Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [Selection of Suitable Preamble Sequence Sets in UWB Wireless Communications in the Presence of Multiple Coexisting VBANs]

Date Submitted: [10th January 2025]

Source: [Hiroaki Yoshitake[1], Tetsuya Nomura[2], Makoto Okuhara[3]] [DENSO TEN]
Address [2-28 Gosho-dori, 1-chome, Hyogo-ku, Kobe, Hyogo 652-8510 , Japan]
Voice:[+81-78-682-1427],
Email:[1: hiroaki.yoshitake.j7d@jpgr.denso.com, 2: tetsuya.nomura.j7c@jpgr.denso.com, 3: makoto.okuhara.j8s@jpgr.denso.com]

Re: []

Abstract: [This document proposes a practical way to mitigate mutual interference among transmitted packets from coexisting multiple BANs to reduce packet synchronization errors by using suitable or preferable sets of preamble sequences assigned to coexisting BANs with UWB in PHY. This is an optional way to avoid packet contention errors in P802.15.6ma. Analysis is based on cases of vehicle BANs (VBANs) but can be applicable to human BANs (HBANs) as well.]

Purpose: [information]

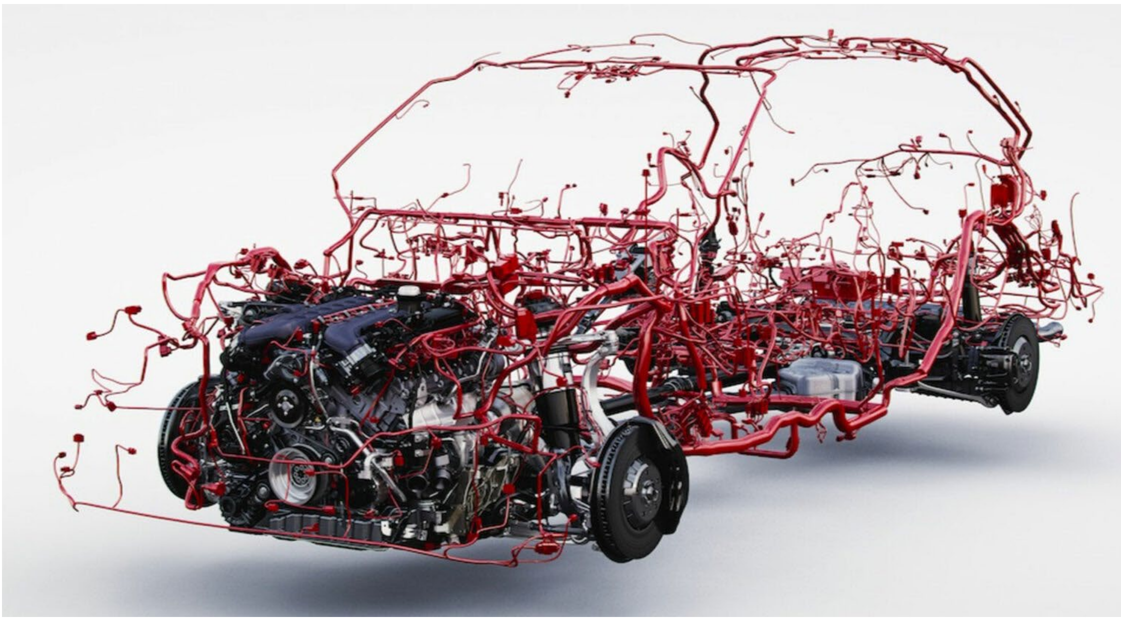
Selection of Suitable Preamble Sequence Sets in UWB Wireless Communications in the Presence of Multiple Coexisting VBANs

Hiroaki Yoshitake, Tetsuya Nomura, Makoto Okuhara
DENSO TEN Ltd.

1. Background
   1.1 Motivation and Aim of this Study
   1.2 Review of the Previous Presentation and Contents of this New Presentation
2. Analysis Using Computer Simulation
   2.1 Simulation Specification
   2.2 Derived Preferable Sets of Preamble Sequences
3. Conclusion and Further Study

Motivation:

The number of wire harnesses has increased as car control systems have advanced



Source: CARSCOOPS "Carmakers Are Rushing To Adopt Simpler Modular Wiring Harnesses“
https://www.carscoops.com/2022/05/carmakers-are-rushing-to-adopt-simpler-modular-wiring-harnesses/

<u>Problem</u>

■More weight：
- leads to degradation in a fuel and electric efficiency
- results in increase of CO2 emissions

■ More components：
- leads to restrict in interior comfort
- results in increase of process in manufacture line

Aim of This Study:

In order to reduce the weight and components of cars, while maintaining the reliability of sensing and control, UWB wireless networks, i.e. VBAN can be applied for harnessless or wireless harness.

Particularly, we derive the appropriate sets of sequences to avoid packet and frame errors due to interference from coexisting VBANs for practical use cases.

1. Background
   1.1 Motivation and Aim of this Study
   1.2 Review of the Previous Presentation and Contents of this New Presentation
2. Analysis Using Computer Simulation
   2.1 Simulation Specification
   2.2 Derived Preferable Sets of Preamble Sequences
3. Conclusion and Further Study

Review of the Previous Presentation :

■Our problems

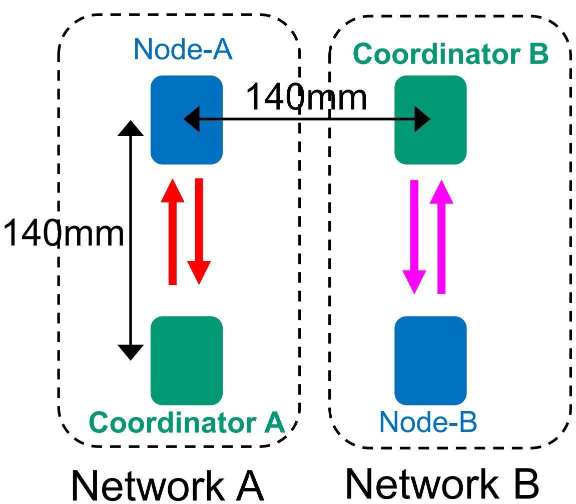
- It is necessary to reduce the impact of interference from VBANs of nearby vehicles.
- Real-time communication within the permissible delay in a VBAN should be performed.

■Our proposal

- Proposed an optional scheme in a draft standard to assign quasi-orthogonal preamble sequence to coexisting VBANs of cars, allowing simultaneous communication with less interference. (assignment of preamble sequence in C2CP)
- Assignment of quasi-orthogonal preamble sequence allows multiple VBANs to coexist while reducing interference and enabling real-time communication.

