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]

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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]

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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. Confirmation of Simulation Accuracy through Experimental Evaluation
   2.1 Experimental and Simulation Specification
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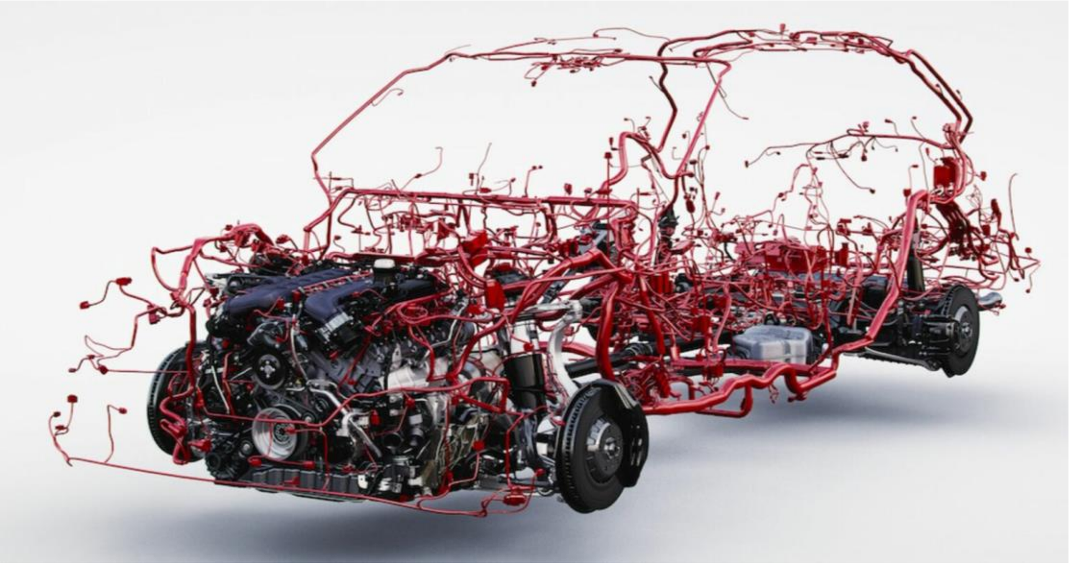
3. Study on the Number of Coexisting VBANs through Simulation
4. Conclusion

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/

Problem

■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.
In practical use cases, assigning an appropriate sequence set helps avoid packet and frame errors due to synchronization errors caused by interference from coexisting VBANs which is categorized as Class 1 of coexistence in P802.15.6ma_D3&D4.

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Review of the Previous Presentation :

■Our problems

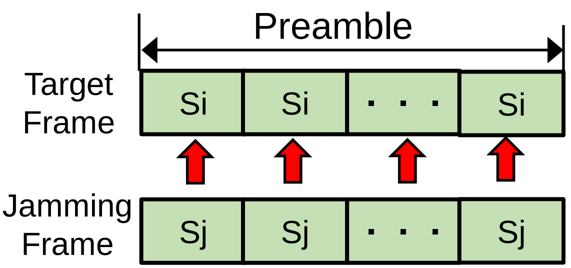
- It is necessary to reduce the impact of interference from VBANs of nearby vehicles.
- Real-time communication within the permissible delay in a VBAN should be performed.

■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.

■Verification of Effectiveness through Simulation

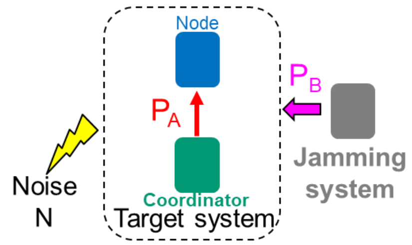
Simulation confirmed that assigning an appropriate preamble sequence enables synchronization even with multiple networks communicating simultaneously.



Frame in simulation

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

Target frame and Jamming frame are input to the receiver at the same timing



Example: one jamming system

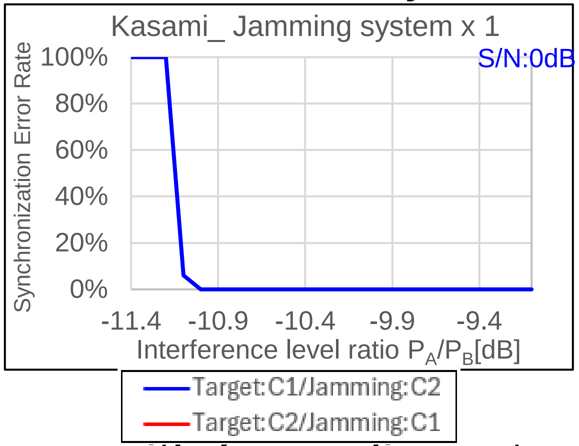
P_A :Power received from the Target system
P_B :Power received from the Jamming system

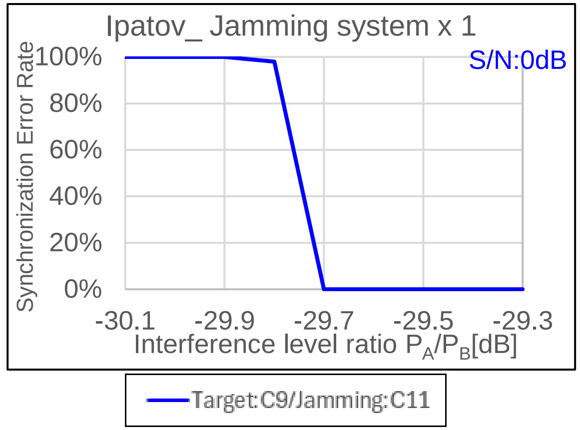
- Using 1 or 4 unit of the jamming system, the superiority of the combination of preamble sequence is compared by simulation.
- According to the desired signal A to interference B power ratio P_A/P_B, we tested whether frame synchronization succeeds or fails, and identified the lowest power ratios of desired signal to interference P_A/P_B that can maintain frame synchronization.

