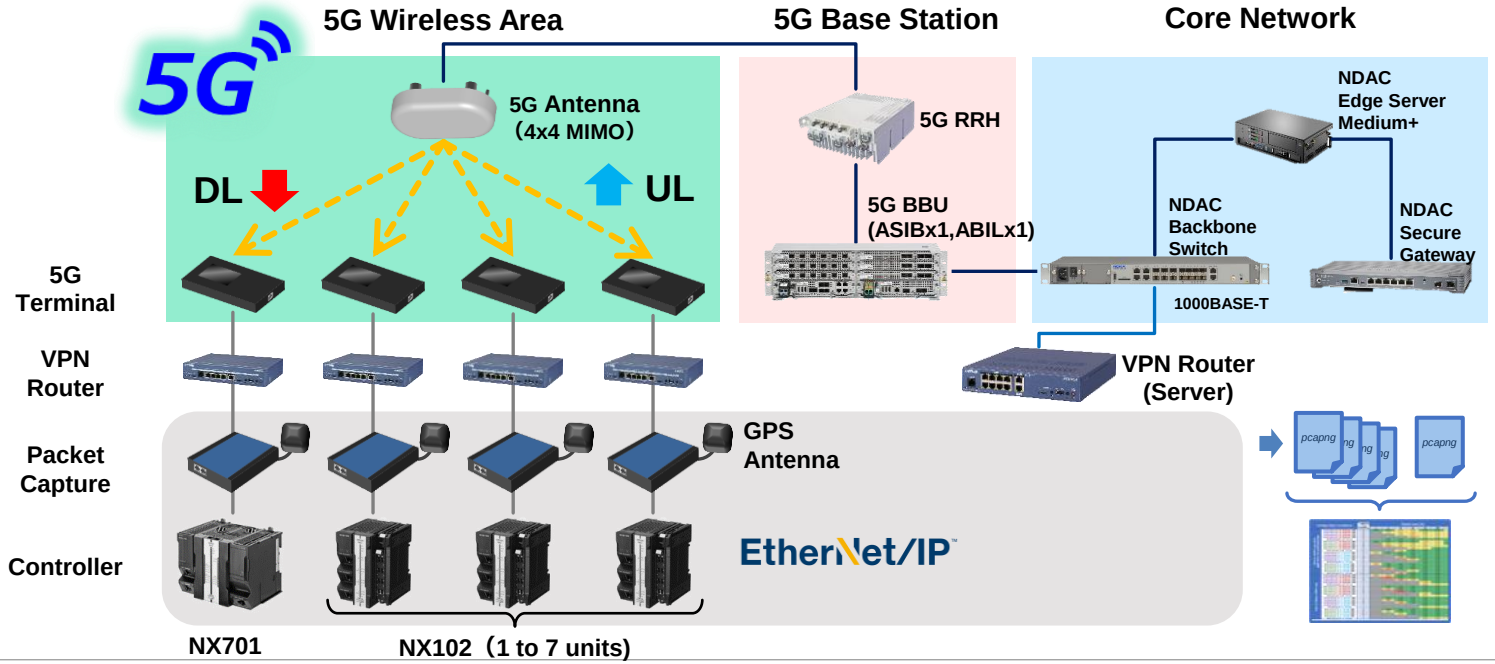
Results of throughput evaluation test for 5G terminal using iperf



iperf - Command-line tool used to measure network performance by establishing a client-server connection and testing throughput, latency, and packet loss.
MIMO - Multiple Input Multiple Output
SISO - Single Input Single Output

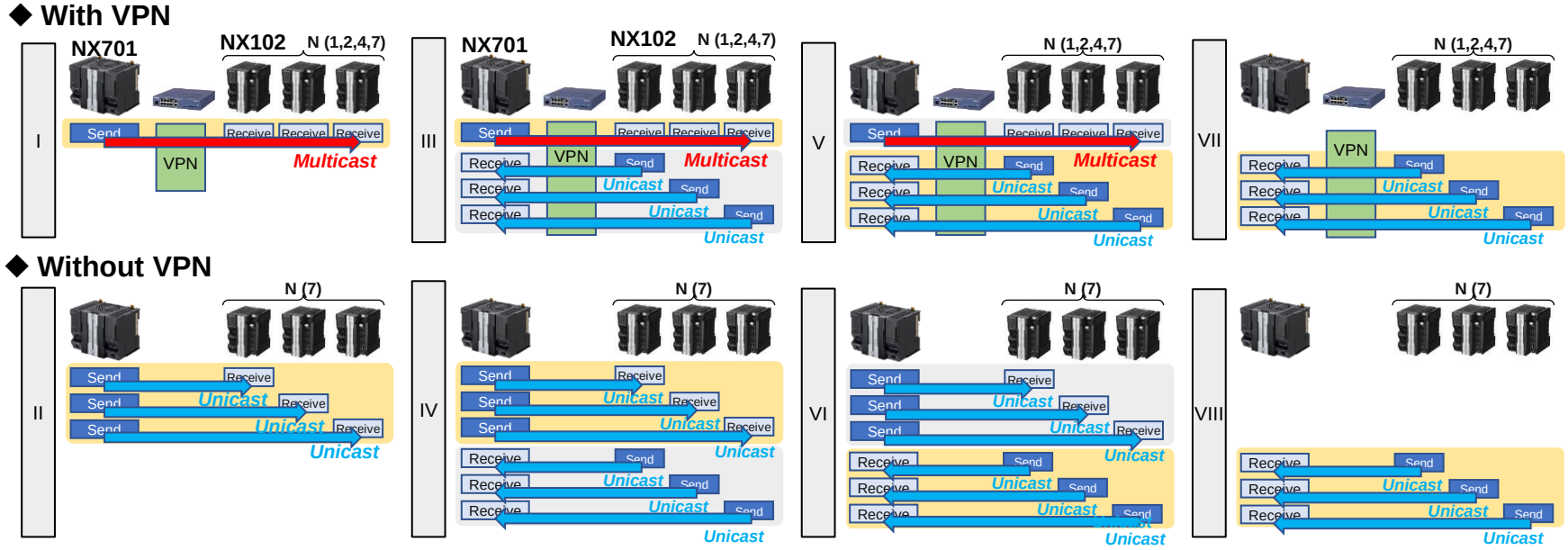
EtherNet/IP - Evaluation Configuration

Measuring packet loss and latency in controller-to-controller communication (NX701 ⇔ NX102s)