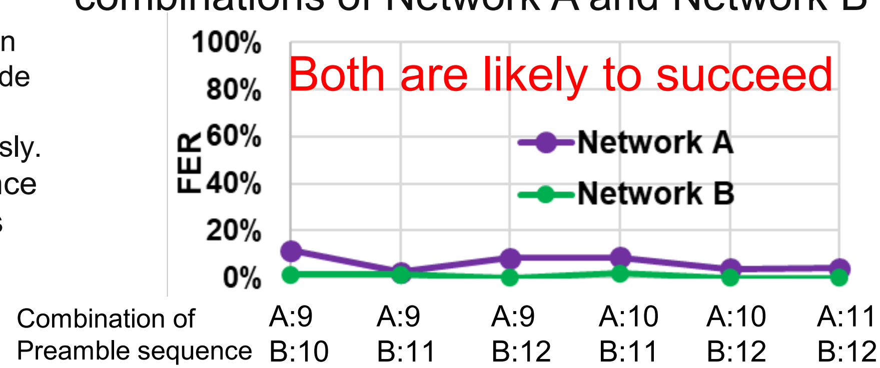
■Experimental Results

By using UWB modules, we have already confirmed that setting different preamble sequence helps reduce the interference in a few limited practical use cases.



- Each network system consists of one node and one coordinator
- Communication between the Coordinator and Node in networks A and B is carried out simultaneously.
- Confirm the interference impact on network A's communication from network B and vice versa.

Check FER with preamble sequence combinations of Network A and Network B



New Presentation :

■ Remaining issues

- Demonstrating the interference reduction effect of preamble sequences used in IEEE802.15.6ma.
- Confirming the interference reduction effect when more multiple VBANs coexist in various channel environments.
- Presenting the appropriate sets of preamble sequence according to more practical environments.

■ Contents of this New Presentation

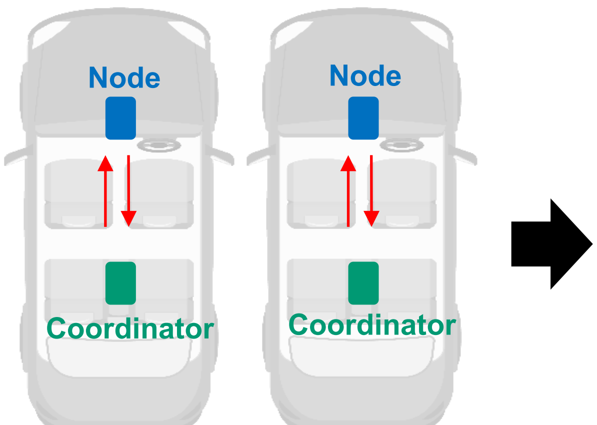
Details of the interference reduction effect of appropriate combinations of preamble sequence in different environments.

- Results of simulations assuming coexistence with multiple vehicles to confirm the effectiveness of the proposal
- Results of confirming appropriate sets of preamble sequences (Kasami, Ipatov) for use in vehicles

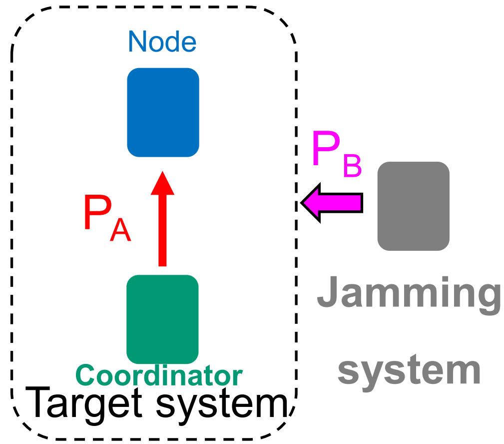
1. Background
   1.1 Motivation and Aim of this Study
   1.2 Review of the Previous Presentation and Contents of this New Presentation
2. Analysis Using Computer Simulation
   2.1 Simulation Specification
   2.2 Derived Preferable Sets of Preamble Sequences
3. Conclusion and Further Study

Methods for verification through simulation 1:

Simulations have confirmed that it is possible to achieve error-free frame synchronization even in the presence of interference from coexisting VBANs and a noise by using appropriate preamble sequences and have demonstrated the interference reduction effect.



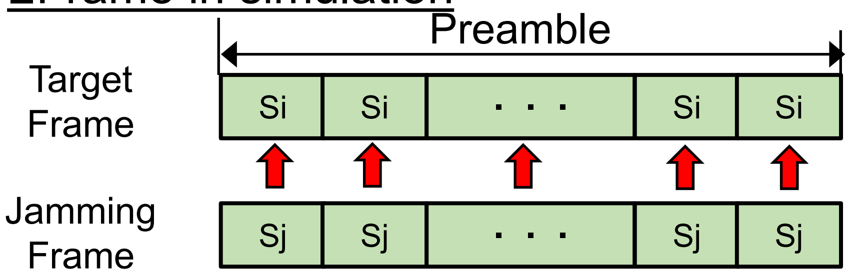
Assuming that vehicles with the same system are adjacent



P_A :Power received from the Target system
P_B :Power received from the Jamming system

- In-vehicle systems use a polling method to ensure responsiveness, and this simulation adopted such a model that only one pair of a coordinator and a node can access a channel in each time slot.
- Check for frame synchronization errors in the target system or VBAN when a coexisting jamming system or VBAN with a different preamble sequence interferes to the target system or VBAN.

■Frame in simulation



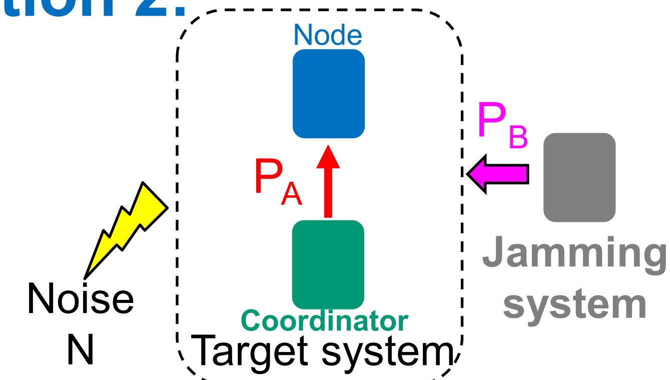
Si : Preamble sequence of the Target system
Sj : Preamble sequence of the Jamming system

- To simulate synchronization frame error rate (FER) only, the frame structure is set to contain only the preamble sequence, with no data payload.
- Synchronization can be performed by detecting a peak of correlator output between received signals and a local preamble sequence in the target system in a presence of additive white Gaussian noise.