Review of the Previous Presentation :

■Simulation Results

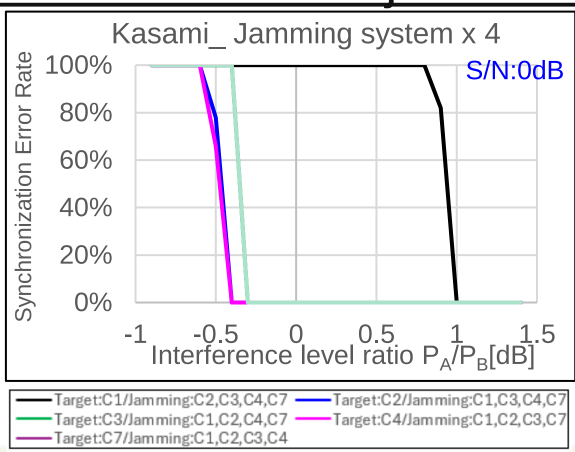
Case with one adjacent vehicle or coexisting VBAN

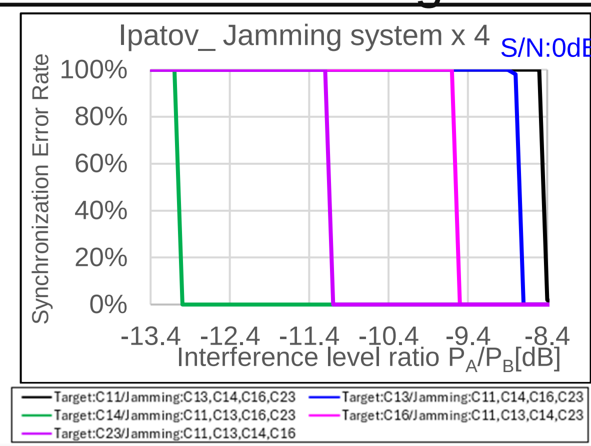




- Left side figures show synchronization frame errors can be reduced in even low power ratio of desired signal to interference P_A/P_B
- Synchronization during simultaneous communication of coexisting VBANs is possible using either some set of the Kasami sequence or the Ipatov sequence.

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.

Selecting the appropriate set of preamble sequences can reduce interference effects even when multiple vehicles coexist, and result in stable or dependable packet and frame synchronization.

New Presentation :

■ Remaining Issues and Their Solutions

- Validation of interference reduction effectiveness through simulation
  ➞Validation of proposed effectiveness through practical evaluation

- Considering phase shift or offset in frames between desired target and jamming systems
  ➞ Investigating affect phase shift or offset in frames between desired target and jamming systems by computer simulations

- Confirming improvement of synchronization corresponding to the number of coexisting VBANs in case of using appropriate sets of preamble sequences
  ➞Deriving the maximum number of coexisting VBANs with successful synchronization by simulation

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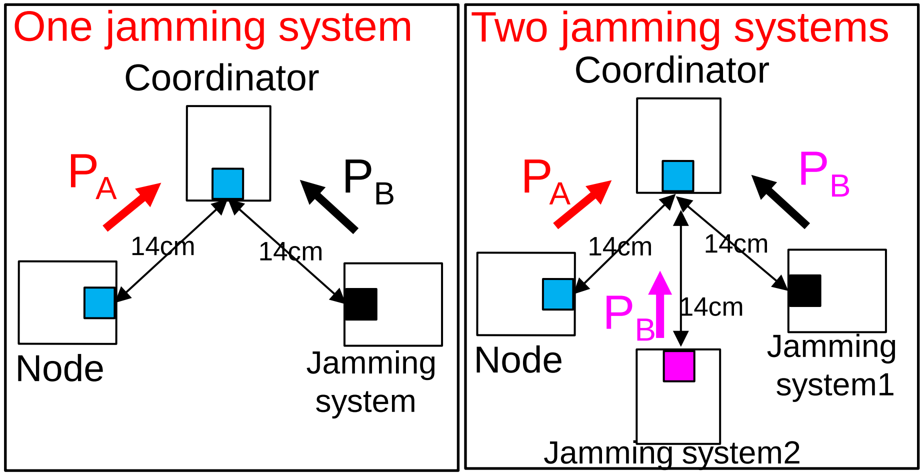
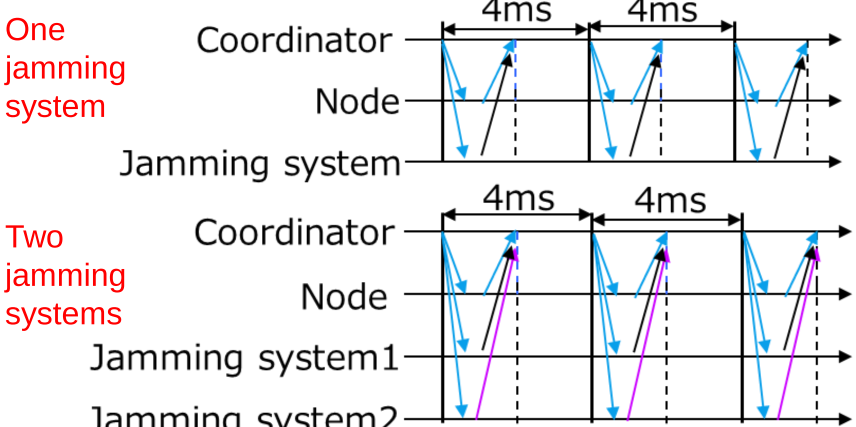
Experimental Specification :

By using currently available UWB devices, it was confirmed that setting an appropriate preamble sequence can reduce the impact of interference.



