

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

**Submission Title:** [Performance Improvement by Proper Sets of Preamble Codes in UWB Wireless Communications in a Presence of Multiple Coexisting VBANs]

**Date Submitted:** [31<sup>st</sup> October 2024]

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**Abstract:** [This is an introduction of initial evaluation results for UWB data communication in the automotive environment in an automotive use case of wireless BAN standard IEEE802.15.6ma. This proposal confirms that proper sets of preamble codes can improve performance of UWB communications in a presence of multiple coexisting VBANs.]

**Purpose:** [information]

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# Performance Improvement by Proper Sets of Preamble Codes in UWB Wireless Communications in a Presence of Multiple Coexisting VBANs

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DENSO TEN Ltd.

1. Motivation and Aim of This Study
2. Problems
  - 2.1 Experiment of UWB wireless networks in multiple coexisting vehicles
  - 2.2 Problems
3. Proposed Scheme
  - 3.1 Proper sets of preamble codes
  - 3.2 Experimental performance evaluation
4. Conclusion and Further Study

# 1. Motivation and Aim of This Study

## 2. Problems

2.1 Experiment of UWB wireless networks  
in multiple coexisting vehicles

### 2.2 Problems

## 3. Proposed Scheme

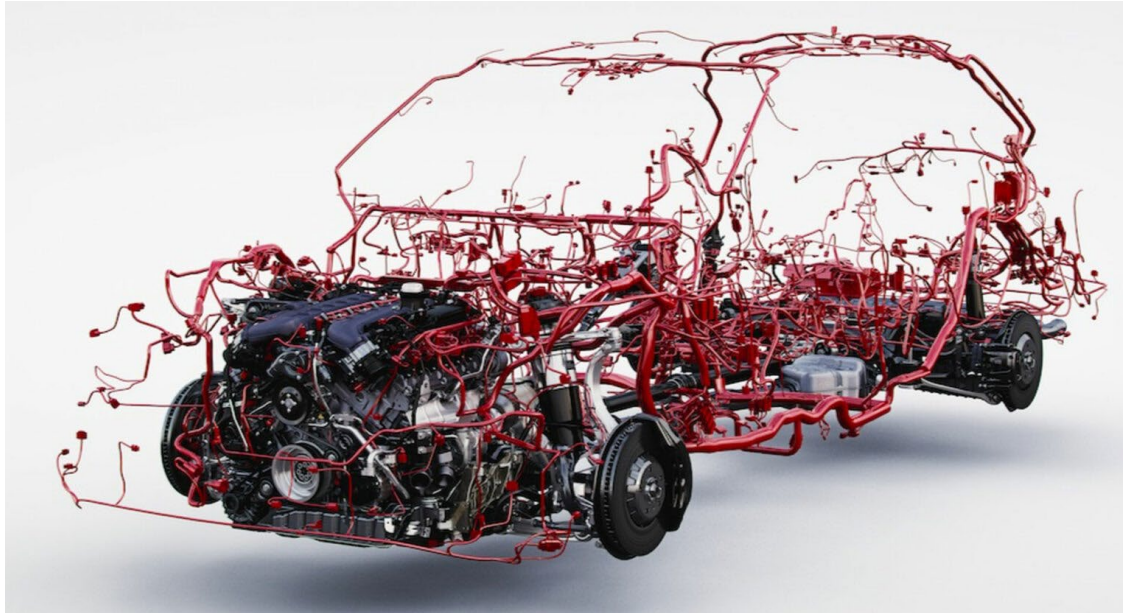
3.1 Proper sets of preamble codes

3.2 Experimental performance evaluation

## 4. 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/>

## 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 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.

## Challenges of using wireless technology:

Using wireless technology in vehicles is challenging because it must be as reliable and fast as wired systems, especially in noisy environments

- Electromagnetic noise effects from motors, inverters, and engines
- Multipath in enclosed spaces
- Interference from and to coexisting systems