Methods for verification through simulation 2:

■Simulation parameter

	Parameter	
Preamble	sequence	Kasami:C1～C8 Ipatov:C9～C24
	Number of executions	64
Jamming System	Number of unit	1 unit/4units
	Interference ratio(P_A/P_B)	-40dB～5dB
Noise	S/N ratio(P_A/N)	0dB,-10dB,-20dB



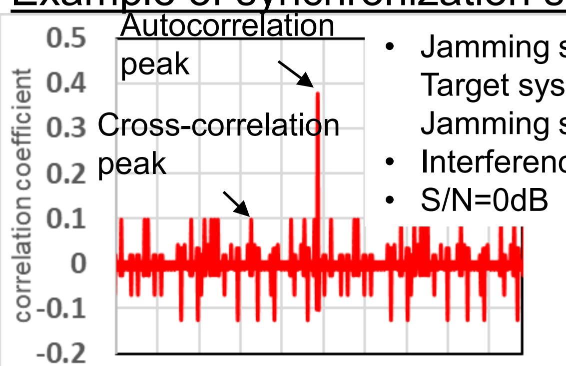
P_A :Power received from the Target system
P_B :Power received from the Jamming system

Example: one interference system

■Judge for synchronization error

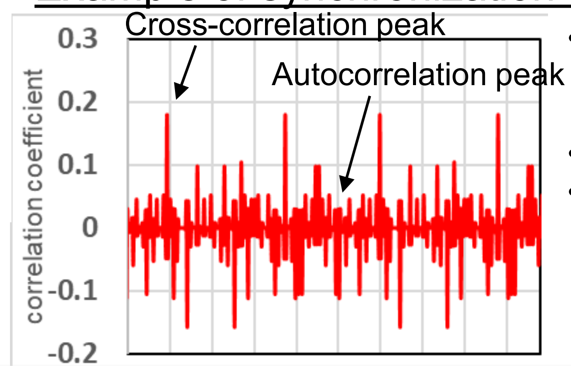
A synchronization frame error is counted if summation of all cross-correlation among preamble sequences and noise in each time slot exceeds beyond the autocorrelation peak of preamble sequence of target system in the output of correlator in a target system as right figure below.

Example of synchronization success



- Jamming system: 1unit
  Target system:C3
  Jamming system:C5
- Interference ratio(P_A/P_B)=0dB
- S/N=0dB

Example of synchronization errors



- Jamming system: 4 units
  Target system:C5
  Jamming system:C1,4,7,8
- Interference ratio(P_A/P_B)=5dB
- S/N=0dB

Simulations have been performed to evaluate synchronization frame error rate (FER) by various numbers of interference systems, interference levels, and noise level.

Preamble sequence:

Examination of preamble sequence specified as main/optional in draft standards

Kasami 63Length

	code sequences
C_1	1 1 1 1 1 1 0 1 0 1 0 1 1 0 0 1 1 0 1 1 1 0 1 1 0 1 0 0 1 0 0 1 1 1 0 0 0 1 0 1 1 1 1 0 0 1 0 1 0 0 0 1 1 0 0 0 0 1 0 0 0 0 0
C_2	0 0 0 1 1 0 0 0 1 0 0 1 0 0 1 0 0 0 1 0 1 1 0 0 0 1 1 0 0 1 1 1 1 0 0 1 1 0 0 1 0 1 0 1 1 1 0 0 0 1 1 0 1 0 1 0 1 0 1 0 0 1 0
C_3	1 0 0 0 1 1 1 1 1 0 1 1 1 1 0 0 0 1 1 1 0 0 0 0 1 1 0 1 1 1 1 0 1 1 1 0 1 0 1 1 1 0 1 1 1 0 0 1 1 0 1 0 0 0 0 1 0 0 1 1 0 0 1
C_4	0 1 0 0 0 1 0 0 0 0 1 0 1 0 1 1 0 1 0 1 1 1 1 0 1 0 0 0 0 0 1 0 0 1 0 1 0 0 1 0 1 1 0 0 1 0 1 1 0 1 0 0 0 1 0 0 1 1 1 1 1 0 0
C_5	1 0 1 0 0 0 0 1 1 1 1 0 0 0 0 0 1 1 0 0 1 0 0 1 1 0 1 0 1 1 0 0 0 0 0 0 1 1 1 0 0 1 1 1 0 0 1 0 0 0 1 1 0 1 1 0 0 0 0 1 1 1 0
C_6	1 1 0 1 0 0 1 1 0 0 0 0 0 1 0 1 0 0 0 0 0 0 1 0 0 0 1 1 1 0 1 1 0 0 1 0 0 0 0 0 0 0 1 0 1 1 1 0 1 0 0 0 1 1 1 1 0 1 1 0 1 1 1
C_7	0 1 1 0 1 0 1 0 0 1 1 1 0 1 1 1 1 1 1 0 0 1 1 1 1 1 1 1 0 0 0 0 1 0 1 1 0 1 1 1 0 0 0 0 0 0 0 0 1 1 0 1 0 0 1 1 1 1 0 1 0 1 1
C_8	0 0 1 1 0 1 1 0 1 1 0 0 1 1 1 0 1 0 0 1 0 1 0 1 0 0 0 1 0 1 0 1 0 1 1 1 1 1 0 0 1 0 0 1 0 1 1 1 1 1 1 1 1 1 0 1 1 0 0 0 1 0 1