Setting of UWB Devices

■Communication Timing



■Assumed Frame Structure

Preamble	SFD	PHR	PHY Payload

■Evaluation parameter

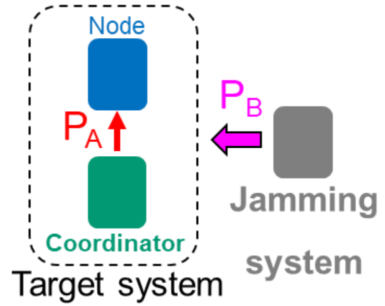
	Parameter	
Preamble	Combination of preamble sequence [Target / Jamming]	One jamming system : $[C_9/C_{11}]$,$[C_{15}/C_{20}]$ Two jamming systems : $[C_{11}/C_{16}C_{22}]$, $[C_{16}/C_{11}C_{22}]$, $[C_{22}/C_{11}C_{16}]$, $[C_{15}/C_{20}C_{21}]$
SFD	Length	8
PHY Payload	Length	17 Octets
Jamming System	Number of unit	1 unit/2units
	Interference ratio(P_A/P_B)	-20dB〜0dB

- Measure the Frame Error Rate (FER) of the received signal at the coordinator when communications with different preamble sequences are transmitted simultaneously from nodes and jamming systems.
- The preamble sequences used in the experiment are selected from combinations that produced both appropriate and inappropriate results in the simulation.

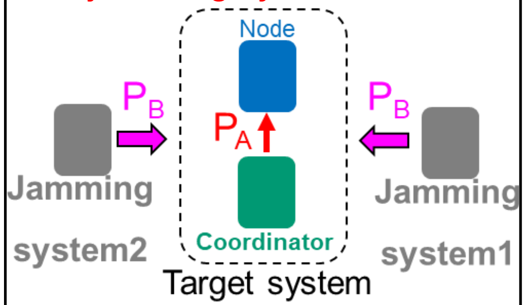
Simulation Specification 1:

As a comparison to hardware experiment, the synchronization error rate at the same evaluation level was verified through computer simulation.

One jamming system



Two jamming systems



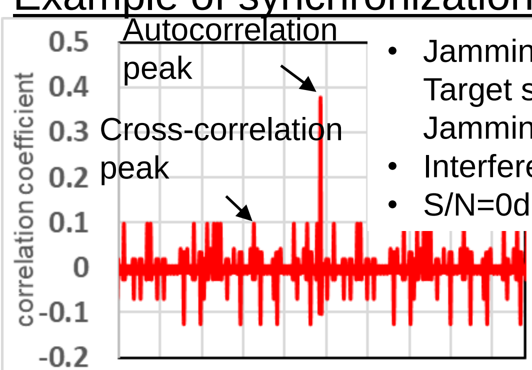
■Simulation parameter

	Parameter	
Preamble	Combination of preamble sequence	One jamming system : [C_9/C_{11}],[C_{15}/C_{20}] Two jamming systems : [C_{11}/$C_{16}C_{22}$], [C_{16}/$C_{11}C_{22}$], [C_{22}/$C_{11}C_{16}$], [C_{15}/$C_{20}C_{21}$]
Jamming System	Number of unit	1 unit/2units
	Interference ratio(P_A/P_B)	-20dB～0dB
Noise	S/N ratio(P_A/N)	0dB

■Judge for synchronization error

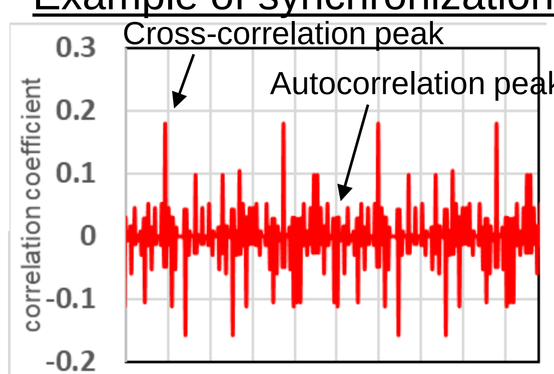
A synchronization frame error is counted if summation of all cross-correlation among preamble sequences and noise in each time slot exceeds beyond the autocorrelation peak of preamble sequence of target system in the output of correlator in a target system as right figure below.