## Reasons for adopting UWB:

1 ) Less radio interference

- Low spectral density lower than noise for giving interference to others
- High frequency diversity due to ultra-wide band for getting interference
- Security in physical level

2 ) High resolution of ranging and positioning

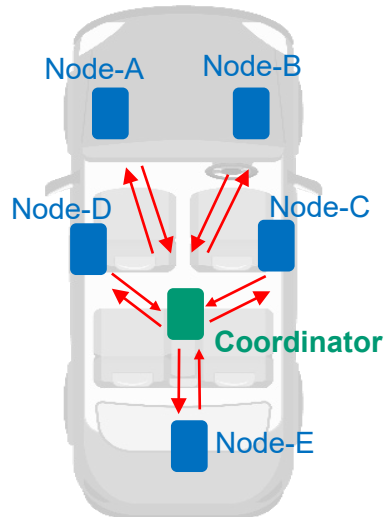
- Ultra-short pulse less than 1ns

**Considering UWB for vehicles due to its strong resistance to radio interference**

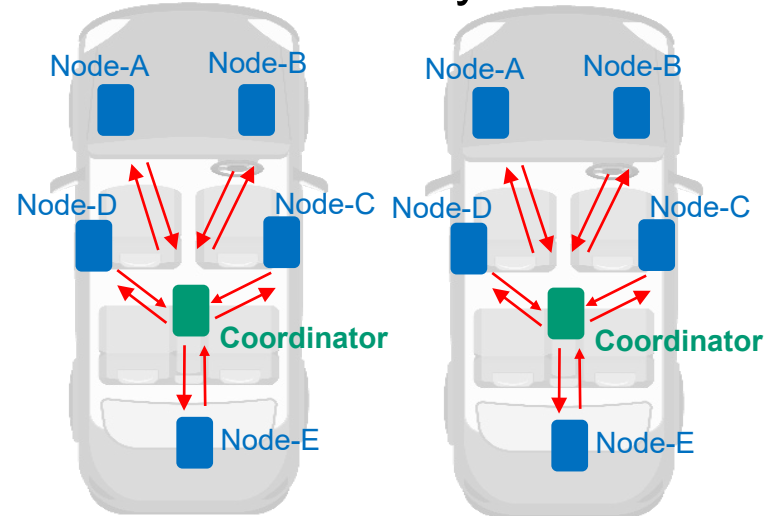
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## Steps to investigate wireless use:

- Step1 Check if UWB communication works inside one car well or not  
 Step2 Check if UWB communication works with nearby car well or not



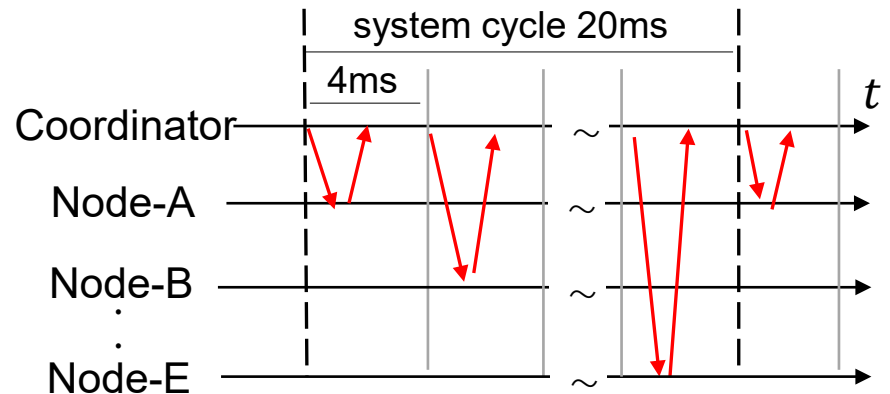
Communications in a car



Communications in two cars

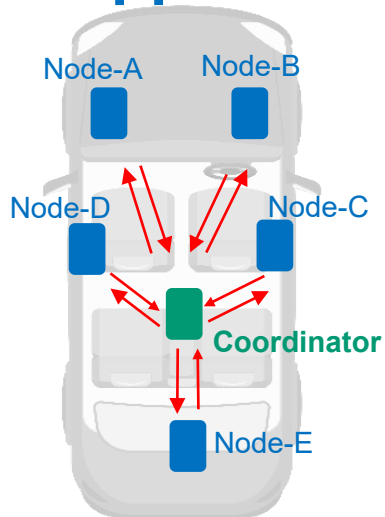
## Communication method:

- System response time: < 25ms
- MAC: Polling method
- PHY: UWB
- Time slot: 4ms





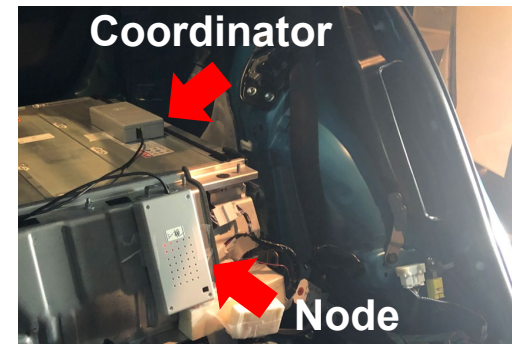
# UWB applicability in a car:



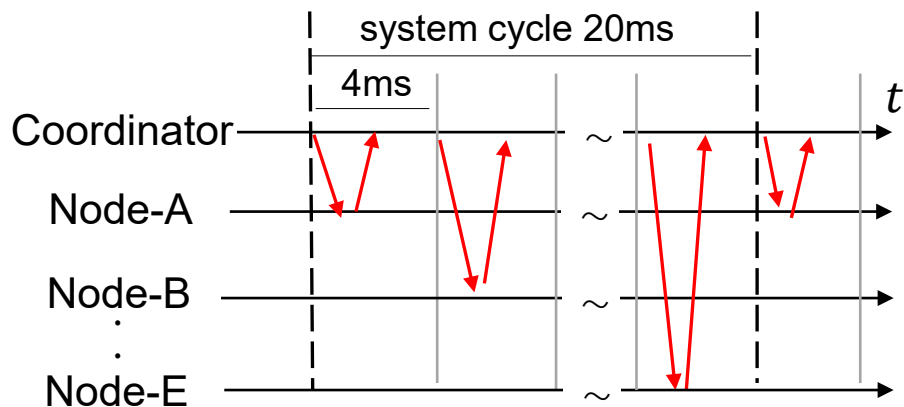
Node-A&B in engine compartment



Node-C&D in passenger compartment



Coordinator & Node-E in trunk



	Passenger compartment	Engine compartment	Trunk
ACC-ON	✓	✓	✓
IG-ON	✓	✓	✓
IDLING	✓	✓	✓

✓ : 100% success

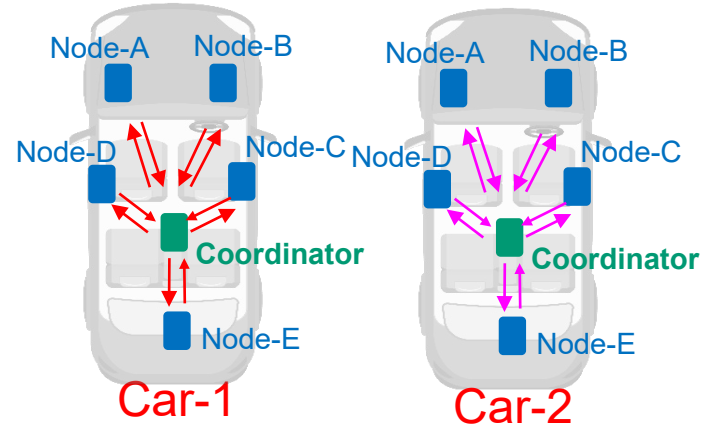
Communication is successful at any location, regardless of car status