EtherNet/IP - Measurement Conditions

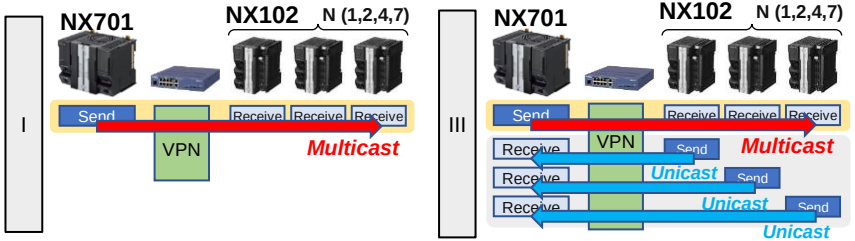
Measurement of communication performance under conditions of with VPN and without VPN, as well as with and without communication load



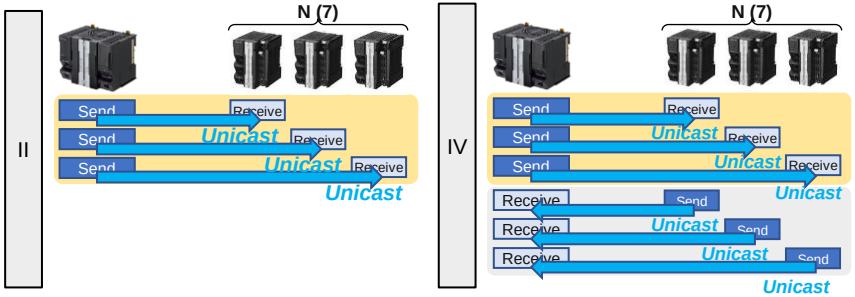
EtherNet/IP - Measurement Conditions

Measurement of communication performance under conditions of with VPN and without VPN, as well as with and without communication load

◆ **With VPN**



◆ **Without VPN**



Measurement Area | Communication Load

Measurement Parameters

- VPN (w/, w/o)
- Multicast, Unicast
- Data size (600byte)
- Number of Nodes (1,2,4,7)
- Number of Connections (32 x Nodes)
- Communication Load
  (Reverse-direction and half the number of connections)
- RPI: Requested Packet Interval
  (1ms, 5ms,10ms, 20ms,100ms, 200ms)

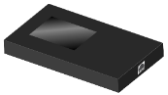
EtherNet/IP - Evaluation Results

With L2TPv3 tunneling communication using a VPN router, multicast communication has been achieved.
Packet loss: Zero within the green area enclosed by the blue border; Latency: 16.8ms to 31.2ms in the conditions.

Type	Measurement Conditions	Additional Load Conditions	RPI[ms] / # nodes	Packet Loss [%]							Latency [ms]						
				1	5	10	20	50	100	200	1	5	10	20	50	100	200
I	*1->N Multi.*	-, VPN	1	0.659	0.001	0.000	0.000	0.000	0.000	0.000	419.4	24.2	22.1	22.0	19.9	21.4	20.9
			2		10.714	0.000	0.000	0.000	0.000	0.000		344.2	25.1	22.9	20.9	21.4	20.9
			4			5.066	1.494	0.000	0.000	0.000			136.1	74.3	25.3	23.2	21.7
			7					1.595	0.000	0.000					86.3	27.5	24.6
II	*1->N Uni.*	-,-	7					0.004	0.004	0.004					25.4	20.6	18.7
III	*1->N Multi.*	*N->1 Uni.*, VPN	1		0.000	0.000	0.000	0.000	0.000	0.000		22.2	20.2	19.8	19.6	21.2	20.4
			2		4.161	0.000	0.000	0.000	0.000	0.000		601.8	23.0	22.3	21.1	22.0	21.1
			4			13.551	0.000	0.000	0.000	0.000			751.5	31.2	25.1	25.2	22.0
			7					0.001	0.000	0.000					31.6	26.0	23.4
IV	*1->N Uni.*	*N->1 Uni.*, -	7					0.005	0.005	0.003					26.9	22.5	18.4
V	*N->1 Uni.*	*1->N Multi*, VPN	1		0.000	0.000	0.000	0.000	0.000	0.000		19.1	18.0	18.8	16.8	19.4	17.9
			2		0.062	0.000	0.000	0.000	0.000	0.000		21.0	19.3	18.0	19.1	17.6	17.9
			4			0.109	0.000	0.000	0.000	0.000			20.4	20.5	20.0	19.6	18.3
			7					0.000	0.000	0.000					22.2	21.4	20.1
VI	*N->1 Uni.*	*N->1 Uni.*, -	7					0.002	0.002	0.003					21.5	21.4	19.9
VII	*N->1 Uni.*	-, VPN	1		0.000	0.000	0.000	0.000	0.000	0.000		20.7	19.6	18.6	17.7	18.6	18.6
			2		2.865	0.000	0.000	0.000	0.000	0.000		731.9	18.9	17.6	18.3	18.5	16.9
			4			3.390	0.000	0.000	0.000	0.000			1474.5	20.0	19.1	19.6	18.6
			7					0.000	0.000	0.000					21.8	19.9	19.5
VIII	*N->1 Uni.*	-, -	7					0.002	0.002	0.002					21.9	21.2	19.2