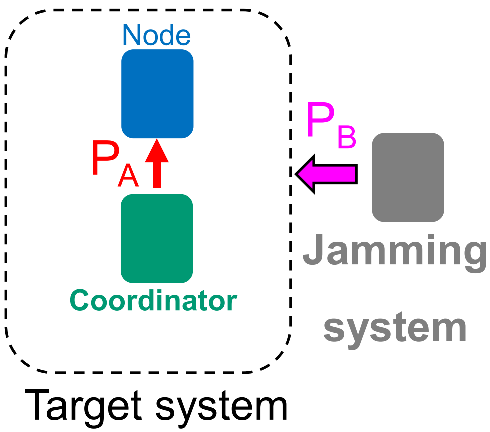
Ipatov 127Length

	code sequences
C_9	+ 0 0 + 0 0 0 - 0 - - 0 0 - - + 0 + 0 + 0 0 - + - + + 0 + 0 0 0 0 + + - 0 0 0 + 0 0 - 0 0 - - 0 - + 0 + 0 - - 0 - + + + 0 + + 0 0 0 + - 0 + 0 0 - 0 + + - 0 + + + 0 0 - + 0 0 + 0 + 0 - 0 + + - + - - + 0 0 0 0 0 0 + 0 0 0 0 0 - + 0 0 0 0 - 0 - 0 0 0 - - +
C_{10}	+ + 0 0 + 0 - + 0 0 + 0 0 + 0 0 0 0 0 0 - 0 0 0 - 0 0 - - 0 0 0 - 0 + - + 0 - 0 + - 0 - + 0 0 0 0 0 + - 0 0 + + 0 - 0 + 0 0 - - + 0 0 + + - + 0 + - 0 + 0 0 0 0 - 0 - 0 - 0 - + + -+ 0 + 0 0 + 0 + 0 0 0 - + 0 + + + 0 0 0 - - - - + + + 0 0 0 0 + + + 0 - -
C_{11}	- + - 0 0 0 0 + 0 0 - - 0 0 0 0 0 - 0 + 0 + 0 + - 0 + 0 0 + 0 0 + 0 - 0 0 - + + + 0 0 + 0 0 0 - + 0 + 0 - 0 0 0 0 + + + + + - + 0 + - - 0 + - 0 + + - - 0 - 0 0 0 + 0 - + 0 0 + 0 + - - - - 0 0 0 - 0 0 0 0 0 0 - + 0 0 + - 0 + + 0 0 0 + + - 0 0 + + - 0 - 0
C_{12}	- + 0 + + 0 0 0 0 0 0 - 0 + 0 - + 0 - - - + - + + 0 0 - + 0 + + 0 + 0 + 0 + 0 0 0 - 0 0 - 0 0 - + 0 0 + - + + 0 0 0 - + - 0 - + + 0 - 0 + + + + 0 - 0 0 - 0 + + 0 0 + 0 + 0 0 + + - 0 0 + 0 0 0 + - 0 0 0 - 0 - - + 0 0 0 0 - 0 0 0 0 - - 0 + 0 0 0 0 0 + - -
C_{13}	+ 0 0 0 – – 0 0 0 0 – – + + 0 – + + + + 0 – 0 + + 0 + 0 – 0 0 – + 0 + + 0 0 + + – 0 + + 0 + – + 0 – 0 0 + 0 0 – 0 – – 0 0 0 – + – 0 0 + 0 0 0 0 – 0 + + – 0 0 0 0 0 + – 0 – 0 0 0 0 0 0 – 0 0 – + – + + – + 0 0 0 – 0 + 0 + 0 + + + – 0 0 – – 0 0 + 0 + 0 0 0
C_{14}	+ 0 0 0 + + 0 – 0 + 0 – 0 0 + – 0 – + 0 – 0 0 + 0 + 0 0 0 0 + 0 + – 0 0 0 0 + + 0 0 + 0 + + + + + – + 0 – 0 + – 0 – – + 0 + + – – 0 0 0 – – – 0 + 0 0 0 + 0 + 0 – + – 0 0 0 0 0 0 + – + – 0 – – 0 0 + + 0 0 0 – 0 0 + 0 0 + + – 0 0 – – + + – 0 0 – 0 0 0 0 0
C_{15}	0 + – 0 0 + 0 – 0 0 0 – + + 0 0 0 0 – – – + + 0 0 0 + 0 + – 0 – + 0 0 – + 0 0 0 – – 0 – 0 0 – – 0 – – + + + – + 0 – + + 0 0 + – + + 0 + 0 0 0 0 0 + 0 – 0 + + + – 0 0 + 0 0 + 0 0 0 – 0 0 0 0 + 0 0 – – + 0 + + 0 + 0 + 0 – 0 0 – 0 – + – 0 + 0 + + 0 0 0 0 0
C_{16}	+ + 0 0 0 0 + 0 0 0 + 0 0 + – – 0 + – + + 0 – 0 0 0 – – 0 0 + – 0 + 0 0 + + 0 0 0 + + + 0 0 + 0 + 0 – 0 – + – 0 – 0 + 0 0 + 0 0 + 0 + + – – – – + 0 0 + + – – + 0 + – 0 – – + 0 0 0 0 0 0 – 0 – 0 0 0 0 – + 0 – – 0 0 + 0 0 0 0 0 + – + + 0 0 0 – 0 – + 0 + 0
C_{17}	+ – – 0 0 0 – 0 – 0 0 0 0 + – 0 0 0 0 0 + 0 0 0 0 0 0 + – – + – + + 0 – 0 + 0 + 0 0 + – 0 0 + + + 0 – + + 0 – 0 0 + 0 – + 0 0 0 + + 0 + + + – 0 – – 0 + 0 + – 0 – – 0 0 – 0 0 + 0 0 0 – + + 0 0 0 0 + 0 + + –+ – 0 0 + 0 + 0 + – – 0 0 – – 0 – 0 0 0 + 0 0 +
C_{18}	– – 0 + + + 0 0 0 0 + + + – – – – 0 0 0 + + + 0 + – 0 0 0 + 0 + 0 0 + 0 + – + + – 0 – 0 – 0 – 0 0 0 0 + 0 – + 0 + – + + 0 0 + – – 0 0 + 0 – 0 + + 0 0 – + 0 0 0 0 0 + – 0 – + 0 – 0 + – + 0 – 0 0 0 – – 0 0 – 0 0 0 – 0 0 0 0 0 0 + 0 0 + 0 0 + – 0 + 0 0 + +
C_{19}	– 0 – + + 0 0 – + + 0 0 0 + + 0 – + 0 0 + – 0 0 0 0 0 0 – 0 0 0 – – – – + 0 + 0 0 + – 0 + 0 0 0 – 0 – – + + 0 – + 0 – – + 0 + – + + + + + 0 0 0 0 – 0 + 0 + – 0 0 0 + 0 0 + + + – 0 0 – 0 + 0 0 + 0 0 + 0 – + 0 + 0 + 0 – 0 0 0 0 0 – – 0 0 + 0 0 0 0 – + – 0
C_{20}	– – + 0 0 0 0 0 + 0 – – 0 0 0 0 – 0 0 0 0 + – – 0 – 0 0 0 – + 0 0 0 + 0 0 – + +0 0 + 0 + 0 0 + + 0 – 0 0 – 0 + + + + 0 – 0 + + – 0 – + – 0 0 0 + + – + 0 0 + – 0 0 – 0 0 – 0 0 0 + 0 + 0 + 0 + + 0 + – 0 0 + + – + – – – 0 + – 0 + 0 – 0 0 0 0 0 0 + + 0 + –
C_{21}	+ 0 + 0 0 – – 0 0 – + + + 0 + 0 + 0 – 0 0 0 + – + + – + – 0 0 – 0 0 0 0 0 0 – 0 – + 0 0 0 0 0 – + + 0 – 0 0 0 0 + 0 0 – + – 0 0 0 – – 0 – 0 0 + 0 0 – 0 + – + 0 + + 0 – + + 0 0 + + 0 + – 0 0 – 0 + 0 + + 0 – 0 + + + + – 0 + + – – 0 0 0 0 – – 0 0 0 + 0 0 0
C_{22}	0 – 0 0 – + + – – 0 0 – + + 0 0 + 0 0 – 0 0 0 + + 0 0 – – 0 – + – + 0 0 0 0 0 0 – + – 0 + 0 + 0 0 0 + 0 – – – 0 0 0 – – + + 0 + – – 0 – + 0 – 0 + – + + + + + 0 + 0 0 + + 0 0 0 0 – + 0 + 0 0 0 0 + 0 + 0 0 – 0 + – 0 – + 0 0 – 0 + 0 – 0 + + 0 0 0 + 0 0 0 0
C_{23}	0 0 0 + + 0 + 0 – + – 0 – 0 0 – 0 + 0 + 0 + + 0 + – – 0 0 + 0 0 0 0 – 0 0 0 + 0 0 + 0 0 – + + + 0 – 0 + 0 0 0 0 0 + 0 + + – + 0 0 + + – 0 + – + + + – – 0 – – 0 0 – 0 – – 0 0 0 + – 0 0 + – 0 – + 0 + 0 0 0 + + – – – 0 0 0 0 + + – 0 0 0 – 0 + 0 0 – + 0 0 0
C_{24}	+ 0 + – 0 – 0 0 0 + + – + 0 0 0 0 0 + 0 0 – – 0 + – 0 0 0 0 – 0 – 0 0 0 0 0 0 + – – 0 – + 0 + – – + + 0 0 + – – – – + + 0 + 0 0 + 0 0 + 0 – 0 – + – 0 – 0 + 0 + 0 0 + + + 0 0 0 + + 0 0 + 0 – + 0 0 – – 0 0 0 – 0 + + – + 0 – – + 0 0 + 0 0 0 + 0 0 0 0 + + 0