Example of synchronization success



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

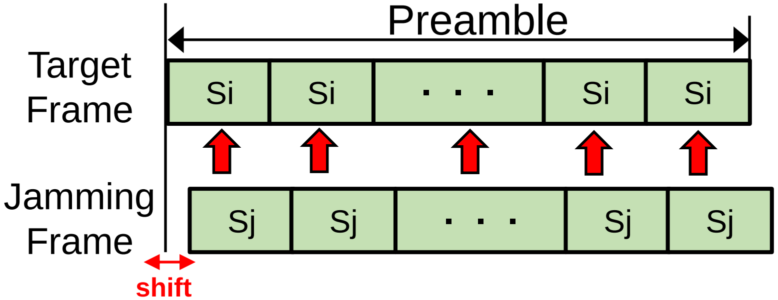
Example of synchronization errors



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

Simulation Specification 2:

■Frame in simulation

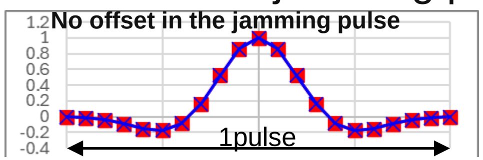


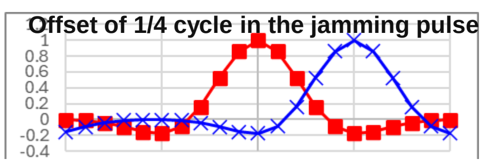
Si : Preamble sequence of the Target system
Sj : Preamble sequence of the Jamming system

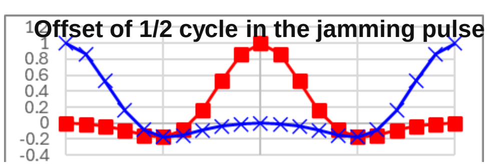
- To simulate synchronization frame error rate (FER) only, the frame structure is set to contain only the preamble sequence, with no data payload.
- Synchronization can be performed by detecting a peak of correlator output between received signals and a local preamble sequence in the target system in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

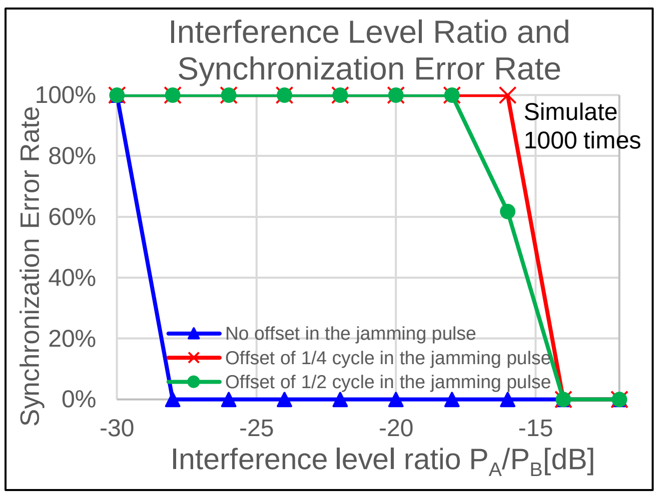
■ Consideration of Phase Misalignment in Jamming Frames

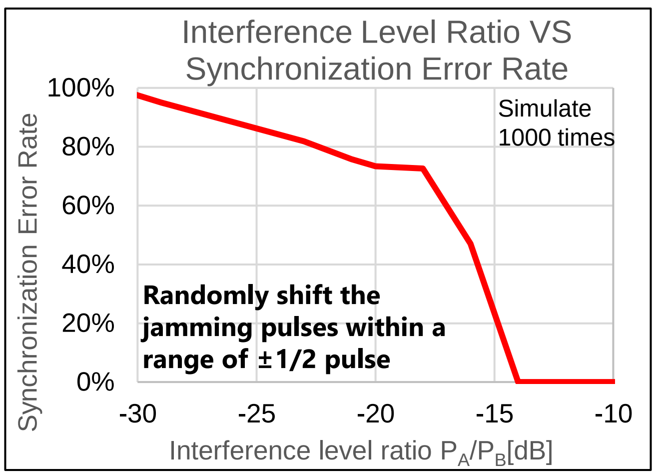
Analyze the synchronization frame error rate with random phase shifts or offsets between frames in jamming pulses and compare it with actual devices.











Conduct analysis assuming that phase shifts in jamming pulses occur randomly

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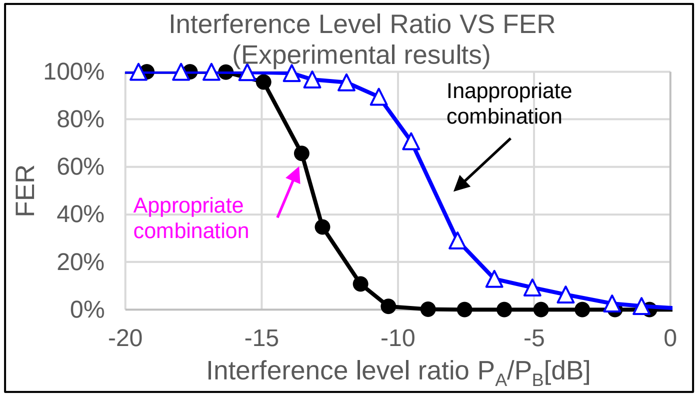
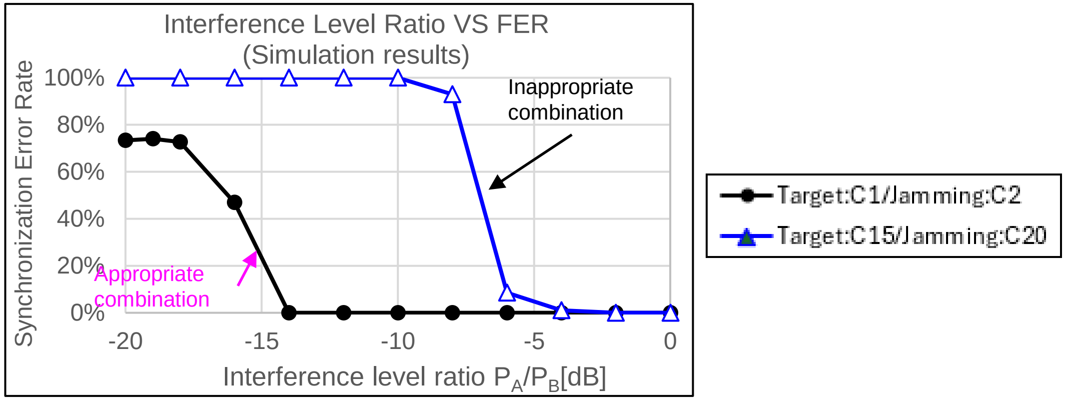
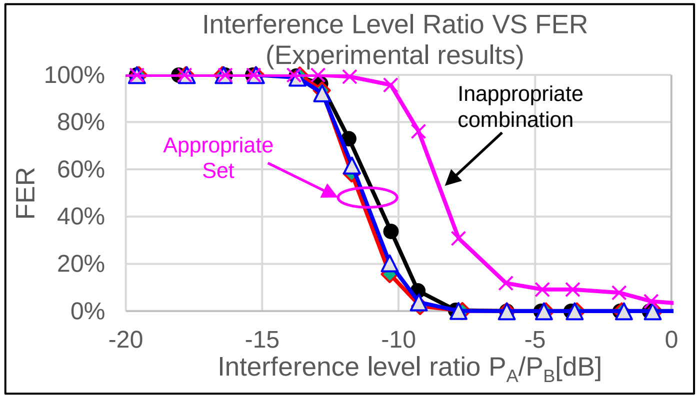
Experimental Results :