Bandwidth Requirement in Evaluation Conditions

In the case of multicast communication, VPN server's capability is more decisive for performance than the UL throughput performance of the 5G terminal



Type	Measurement Conditions	Additional Load Conditions	RPI[ms] / # nodes	UL required communication bandwidth [Mbps]							DL required communication bandwidth [Mbps]						
				1	5	10	20	50	100	200	1	5	10	20	50	100	200
I	*1->N Multi.*	-, VPN	1	57.5	37.3	18.9	9.8	4.3	2.4	1.2	57.5	37.3	18.9	9.8	4.3	2.4	1.2
			2	57.7	37.8	19.2	10.1	4.6	2.7	1.4	114.7	73.9	37.3	18.9	7.9	4.3	2.1
			4	46.4	39.0	19.8	10.6	5.2	3.3	1.7	183.4	147.2	73.9	37.3	15.3	7.9	4.0
			7	23.4	28.1	20.7	11.5	6.0	4.2	2.1	160.5	176.8	128.9	64.7	26.3	13.4	6.7
II	*1->N Uni.*	-,-	7	149.5	165.7	121.7	62.0	26.2	14.3	7.2	149.5	165.7	121.7	62.0	26.2	14.3	7.2
III	*1->N Multi.*	*N->1 Uni.*, VPN	1	57.5	37.3	18.9	9.8	4.3	2.4	1.2	57.5	37.3	18.9	9.8	4.3	2.4	1.2
			2	86.3	56.2	28.5	14.8	6.5	3.8	1.9	114.8	74.2	37.6	19.2	8.2	4.6	2.3
			4	115.2	94.0	47.8	24.8	11.1	6.5	3.3	183.7	148.1	74.8	38.1	16.1	8.8	4.4
			7	92.2	103.7	76.6	39.9	17.9	10.6	5.3	160.7	178.1	130.7	66.5	28.0	15.2	7.6
IV	*1->N Uni.*	*N->1 Uni.*, -	7	149.5	165.7	121.7	62.0	26.2	14.3	7.2	149.5	165.7	121.7	62.0	26.2	14.3	7.2
V	*N->1 Uni.*	*1->N Multi*, VPN	1	57.5	37.3	18.9	9.8	4.3	2.4	1.2	57.5	37.3	18.9	9.8	4.3	2.4	1.2
			2	86.3	56.2	28.5	14.8	6.5	3.8	1.9	114.8	74.2	37.6	19.2	8.2	4.6	2.3
			4	115.2	94.0	47.8	24.8	11.1	6.5	3.3	183.7	148.1	74.8	38.1	16.1	8.8	4.4
			7	92.2	103.7	76.6	39.9	17.9	10.6	5.3	160.7	178.1	130.7	66.5	28.0	15.2	7.6
VI	*N->1 Uni.*	*N->1 Uni.*, -	7	149.5	165.7	121.7	62.0	26.2	14.3	7.2	149.5	165.7	121.7	62.0	26.2	14.3	7.2
VII	*N->1 Uni.*	-, VPN	1	57.5	37.3	18.9	9.8	4.3	2.4	1.2	57.5	37.3	18.9	9.8	4.3	2.4	1.2
			2	114.9	74.5	37.8	19.5	8.5	4.9	2.4	114.9	74.5	37.8	19.5	8.5	4.9	2.4
			4	183.9	149.0	75.7	39.0	17.0	9.7	4.9	183.9	149.0	75.7	39.0	17.0	9.7	4.9
			7	160.9	179.3	132.5	68.3	29.8	17.0	8.5	160.9	179.3	132.5	68.3	29.8	17.0	8.5
VIII	*N->1 Uni.*	-, -	7	149.5	165.7	121.7	62.0	26.2	14.3	7.2	149.5	165.7	121.7	62.0	26.2	14.3	7.2