Combinations of preamble sequences (only one jamming system: 1unit):

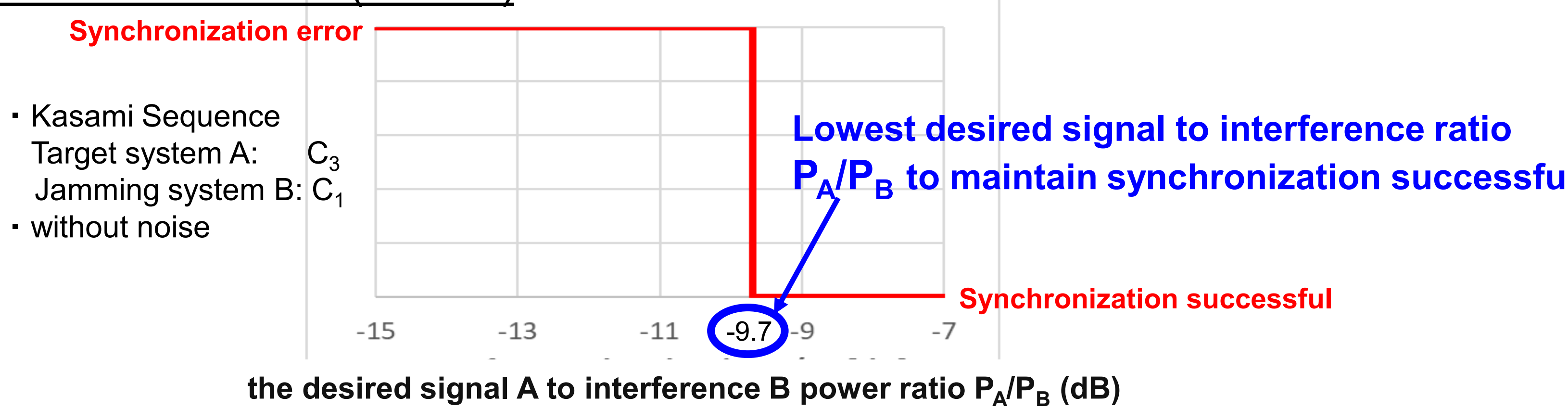
Using 1 unit of the jamming system, the superiority of the combination of preamble sequence is compared by simulation.

All the combinations of preamble sequences are selected in the same family with of the same length while combination of Kasami and Ipatov sequence families is not the subject of this study.



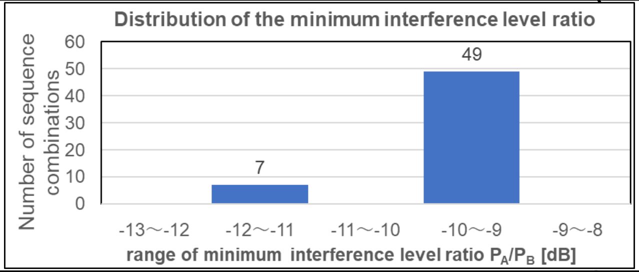
- Tested all combinations among preamble sequences for target and jamming systems.
- According to the desired signal A to interference B power ratio P_A/P_B, it is tested whether frame synchronization succeeds or fails to derive such a lowest desired signal to interference ratio P_A/P_B that frame synchronization can be maintained for all the combination among sequences.
- It is assumed in this simulation that there is no noise in order to evaluate only the superiority of combination of preamble sequence.

<u>Example of simulation result(Kasami)</u>



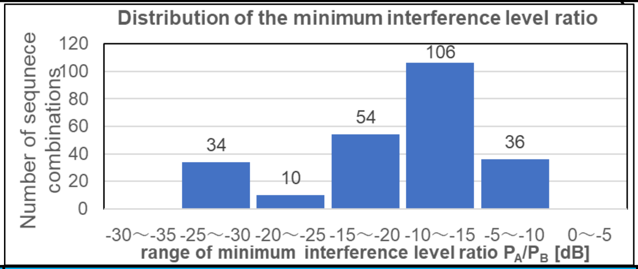
Combinations of preamble sequence (only a jamming system for target one)

Results of Interference level ratio(Kasami)



Rank	Combination of preamble sequence [Target / Jamming]	Lowest desired signal to interference ratio P_A/P_B
1	[C_1/C_2] [C_1/C_3] [C_1/C_4] [C_1/C_5] [C_1/C_6] [C_1/C_7] [C_1/C_8]	-11.3 dB
2	[C_2/C_1] [C_2/C_3] [C_2/C_4] [C_2/C_5] [C_2/C_6] [C_2/C_7] [C_2/C_8] [C_3/C_1] [C_3/C_2] [C_3/C_4] [C_3/C_5] [C_3/C_6] [C_3/C_7] [C_3/C_8] [C_4/C_1] [C_4/C_2] [C_4/C_3] [C_4/C_5] [C_4/C_6] [C_4/C_7] [C_4/C_8] [C_5/C_1] [C_5/C_2] [C_5/C_3] [C_5/C_4] [C_5/C_6] [C_5/C_7] [C_5/C_8] [C_6/C_1] [C_6/C_2] [C_6/C_3] [C_6/C_4] [C_6/C_5] [C_6/C_7] [C_6/C_8] [C_7/C_1] [C_7/C_2] [C_7/C_3] [C_7/C_4] [C_7/C_5] [C_7/C_6] [C_7/C_8] [C_8/C_1] [C_8/C_2] [C_8/C_3] [C_8/C_4] [C_8/C_5] [C_8/C_6] [C_8/C_7]	-9.7dB

Results of Interference level ratio(Ipatov)