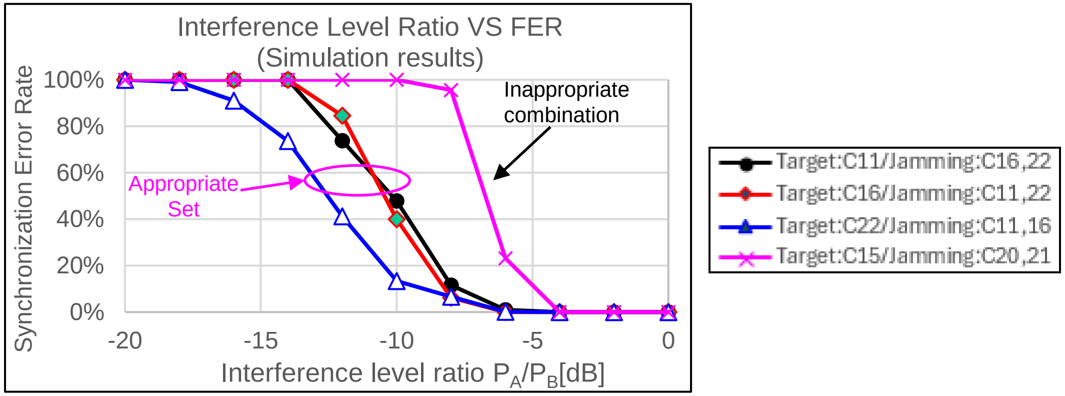
One jamming system





Two jamming systems





By assigning the appropriate preamble sequence in both hardware experiment and computer simulation, the validity of the proposal was confirmed, as frame synchronization was successful without errors even at high interference levels. The simulation results showed a consistent trend with the experimental results, confirming the reliability of our simulation-based analysis.

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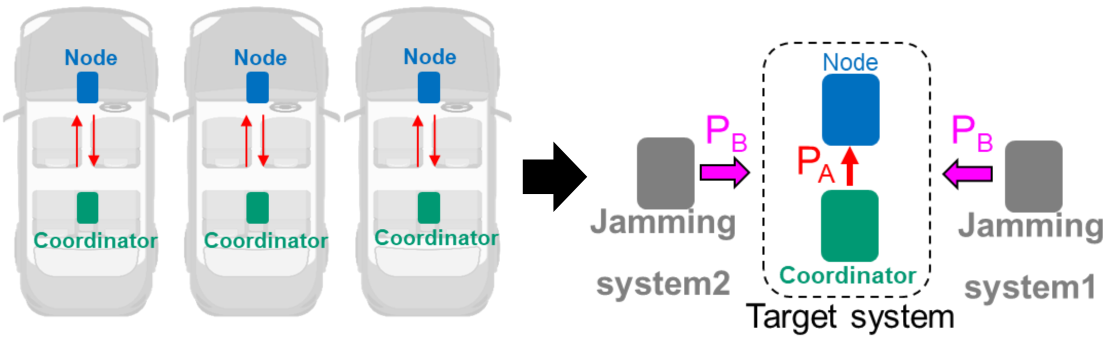
Methods for verification through simulation :

We verified through simulation how many systems can simultaneously communicate and coexist while maintaining synchronization when the appropriate sets of preamble sequences are assigned.



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 high QoS level of packet transmission (as definition of IEEE802.15.6ma), and simulation adopted such a model in which only one pair of a coordinator and a node accesses 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.