51Mbps

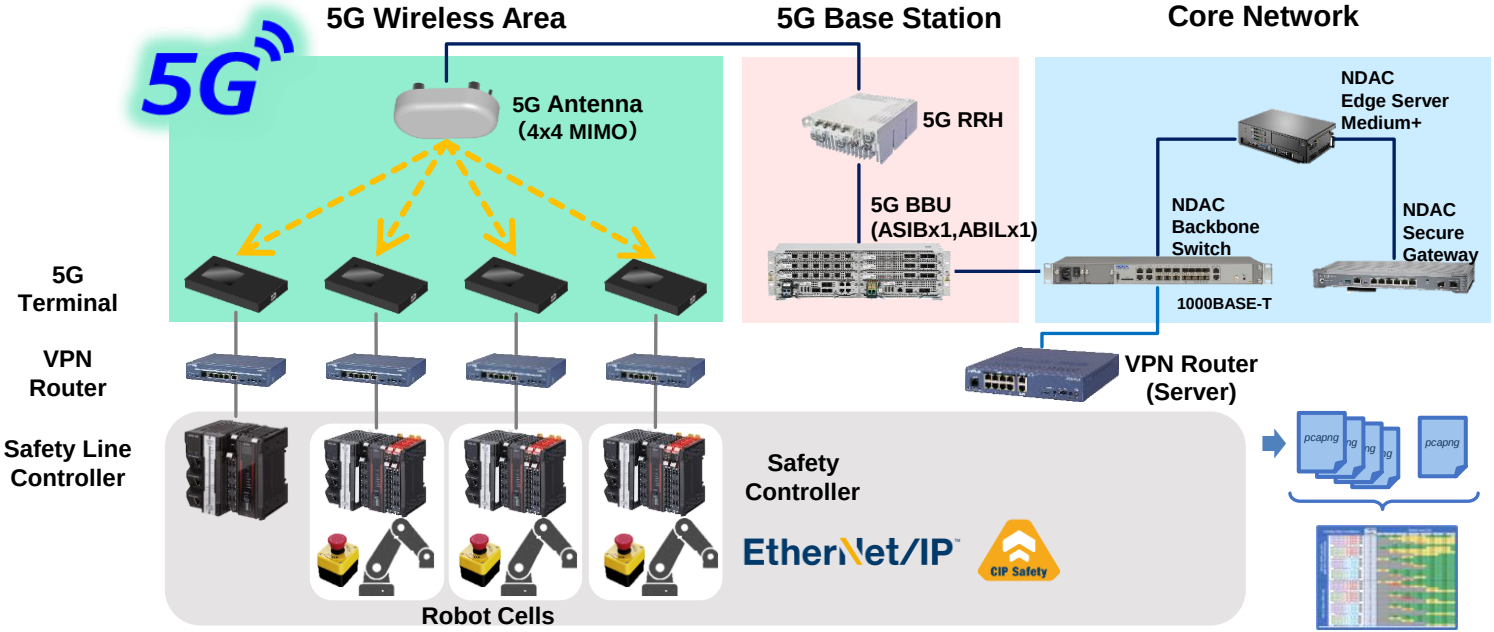
784Mbps

Summary of EtherNet/IP Evaluation Results

1. By utilizing L2TPv3 tunneling with a VPN router, multicast communication has been achieved.
2. Under several conditions with VPN, zero packet loss was observed.
3. In the conditions which packet loss was zero, latency values between 16.8ms and 31.2ms were obtained.
4. The TDD frame structure, which maintains a communication performance ratio of 3.25:1 between DL and UL, may have resulted in lower UL performance, making it challenging to achieve a latency of 10ms or lower.
5. In the case of multicast communication between controllers using 5G transmission, VPN server's multicast performance becomes a critical factor in determining the system's performance.

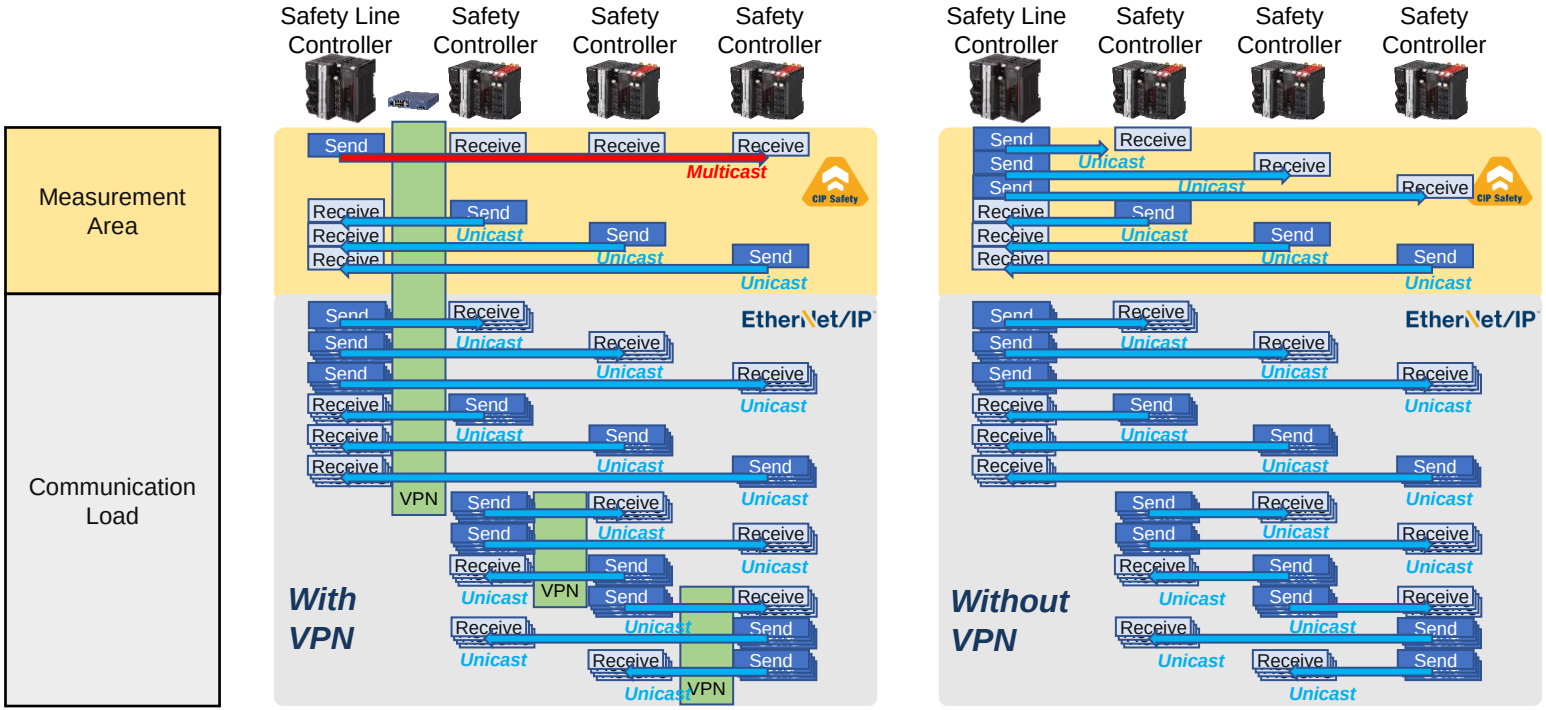
CIP Safety - Evaluation Configuration

Measuring packet loss and latency in controller-to-controller communication
(Safety Line Controller ⇔ Safety Controllers)