# UWB application in a car close to another car:



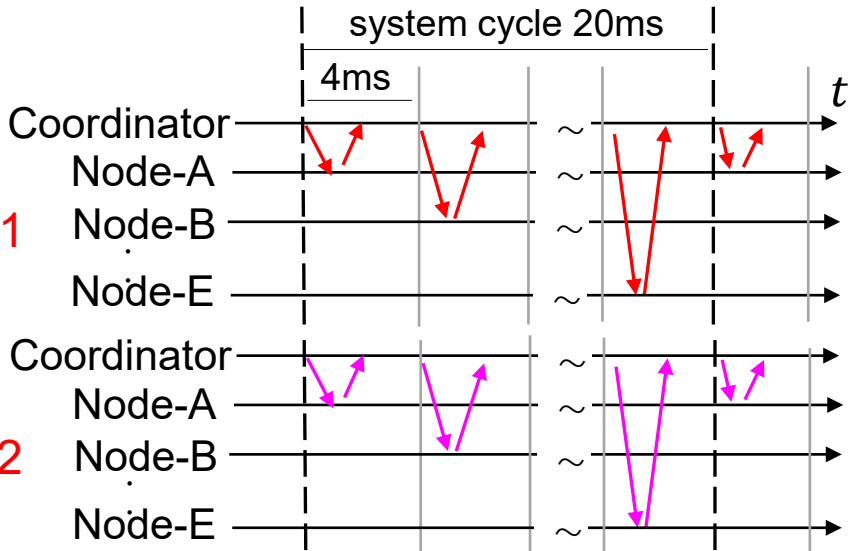
Car-1

Car-2

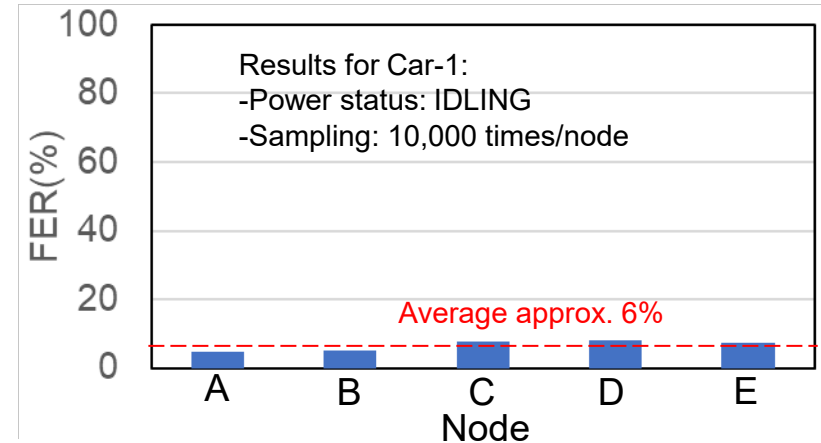


Car-1

Car-2



Preamble code is same as Car-1 and Car-2



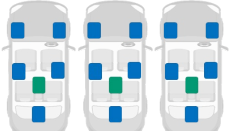


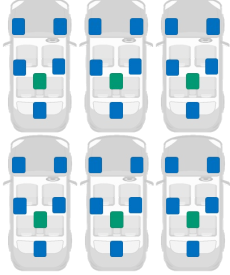
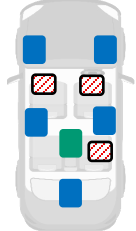



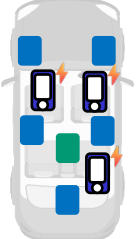



FER: the error rate of communication frames for each node

UWBs at close range interfere with each other, resulting in an FER of approximately 6%

Reducing interference in vehicle applications is a key problem

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# Our problems:

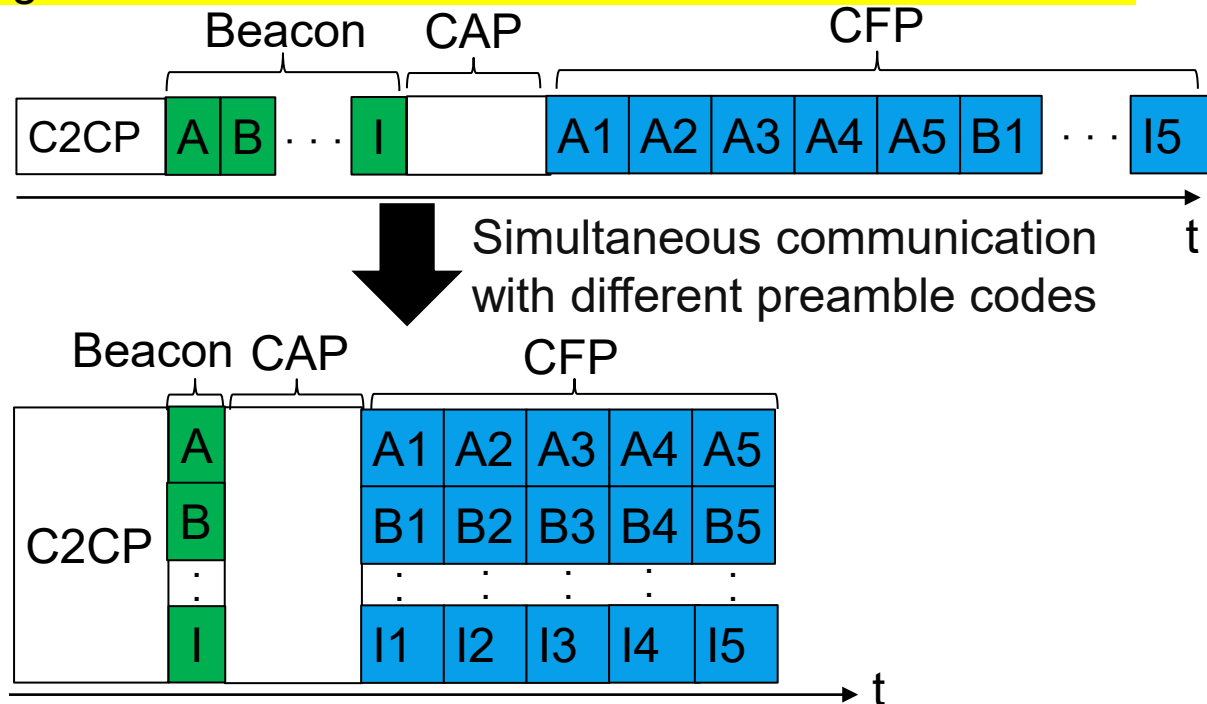
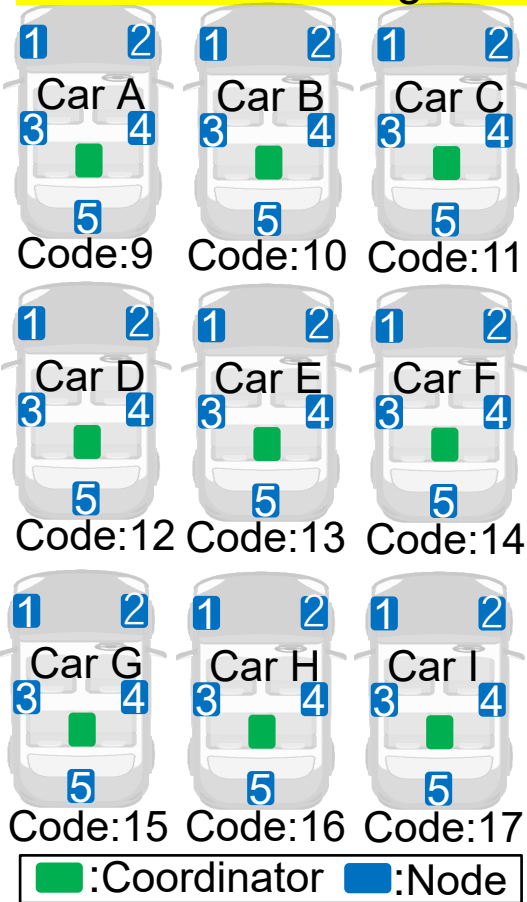
No	Problems		Solutions
1	Interference from nearby vehicles	 <p>(Coexistence Class1)</p> <p> :Coordinator  :Node         </p>	Use of preamble codes
2	Real-time communication within a permissible delay among multiple vehicles	 <p>Consider coexistence of up to 9 units as normal situation</p>	
3	Interference from Legacy BAN	 <p>(Coexistence Class2)</p> <p> :Coordinator  :Node  :Legacy BAN         </p>	MAC handling or Use of preamble codes
4	Interference from IEEE802.15.4 system	 <p>(Coexistence Class4)</p> <p> :Coordinator  :Node  :IEEE802.15.4         </p>	MAC handling or Use of preamble codes