■Simulation parameter

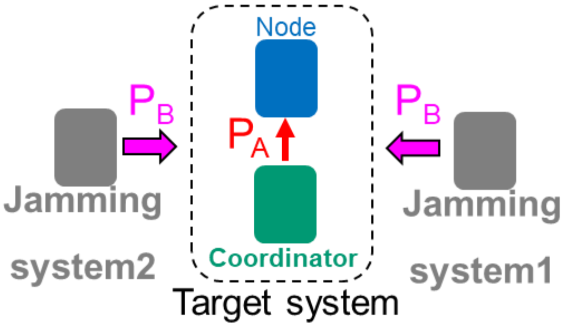
	Parameter	
Preamble	sequence	Kasami:C1～C8 Ipatov:C9～C24
Jamming System	Number of unit	2 unit～4units(Kasami) 5 unit～8units(Ipatov)
	Interference ratio(P_A/P_B)	-20dB～0dB
Noise	S/N ratio(P_A/N)	0dB,-20dB

■ Coexistence criteria

Coexistence is assumed to be feasible if, when assigning the appropriate preamble sequences to both the target and jamming systems, the synchronization error rate is below 0.1% for all systems when the power ratio of the desired signal A to the interference B (P_A/P_B) is 0 dB.

Combinations of preamble sequences:

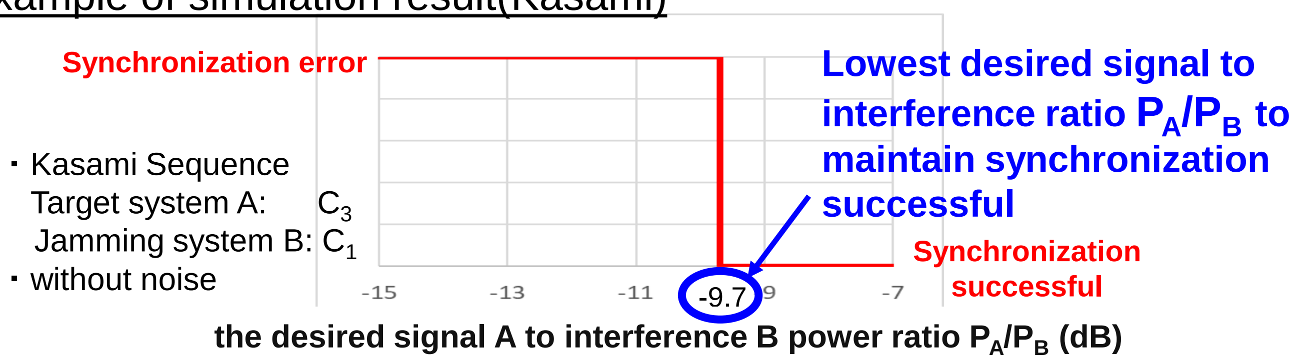
All combinations of preamble sequences are examined to find an appropriate set by simulation. All the combinations of preamble sequences are selected in the same family with of the same length while combination of Kasami and Ipatov sequence families is not the subject of this study.



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

- Examined 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>



Using the verified preamble sets of sequences, the synchronization frame error rate is analyzed, considering noise and phase shifts of jamming frames.

Results of Coexistence Feasibility Verification(Kasami):

Number of Jamming system	Appropriate set of preamble sequence
2	C_1,C_2
3	C_1,C_2,C_3, C_7
4	C_1,C_2,C_3, C_6,C_8