CIP Safety- Measurement Conditions

Evaluating communication performance with and without VPN while applying communication load



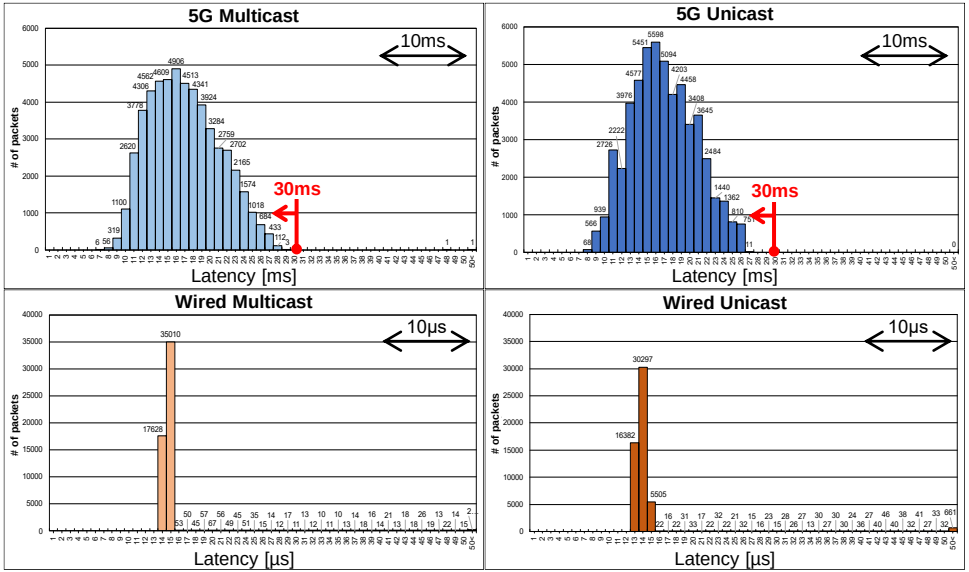
CIP Safety- Evaluation Results

No significant difference between 5G multicast and 5G unicast;
both achieved latency of 30ms or below for almost all CIP Safety packets.

Packet loss and Latency

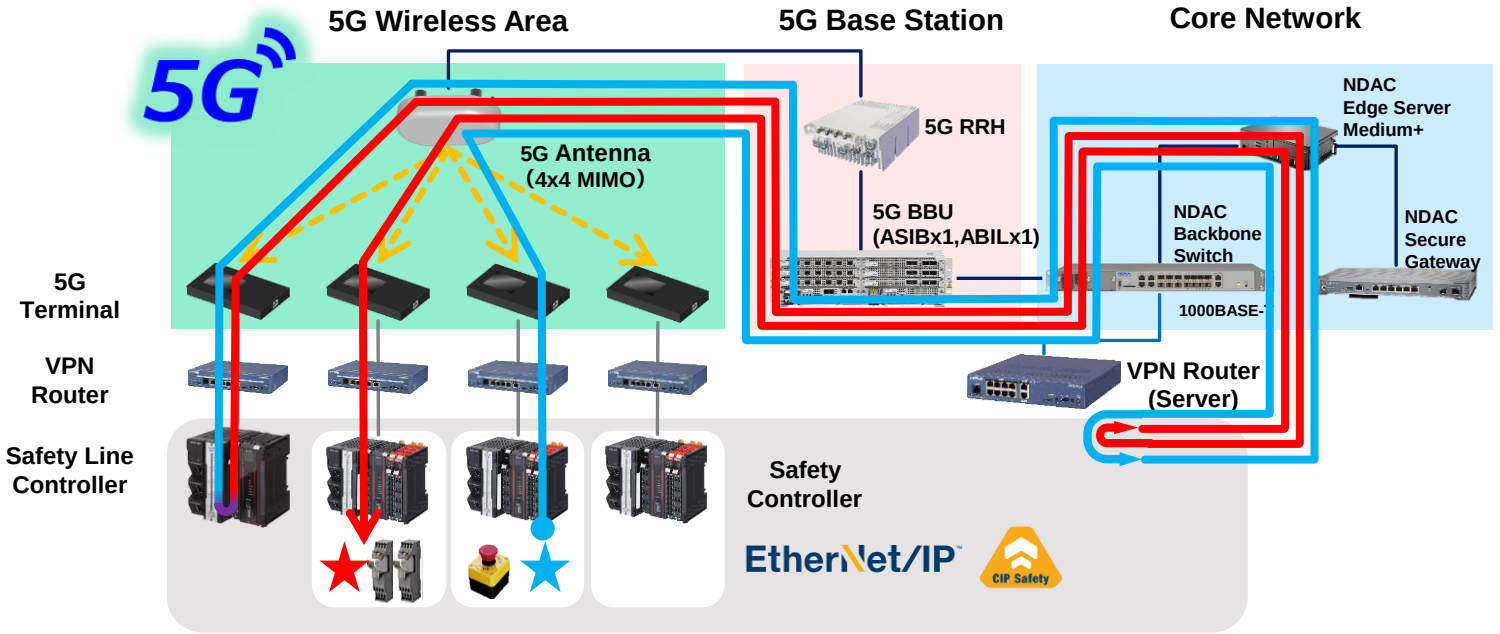
	Measurement Conditions	RPI for Comm. Load [ms]						
	(EPI: 60ms Fixed)	1	5	10	20	50	100	200
Packet Loss [%]	5G *Multicast* w/ VPN	0.000	0.000	0.000	0.000	0.000	0.000	0.001
	5G *Unicast Only*		0.002	0.009	0.009	0.004	0.006	0.002
	Wired *Multicast w/o VPN*	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Wired *Unicast Only*	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Latency [%]	5G *Multicast* w/ VPN	20.7	20.0	17.0	16.3	13.3	12.2	11.6
	5G *Unicast Only*		19.4	17.6	16.5	13.0	12.8	12.3
	Wired *Multicast w/o VPN*	0.02	0.02	0.02	0.01	0.01	0.01	0.01
	Wired *Unicast Only*	0.02	0.01	0.02	0.01	0.01	0.01	0.01