To solve the problems, we propose solutions for interference and real-time communication issues using preamble codes.

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# Proposal:

We propose an optional scheme in a draft standard to assign quasi-orthogonal preamble codes to coexisting cars, allowing simultaneous communication with less interference



- assignment of preamble codes in C2CP

Assignment of quasi-orthogonal preamble codes allows multiple BANs to coexist while reducing interference and enabling real-time communication

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## Approach to validate the proposal:

Check whether the use of quasi-orthogonal preamble codes allows simultaneous communication while reducing interference, even with nearby vehicles

### Frame format

Preamble	SFD	PHY Header (PHR)	MAC Header (MHR)	MAC Payload (MSDU)	MAC Footer (MFR)
Synchronization Header (SHR)		PHY Header (PHR)	PHY Payload (PSDU)		

### Physical layer settings

Frame	Parameter	
Preamble	Preamble code	3, 4, 9, 10, 11, 12
	Preamble length	64 symbol
SFD	SFD length	8 symbol
PHY Header	data rate	6.8Mbps
PHY Payload	data rate	6.8Mbps
	PHY length	127 Octets

Confirmed that the different combinations of preamble codes affects the error rate and considered possible countermeasures



## UWB Frequency Bands:

Channel number	Central frequency(MHz)	Bandwidth(MHz)	Channel attribute
0	499.2	499.2	Optional
1	3494.4	499.2	Optional
2	3993.6	499.2	Mandatory
3	4492.8	499.2	Optional
4	3993.6	1331.2	Optional
5	6489.6	499.2	Optional
6	6988.8	499.2	Optional
7	6489.6	1081.6	Optional
8	7488	499.2	Optional
9	7987.2	499.2	Mandatory
10	8486.4	499.2	Optional
11	7987.2	1331.2	Optional
12	8985.6	499.2	Optional
13	9484.8	499.2	Optional
14	9984	499.2	Optional
15	9484.8	1354.97	Optional

Check on Channel 9, which Japanese radio regulation allows for outdoor use

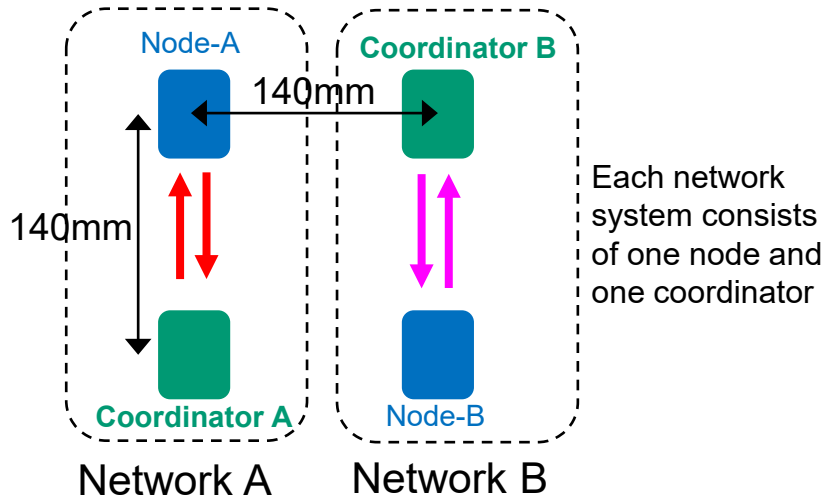
## Preamble codes:

Use preamble code index 3, 4, and 9-12 at 7987.2MHz for the evaluation

PRF	Preamble code		code sequence
16MHz	Low Code	3	- + 0 + + 0 0 0 - + - + + 0 0 + + 0 + 0 0 - 0 0 0 0 - 0 + 0 -
		4	0 0 0 0 + - 0 0 - 0 0 - + + + + 0 + - + 0 0 0 + 0 - 0 + + 0 -
64MHz	High Code	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 - - +
		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 - -
		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
		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 + - -

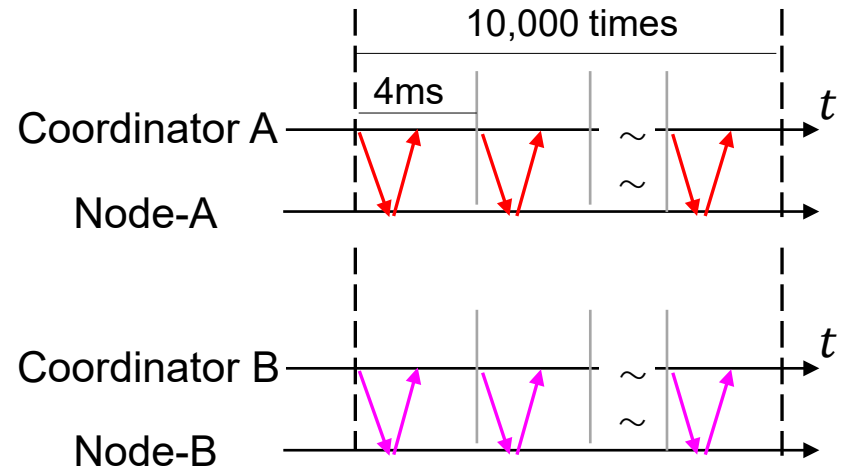
# Performance Evaluation by Experiment:

Checked how the preamble codes of nearby systems affect FER using devices



→ : Radio wave transmission partner

- Conducted basic experiments to see the impact of preamble code combinations
- Keep equal distance between coordinator and nodes, and match SIR and communication timing
- Check FER with preamble code combinations of Network A and Network B

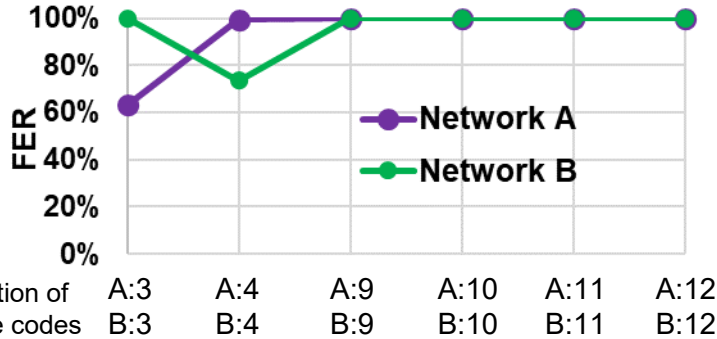


No	combinations of Network A and Network B
1	Same code
2	Low code (except No1.)
3	High code (except No1.)
4	Low and High code

Low code: code3,4 (length31) High code: code9~12 (length127)