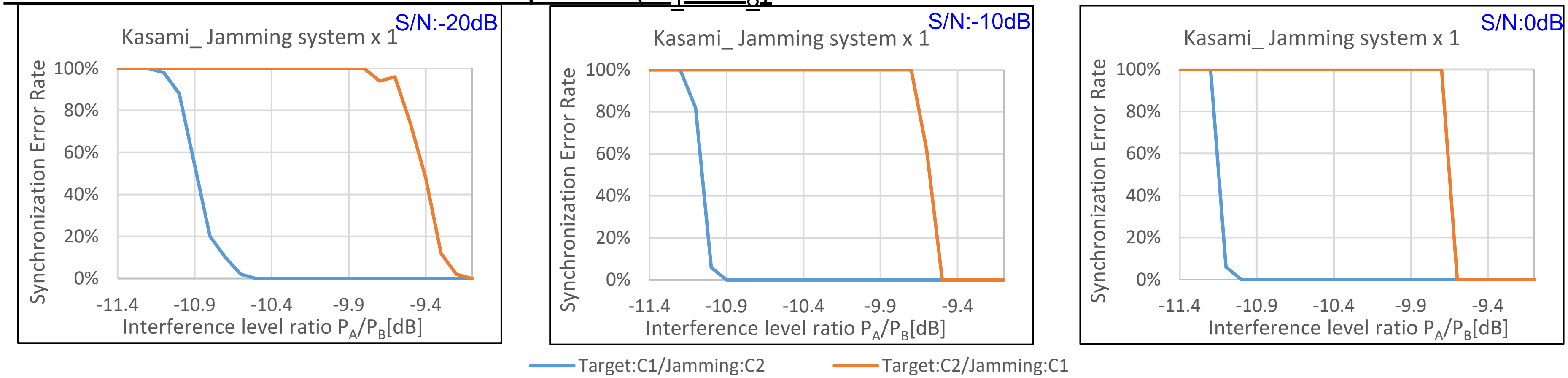


Rank	Combination of preamble sequence [Target / Jamming]	Lowest desired signal to interference ratio P_A/P_B
1	[C_9/C_{11}] [C_{11}/C_9] [C_{10}/C_{12}] [C_{12}/C_{10}] [C_{11}/C_{12}] [C_{12}/C_{11}] [C_{11}/C_{14}] [C_{14}/C_{11}] [C_{11}/C_{23}] [C_{23}/C_{11}] [C_{12}/C_{15}] [C_{15}/C_{12}] [C_{13}/C_{16}] [C_{16}/C_{13}] [C_{14}/C_{16}] [C_{16}/C_{24}] [C_{15}/C_{24}] [C_{24}/C_{15}] [C_{16}/C_{17}] [C_{17}/C_{16}] [C_{16}/C_{23}] [C_{23}/C_{16}] [C_{17}/C_{19}] [C_{19}/C_{17}] [C_{18}/C_{20}] [C_{20}/C_{18}] [C_{18}/C_{23}] [C_{23}/C_{18}] [C_{22}/C_{24}] [C_{24}/C_{22}]	-29.8 dB
2	[C_{13}/C_{17}] [C_{17}/C_{13}]	-27.9dB
3	[C_{10}/C_{24}] [C_{24}/C_{10}]	-26.3dB
39	[C_{15}/C_{21}] [C_{21}/C_{15}]	-5.6dB

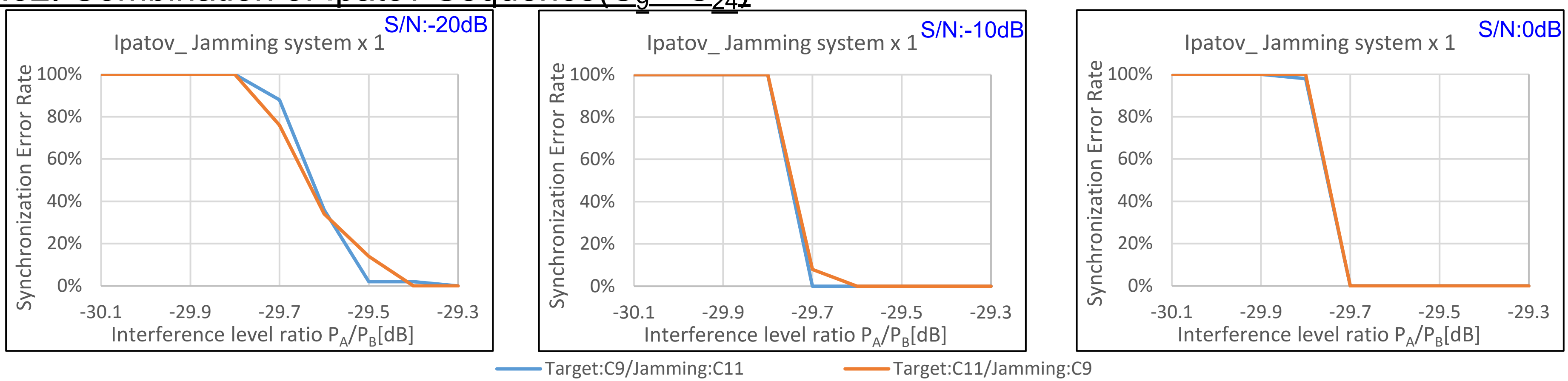
It is confirmed that by choosing appropriate sets of preamble sequences, it is possible to maintain synchronize successful even in the presence of a jamming system. In particular, the family of Ipatov sequences has larger margin of interference from coexisting VBANs if a high rank of combination of sequences [target/jamming] in the above table.

Simulation Results:

No1. Combination of Kasami Sequence(C_1～C_8)



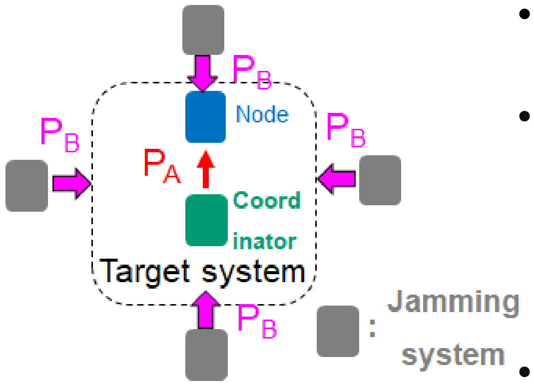
No2. Combination of Ipatov Sequence(C_9～C_{24})



By selecting the appropriate set or high rank combination of preamble sequence, it is possible to synchronize even in the presence of a jamming system. The high rank of combination of Ipatov sequence achieves the best synchronization performance.

Combinations of preamble sequence (4 jamming systems for target one)