Histograms of Latency



Safety Reaction Time - Evaluation Configuration

Measuring the time from pressing the emergency stop to safety relay opening.

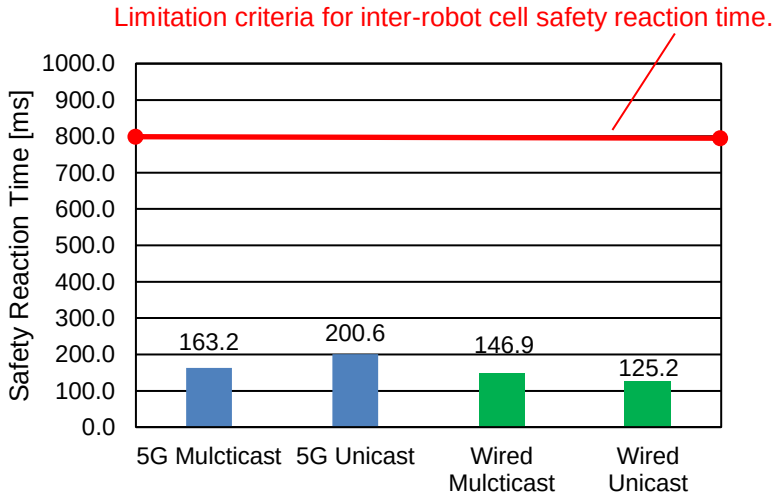


Safety Reaction Time - Evaluation Results

Considering that the acceptable limit requirement for this use case is 800ms, 5G transmission is sufficiently usable.

Robot cell line use case

Safety Reaction Time



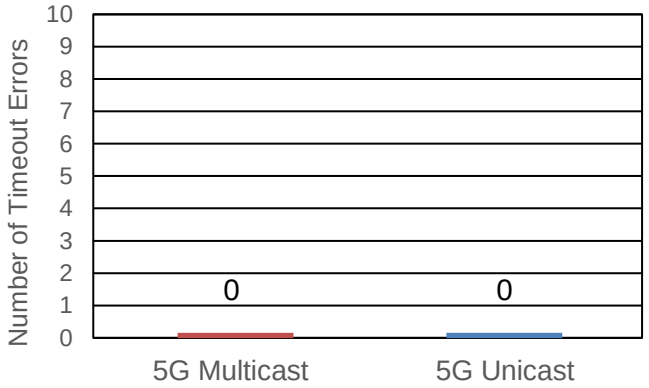
(EPI=60ms, Load RPI=20ms、n=10)

24-hour continuous evaluation - Evaluation Results

No timeout errors occurred in either multicast or unicast communication, and the system operated stably for the entire 24 hours.

Robot cell line use case

Number of Timeout Errors



EPI=60ms, Load RPI=20ms,
Timeout Error Trigger Condition=120ms (EPI x 2)

Summary of CIP Safety Evaluation Results

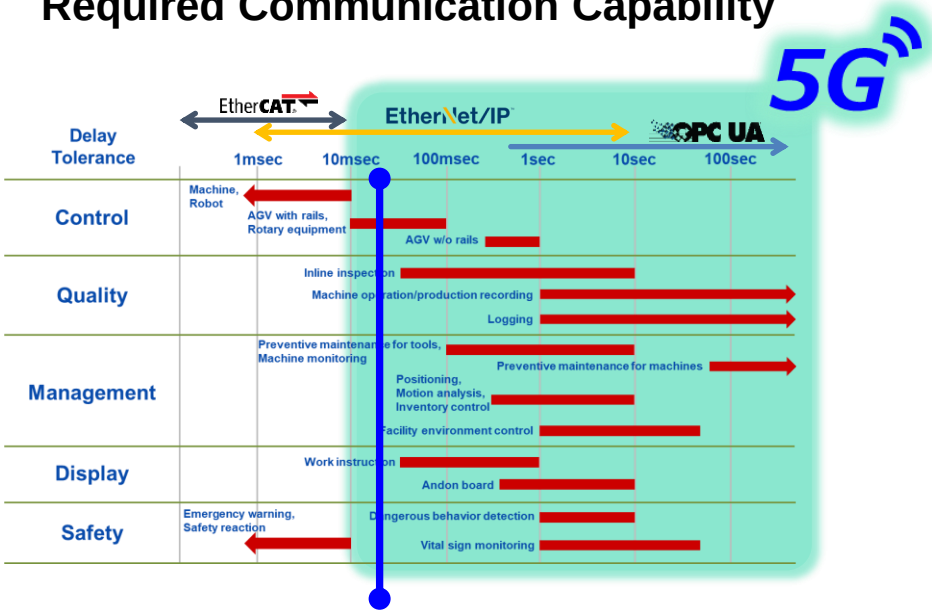
1. **Both 5G multicast and unicast achieved latency of 30ms or below for almost all CIP Safety packets.**
2. **In the robot cell line use case (where the operator operates a safety button), it was confirmed that the achieved safety reaction time (163.2ms) met the performance requirement of 800ms.**
3. **There were no timeout errors and stable operation was possible for 24 hours.**