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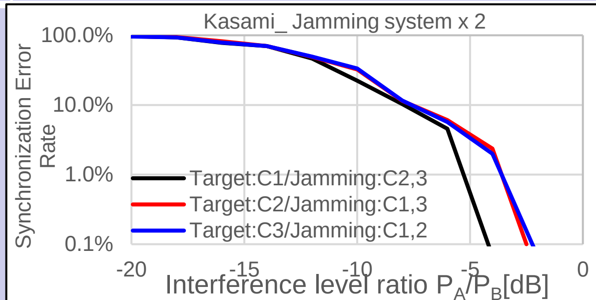
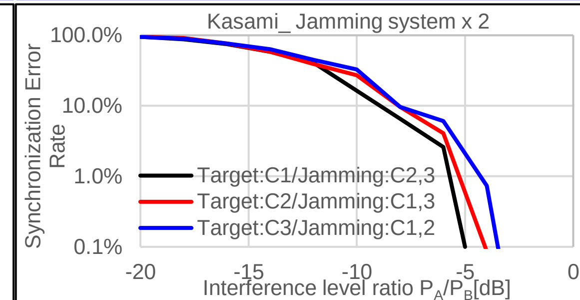
<tr><td>2 units</td><td>
</td><td>
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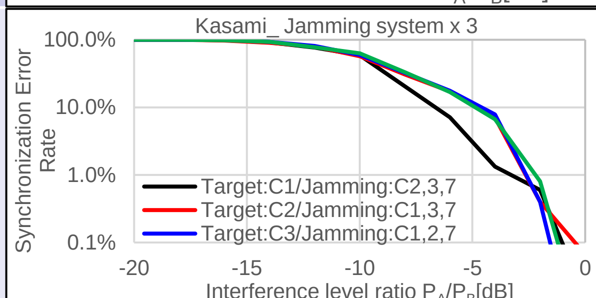
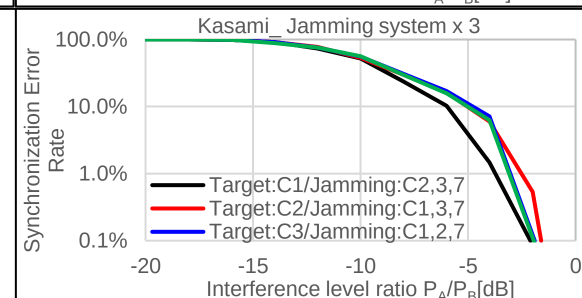
<tr><td>3 units</td><td>
</td><td>
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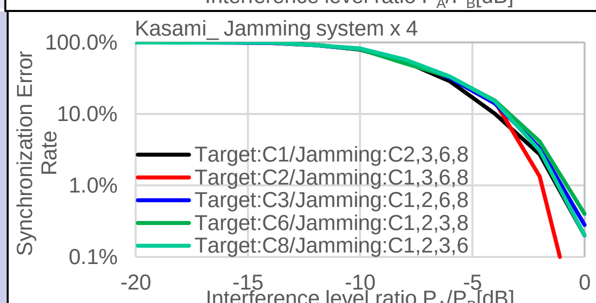
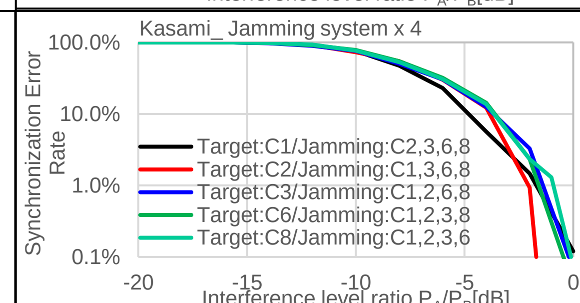
<tr><td>4 units</td><td>
</td><td>
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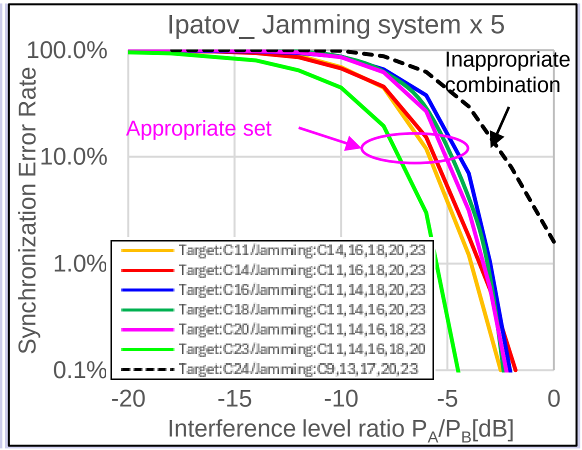
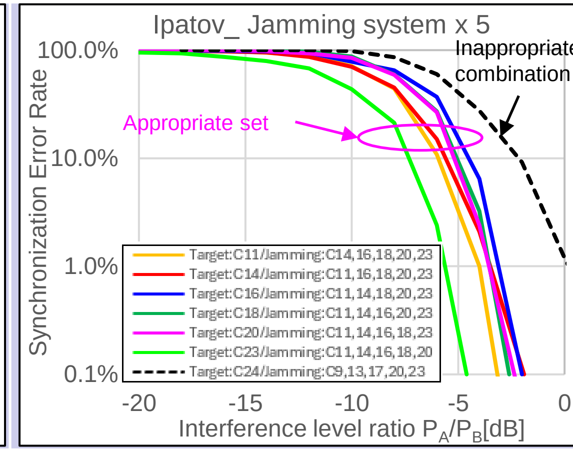
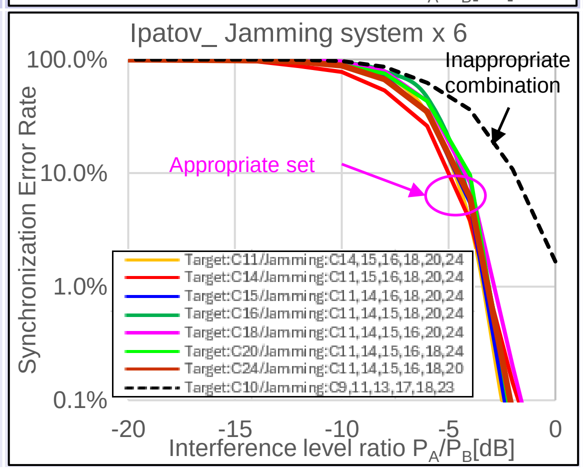
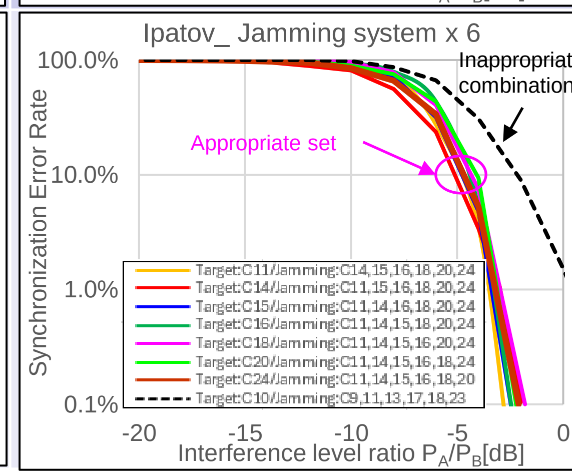
When the appropriate sets of preamble sequences are selected, simulations show that multiple VBANs coexistence is feasible with up to three jamming systems, maintaining a synchronization error rate below 0.1%.