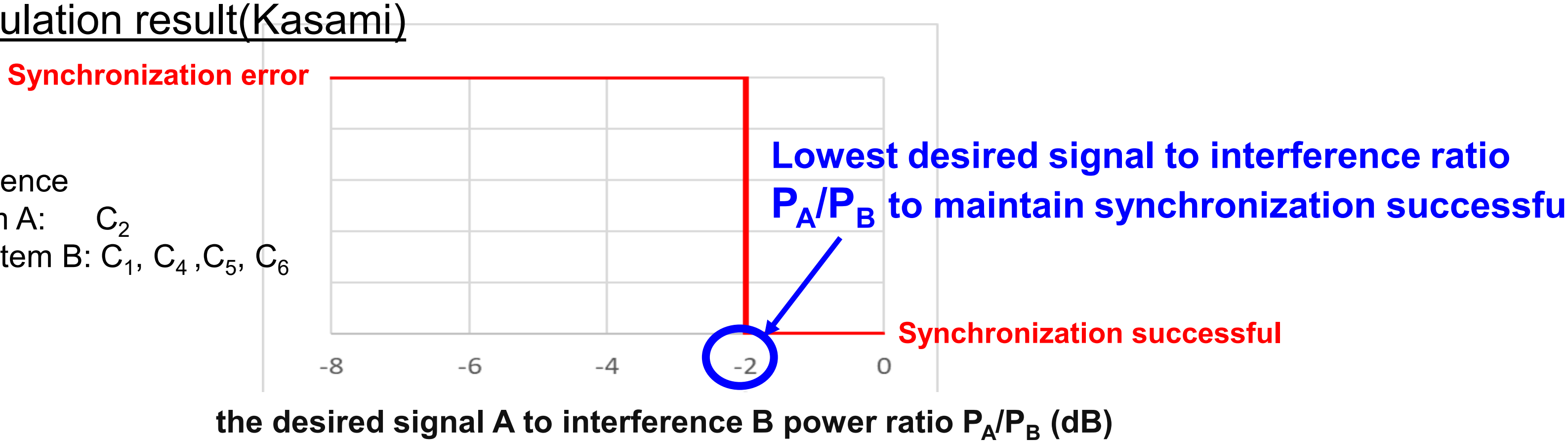
Using 4 units of the jamming system, the superiority of the combination of preamble sequence is compared by simulation.
All the combinations of preamble sequences are selected in the same family with of the same length while combination of Kasami and Ipatov sequence families is not the subject of this study



- Tested all combinations among preamble sequences for target and jamming systems.
- According to the desired signal A to interference B power ratio P_A/P_B, it is tested whether frame synchronization succeeds or fails to derive such a lowest desired signal to interference ratio P_A/P_B that frame synchronization can be maintained for all the combination among sequences.
- It is assumed in this simulation that there is no noise in order to evaluate only the superiority of combination of preamble sequence.

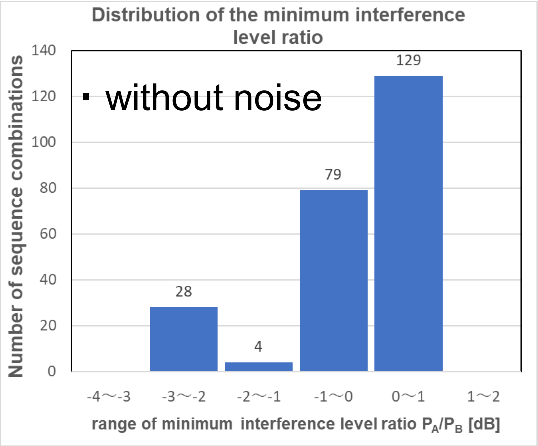
Example of simulation result(Kasami)

- Kasami Sequence
  Target system A: C_2
  Jamming system B: C_1, C_4, C_5, C_6
- without noise



Combinations of preamble sequence (4 jamming systems for target one)

Results of Interference level ratio(Kasami)



Rank	Combination of preamble sequence [Target / Jamming]	Lowest desired signal to interference ratio P_A/P_B
1	$[C_1/C_2,C_3,C_4,C_5]$ $[C_1/C_2,C_3,C_4,C_6]$ $[C_1/C_2,C_3,C_5,C_6]$ $[C_1/C_2,C_3,C_5,C_7]$ etc	-2.0dB
2	$[C_2/C_1,C_3,C_6,C_8]$ $[C_5/C_1,C_3,C_6,C_7]$ etc	-1.7dB
⋮		
Worst	$[C_3/C_4,C_5,C_7,C_8]$ $[C_5/C_3,C_4,C_7,C_8]$ etc	1.0dB

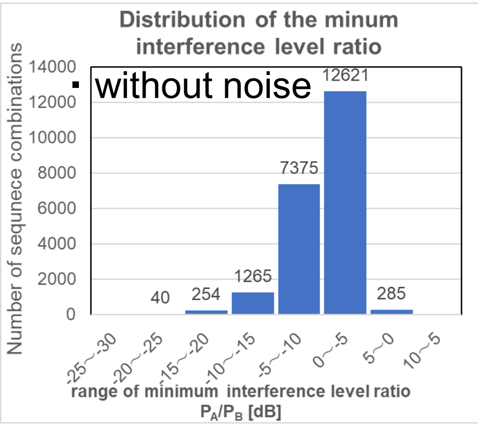
Ranking based on the difference in the preamble sequence selected by the target

Rank	sequence	Lowest desired signal to interference ratio P_A/P_B					
1	C_1,C_2,C_3,C_6,C_8	Target:C_1 0.8dB	Target:C_2 -1.7dB	Target:C_3 -0.6dB	Target:C_6 -0.5dB	Target:C_8 -0.5dB	Worst 0.8dB
	C_1,C_3,C_5,C_6,C_7	Target:C_1 0.8dB	Target:C_3 -0.5dB	Target:C_5 -1.7dB	Target:C_6 -0.5dB	Target:C_7 -0.6dB	Worst 0.8dB
	C_1,C_4,C_6,C_7,C_8	Target:C_1 0.8dB	Target:C_4 -1.7dB	Target:C_6 -0.5dB	Target:C_7 -0.5dB	Target:C_8 -0.6dB	Worst 0.8dB
⋮							
Worst	C_3,C_4,C_5,C_7,C_8	Target:C_3 1.0dB	Target:C_4 -0.6dB	Target:C_5 1.0dB	Target:C_7 1.0dB	Target:C_8 1.0dB	Worst 1.0dB

With four coexisting VBANs or vehicles, the Kasami sequence has no appropriate set to be used because it cannot synchronize when the interference power received from coexisting vehicles is high.

Combinations of preamble sequence (4 jamming systems for target one)

Results of Interference level ratio(Ipatov)



Rank	Combination of preamble code [Target / Jamming]	Lowest desired signal to interference ratio P_A/P_B
1	$[C_{11}/C_9,C_{12},C_{23},C_{24}]$ $[C_{12}/C_{10},C_{13},C_{15},C_{22}]$ etc	-21.9dB
2	$[C_{16}/C_9,C_{17},C_{23},C_{24}]$ $[C_{12}/C_{10},C_{11},C_{22},C_{23}]$ etc	-21.1dB
	⋮	
Worst	$[C_{24}/C_9,C_{13},C_{17},C_{23}]$ $[C_{15}/C_{13},C_{14},C_{21},C_{22}]$	1.7dB