5G Sub6 (n79) Synchronization pattern - Evaluation Results

Evaluation Result of Latency
(16.8ms～31.2ms)

Type	Measurement Conditions	Additional Load Conditions	RPI[ms] / # nodes	Latency [ms] 1	5	10	20	50	100	200
I	*1->N Multi.*	-, VPN	1	419.4	24.2	22.1	22.0	19.9	21.4	20.9
			2		344.2	25.1	22.9	20.9	21.4	20.9
			4			136.1	74.3	25.3	23.2	21.7
			7					86.3	27.5	24.6
II	*1->N Uni.*	-,-	7					25.4	20.6	18.7
III	*1->N Multi.*	*N->1 Uni.*, VPN	1		22.2	20.2	19.8	19.6	21.2	20.4
			2		601.8	23.0	22.3	21.1	22.0	21.1
			4			751.5	31.2	25.1	25.2	22.0
			7					31.6	26.0	23.4
IV	*1->N Uni.*	*N->1 Uni.*, -	7					26.9	22.5	18.4
V	*N->1 Uni.*	*1->N Multi*, VPN	1		19.1	18.0	18.8	16.8	19.4	17.9
			2		21.0	19.3	18.0	19.1	17.6	17.9
			4			20.4	20.5	20.0	19.6	18.3
			7					22.2	21.4	20.1
VI	*N->1 Uni.*	*N->1 Uni.*, -	7					21.5	21.4	19.9
VII	*N->1 Uni.*	-, VPN	1		20.7	19.6	18.6	17.7	18.6	18.6
			2		731.9	18.9	17.6	18.3	18.5	16.9
			4			1474.5	20.0	19.1	19.6	18.6
			7					21.8	19.9	19.5
VIII	*N->1 Uni.*	-, -	7					21.9	21.2	19.2