Results of Coexistence Feasibility Verification(Ipatov):

Number of Jamming system	Appropriate set of preamble sequence
5	C_{11},C_{14},C_{16}, C_{18},C_{20},C_{23}
6	C_{11},C_{14},C_{15} C_{16},C_{18},C_{20},C_{23}

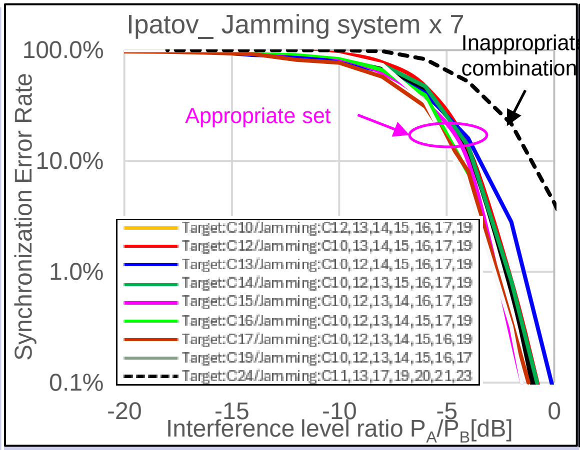
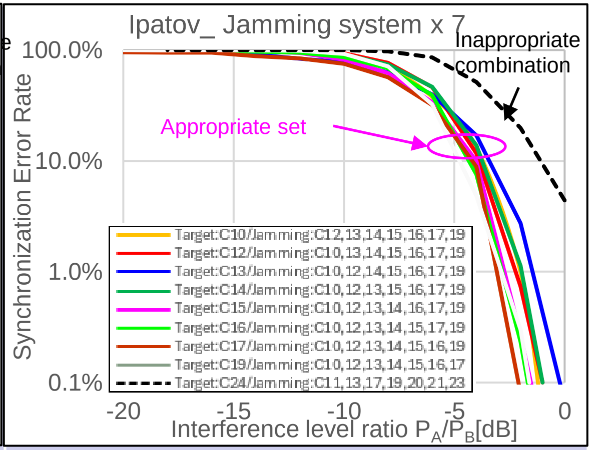
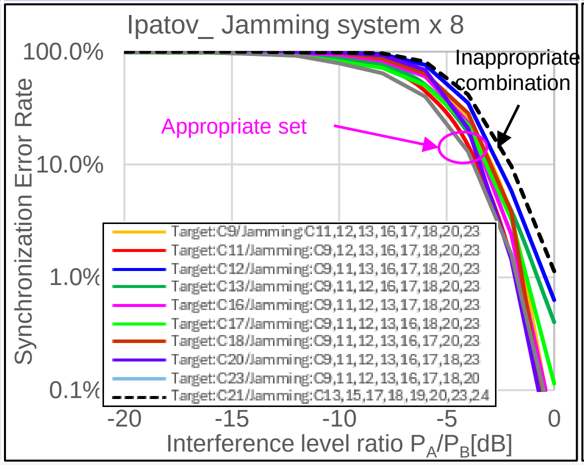
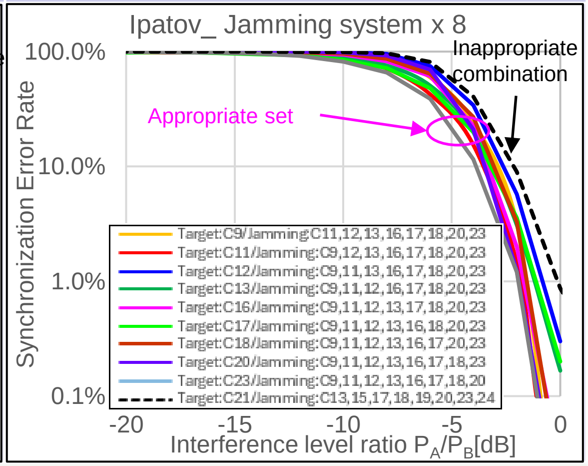
Number of Jamming system	Inappropriate combination of preamble sequence [Target / Jamming]
5	C_{24}/C_9,C_{13},C_{17}, C_{20},C_{23}
6	C_{10}/C_9,C_{11},C_{13}, C_{17},C_{18},C_{23}

Number of Jamming systems	S/N = -20dB	S/N = 0dB
5台		
6台		

Results of Coexistence Feasibility Verification(Ipatov):

Number of Jamming system	Appropriate set of preamble sequence
7	C_{10},C_{12},C_{13} C_{14},C_{15},C_{16},C_{17},C_{19}
8	C_{9},C_{11},C_{12} C_{13},C_{16},C_{17},C_{18},C_{20},C_{23}

Number of Jamming system	Inappropriate combination of preamble sequence [Target / Jamming]
7	C_{24}/C_{11},C_{13},C_{17}, C_{19},C_{20},C_{21},C_{23}
8	C_{21}/C_{13},C_{15},C_{17}, C_{18},C_{19},C_{20},C_{23},C_{24}

Number of Jamming systems	S/N = -20dB	S/N = 0dB
7unit		
8unit		

When the appropriate sets of preamble sequences are selected, simulations show that up to seven VBANs can coexist maintaining a synchronization error rate below 0.1%

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 Kasami and Ipatov sequences to coexisting vehicles or VBANs.
- Using available UWB devices, it was confirmed that multiple VBAN systems can coexist by selecting the appropriate sets of preamble sequences.
- Computer simulations considering the phase shift or offset of interfering frames were conducted, and the simulation results matched the hardware experimental results, demonstrating the validity of the simulation analysis.
- By examining all combinations of preamble sequences, it is confirmed that the selected appropriate sets of Ipatov sequences can perform the best synchronization performance in case of up to seven VBANs coexistence.
- The proposed use of appropriate preamble sequence sets according to the number of coexistence systems can reduce interference effects and perform stable and dependable frame synchronization in Class 1 of multiple BANs coexistence of IEEE802.15.6ma.

Thank you for your attention
and any questions and comments!