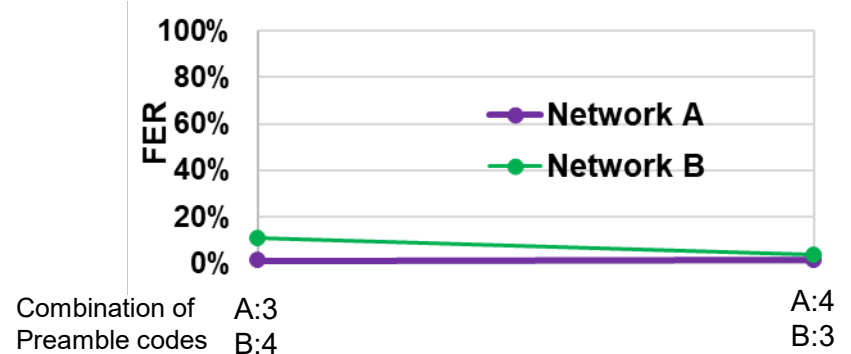
# Experimental Results:

## No1. Combination of the same code



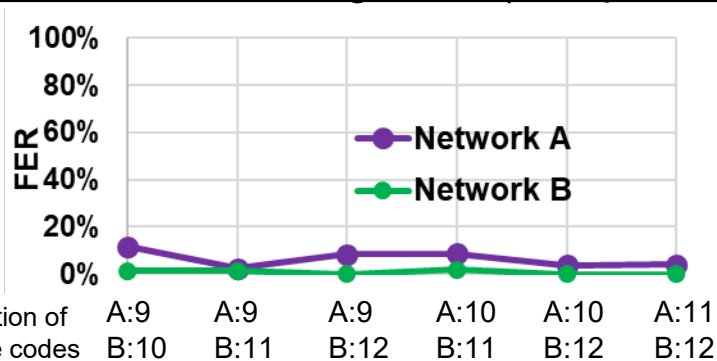
Both are likely to fail

## No2. Combination of Low code(except No1)



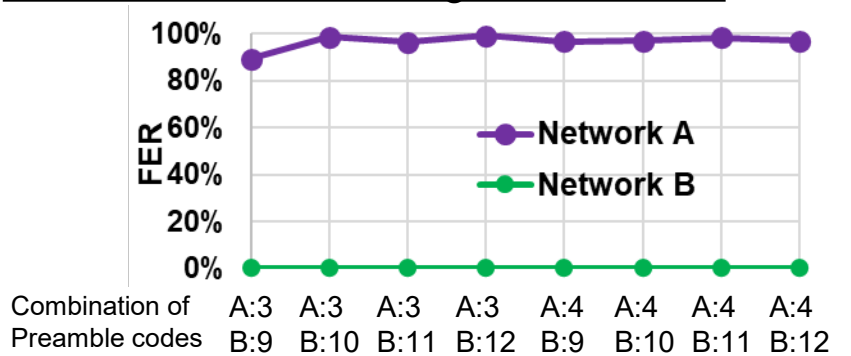
Both are likely to succeed

## No3. Combination of High code(except No1)



Both are likely to succeed

## No4. Combination of High & Low code



High code is more likely to succeed

Using different preamble codes of the same length for each system helps reduce interference

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## Conclusion:

- As an attractive use case for vehicles of IEEE802.15.6ma, UWB VBAN can be applied for reliable sensing and controlling of harness in a presence of interference among coexisting multiple vehicles.
- Proper sets of preamble codes can reduce such interference to maintain reliable sensing and controlling of harness.
- Assignment proper sets of quasi-orthogonal preamble codes allows multiple BANs to coexist with less interference, enabling high throughput with low frame error rate.

## Future Works:

- Provide more detailed comments on the draft standard.
- Experiments have confirmed the effect of preamble code combinations.
- Provide detailed analysis using simulations and theory to show the effectiveness of the proposed preamble codes.
- A way to assign appropriate sets of preamble codes will be derived in a practical environment with various channel and coexistence models.

**Thank you for your attention!**