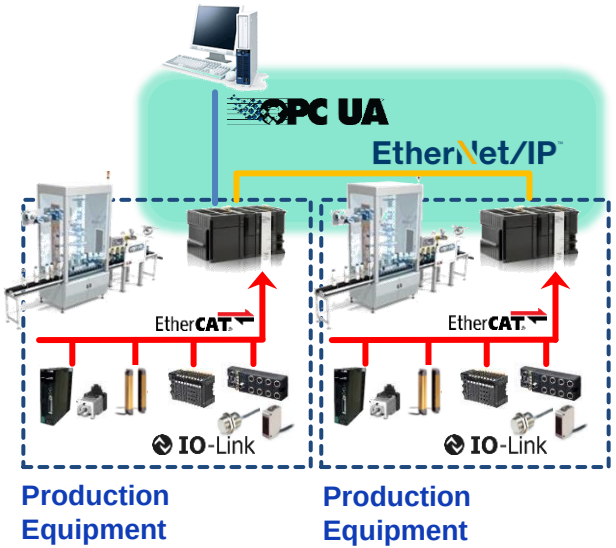
Required Communication Capability



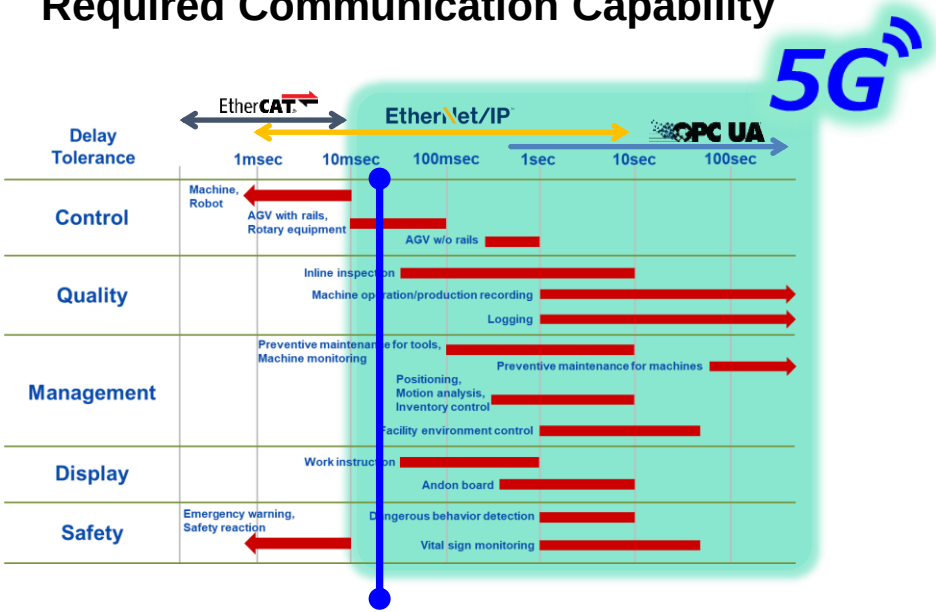
RPI + Latency: 25ms～50ms

5G Communication Capability Required for Layout-Free

Omron's Adopted Communication Hierarchy



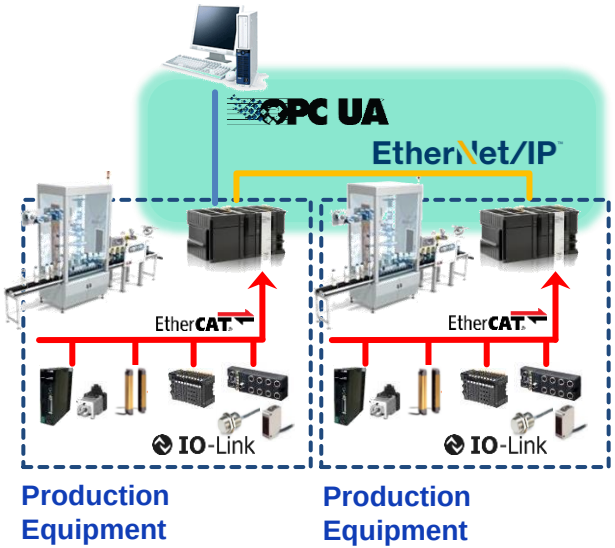
Required Communication Capability



RPI + Latency: 25ms～50ms

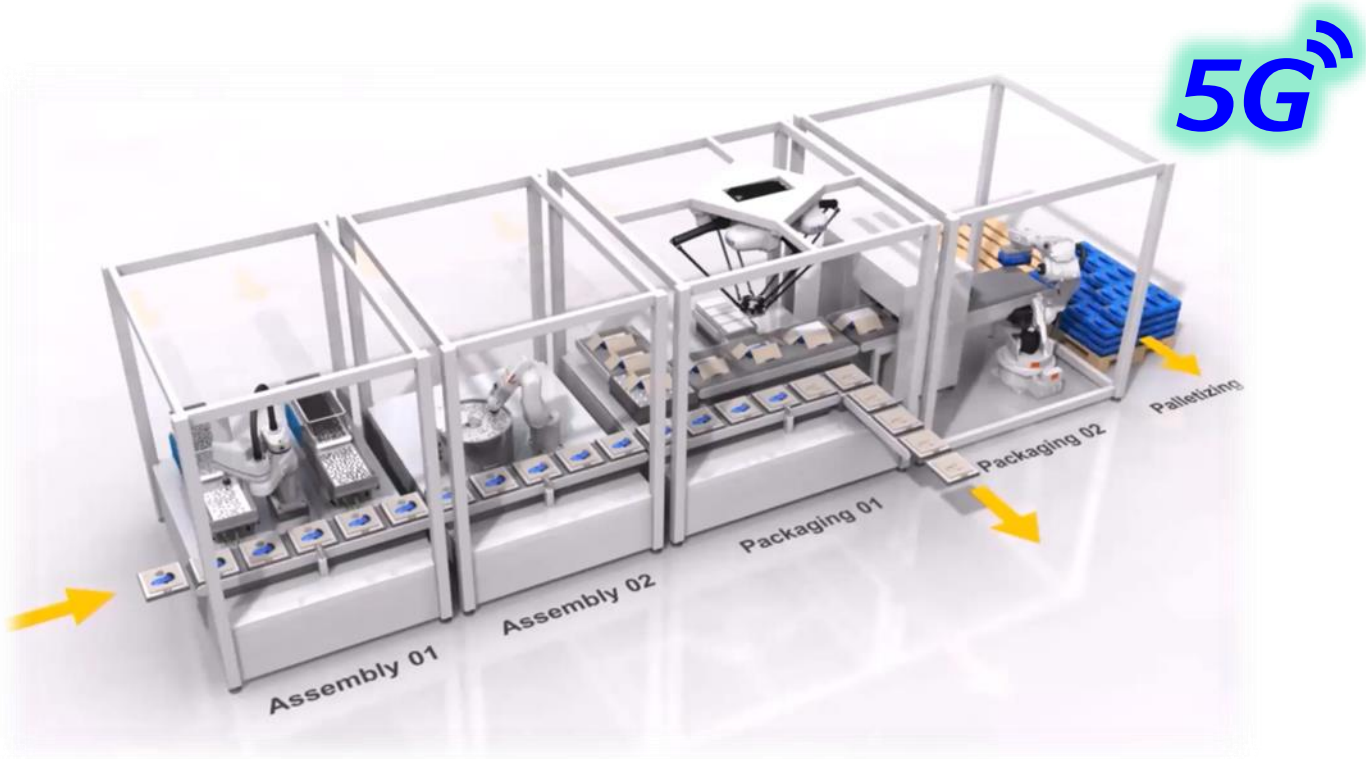
5G Communication Capability Required for Layout-Free

Omron's Adopted Communication Hierarchy



Layout Free Production Line

Layout Free Production Line with 5G



Conclusion

The conclusions obtained from applying 5G communication (5G Sub6 n79 Synchronization pattern) for controller-to-controller communication, evaluating EtherNet/IP performance, measuring safety reaction time of CIP Safety in the robot cell line use case, and conducting a 24-hour continuous evaluation are presented below.

1. **When transmitting EtherNet/IP over 5G for Implicit communication between controllers, multicast communication from Controller 1 to N nodes (N = 1, 2, 4, 7) achieved an average latency of 19.6-31.2ms.This indicates it was possible to achieve the required latency for "AGV control". However, it was not possible to achieve the required latency of 10ms or below for "Machine, and Robot control".**
2. **When transmitting CIP Safety over 5G in the robot cell line use case (where the operator operates a safety button), it was confirmed that the achieved safety reaction time met the performance requirement of 800ms (163.2ms). However, it was not possible to achieve the required latency of 10ms or below for "Emergency warning", which requires high-speed reaction times where the operator does not make safety judgments (e.g., safety light curtains).**

Thank You