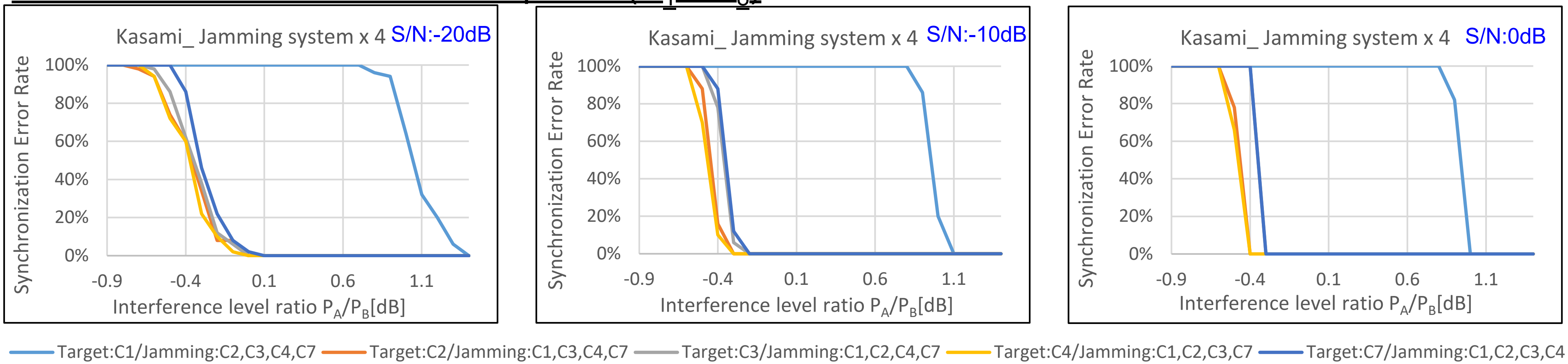
Ranking based on the difference in the preamble sequence selected by the target

Rank	Preamble sequence	Lowest desired signal to interference ratio P_A/P_B					
1	$C_{11},C_{13},C_{14},C_{16},C_{23}$	Target:C_{11} -8.5dB	Target:C_2 -8.8dB	Target:C_3 -13.1dB	Target:C_6 -9.6dB	Target:C_8 -11.2dB	Worst -8.5dB
2	$C_{13},C_{14},C_{16},C_{22},C_{24}$	Target:C_{13} -7.8dB	Target:C_{14} -11.8dB	Target:C_{16} -7.4dB	Target:C_{22} -7.4dB	Target:C_{24} -8.0dB	Worst -7.4dB
3	$C_{15},C_{16},C_{17},C_{19},C_{23}$	Target:C_{15} -6.8dB	Target:C_{16} -11.0dB	Target:C_{17} -17.8dB	Target:C_{19} -7.5dB	Target:C_{23} -7.6dB	Worst -6.8dB
				⋮			
Worst	$C_9,C_{13},C_{17},C_{23},C_{24}$	Target:C_9 -4.5dB	Target:C_{13} -9.4dB	Target:C_{17} -6.6dB	Target:C_{23} -2.6dB	Target:C_{24} 1.7dB	Worst 1.7dB

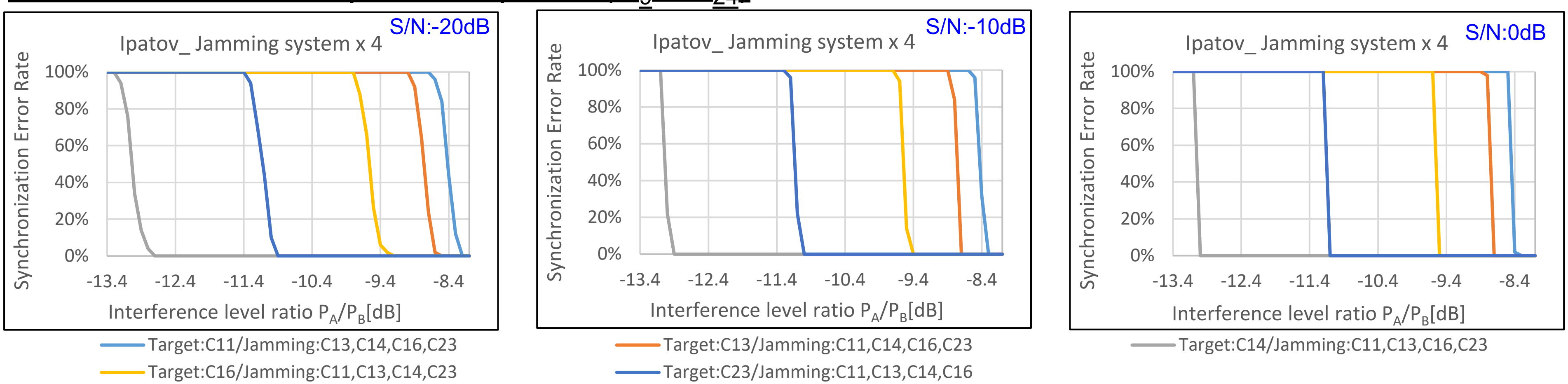
Even with four jamming systems or VBANs, coexistence is possible in the Ipatov sequence by selecting an appropriate set or high rank combination of preamble sequences, even when the interference level is higher than the system level.

Simulation Results:

No1. Combination of Kasami Sequence(C_1～C_8)



No2. Combination of Ipatov Sequence(C_9～C_{24})



With four adjacent vehicles, it is difficult to coexist using the Kasami sequence, so it is preferable to choose from an appropriate combination of the Ipatov sequence.

Summary of simulation results

Case with one adjacent vehicle or coexisting VBAN

- Synchronization during simultaneous communication is possible using either the Kasami sequence or the Ipatov sequence if an appropriate set or high rank combination of sequences, where the Ipatov sequence has better performance.
- When the Ipatov sequence family is selected, the FER performance is depending on the combination of the preamble sequences, so it is necessary to assign an appropriate set or high rank combination of sequences to coexisting VBANs.
- It is desirable for the group BAN coordinator to assign an appropriate set of preamble sequence based on the high rank combination of preamble sequence.

Case with four adjacent vehicles or coexisting VBANs

- The Kasami sequence family is not appropriate for 4 VBANS because it cannot synchronize when the interference power received from adjacent vehicles is high.
- The Ipatov sequence allows synchronization during simultaneous communication by selecting an appropriate set of preamble sequences.
- The group BAN coordinator should assign appropriate preamble set of sequences based on the high rank of the preamble sequence combinations to be assigned to coexisting VBANs.

1. Background
   1.1 Motivation and Aim of this Study
   1.2 Review of the Previous Presentation and Contents of this New Presentation
2. Analysis Using Computer Simulation
   2.1 Simulation Specification
   2.2 Derived Preferable Sets of Preamble Sequences
3. Conclusion and Further Study

Conclusion:

- For in-vehicle use or VBANs, we proposed an optional standard which can perform stable frame synchronization by assigning an appropriate set of quasi-orthogonal preamble sequences such as Ipatov sequences to coexisting vehicles or VBANs.
- In this study, we used computer simulations to select the most suitable set of preamble sequences for use in vehicles or VBANs.
- In the simulations, we confirmed that selecting the appropriate set of preamble sequences can reduce interference effects even when multiple vehicles coexist, and would allow synchronization without errors.

Further Study :

- Submit a comment in the next letter ballot regarding the appropriate sets of preamble sequences which can perform stable frame synchronization in a target vehicle for multiple coexisting vehicle environments.
- Examine how many systems or VBANs can coexist based on the appropriate sets of preamble sequences in various channel environments.

Thank you for your attention and any questions and comments!