Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)
Submission Title: [IG DEP & SG15.6a Activity for Amendment of 15.6 BAN with Enhanced Dependability]
Date Submitted: [12 May 2021]
Source: [Ryuji Kohno, Takumi Kobayashi] [1; Yokohama National University (YNU), 2; YRP International Alliance Institute (YRP-IAI)]
Address [1; 79-5 Tokiwadai, Hodogaya-ku, Yokohama, Japan 240-8501
  2; YRP1 Bldg., 3-4 HikarinoOka, Yokosuka-City, Kanagawa, Japan 239-0847]
Voice:[1; +81-90-5408-0611], FAX: [+81-45-383-5528],
Email:[1: kohno@ynu.ac.jp, kobayashi-takumi-ch@ynu.ac.jp, 2:kohno@yrp-iai.jp, kobayashi-takumi@yrp-iai.jp]

Abstract: [This document summarizes IG-DEP and SG15.6a activity for amendment of IEEE802.15.6 - 2012 Medical Body Area Network (BAN) corresponding to increasing demand for enhanced dependability in wireless sensing and controlling human and car bodies for medical healthcare and automotive uses. After quick overview of IEEE802.15.6 -2012, necessity of the amendment is described in such critical use cases that various types of interference such as intra BAN interference in multiple overlaid BANs, interference among BAN and other PANs in some overlaid frequency band etc. Extension of BAN from human body for medical healthcare to car body for automotive uses and their combination are discussed as a common standard.]

Purpose: [information]

Notice: This document has been prepared to assist the IEEE P802.15. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.

Release: The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15.
IG-DEP & SG15.6a Activity for Amendment of IEEE 802.15.6 BAN with Enhanced Dependability

Ryuji Kohno, Takumi Kobayashi
Yokohama National University, Japan(YNU)
YRP International Alliance Institute, Japan(YRP-IAI)
Agenda

1. Demand for WBAN for Emergent Medical Healthcare Use and Huge Market of Automotive Use

2. Short Review of WBAN Standard IEEE802.15.6-2012

3. Necessity and Uniqueness for Amendment of BAN with Enhanced Dependability

4. Available Technologies in PHY and MAC Layers for the Focused Amendment of std 15.6 BAN with Enhanced Dependability

5. Technical Requirement for the Amendment of Std. 15.6 to Enhance Dependability
1. Demand for WBAN for Emergent Medical Healthcare Use and Huge Market of Automotive Use
1.1 Demand of BAN for Medical Uses

A. Emergent Problems over the world:
   - 1-4% of total population in a world may be suffered by COVID-19, that is a global pandemic.
   - Clinic are overloaded and many business are damaged seriously.

B. Challenging but Feasible Solutions:
   - Provide Remote Vital Sensing and Therapy Using ICT and AI
     ➔ Prevent Epidemic and Maintain Safe and Efficient Diagnosis
   - Promote Global Business of Medical ICT and Data Science

C. Approach:
   1. R&D of Enable Technologies for Pandemic and Daily QoL
   2. Promote International Standard of Wireless Body Network (BAN) and Integrated Platform of BAN/5G/AI for Global Marketing
   3. Regulatory Compliance of Medical Devices & Services to Ensure Safety, Reliability, Security, i.e. Dependability by Regulatory Science
1.2 Medical Inspection and Treatment by BAN

Medical Healthcare Using BAN can perform remote real-time medical diagnosis and therapy
• To prevent pandemic against COVID-19 and medical care incident etc. in daily life.
  > Remote sensing vital sign and monitoring symptoms
  > Evidence based medicine for clinical and nursing actions
• To support safe and efficient medical care for clinical staffs and patients etc.
  > Online diagnosis, PCR and other inspection
  > Protect clinical staffs and care givers with network

WBAN can apply for preventing pandemic and supporting daily care by remote sensing and therapy in digital healthcare.

Symptoms of COVID-19
- Common symptoms:
  - Fever: 83–99%
  - Loss of Appetite: 40–84%
  - Fatigue: 44–70%
  - Loss of smell: 15 to 30%
  - Shortness of breath: 31–40%
  - Cough: 59–82%
  - Coughing up sputum: 28–33%
  - Muscle aches
- Other symptoms:
  - Bluish face or lips
  - Coughing up blood
  - Persistent chest pain
  - Decreased white blood cells
  - Kidney failure

Server on Medical Services
Automatic recording of medical treatments and nursing details
Stock information
Condition of patients
⇒ sensor nodes
Recognition
Medication
1.3 Wireless BAN: Body Area Network

Wearable BAN
Tele-metering or sensing vital signs with various sensors
- ECG
- EEG
- SPO2
- Blood Pressure
- Heartbeat
- Body temperature
- Glucose level
- Medical images (X-ray, MRI) and video

Implant BAN
Tele-control of Medical Equipment and Devices
- Pace Maker
- with ICD
- Wireless Capsule Endoscope

Novel Concept
Intelligent Network of Vital Sensors, eHR, Medical Robots etc.

May 2021

Ryuji Kohno, Takumi Kobayashi (YNU/YRP-IAI)
1.4 BAN- Use Cases for Remote Medical Services

Medical support for developing countries

- BAN
- Satellite Link
- Medical Data Server for Data Mining with Machine Learning
- Medical Center and General Hospitals
- Data mining
- Medical support for developing countries
1.5 AN-base Universal Platform with Network Cloud, Data Mining Server for Medical Healthcare

Data mining or Analysis like Watson

Data storage server; DBMS

Network cloud (5G, 6G)

Gateway

Hospital, Rehabilitation center, or Clinicians

Body Area Network (BAN)

Coordinator

Node

Node

Node

Elderly people

Therapist, Nurses, Care givers

physical assistant and surgery robots
1.6 Universal Platform Based on BAN, Cloud Network, and AI Data Server for General Social Infrastructure beyond Medical Services

Although in a situation such as cyber or physical terrorism and natural disaster, networks are partially destroyed, layered structure network can suppress and limit the effect to the inside of the limited physical area.
1.7 Extension of Use Cases of BAN beyond Medical Healthcare

- **Collision Avoidance Using inter-vehicle and roadside networks**
- **Collision Avoidance and safe driving by inter-vehicle networks**
- **Road to car networks**
- **Inter-vehicle networks**

**Car Navigation & Collision Avoidance Radar**

**Dependable Wireless Networks for Transportation**

**Wearable BAN**
- Tele-metering vital data
  - EEG
  - ECG
  - Blad Pressure
  - Temperature
  - MRI images
  - Etc.

**Implant BAN**
- Tele-controlling implant devices
  - Pacemaker with IAD
  - Dependable Network among vital sensors, actuators, robots

- **UWB can solve such a problem that radio interferes a human body and medical equipments**

**Dependable Network among vital sensors, actuators, robots**

**Dependable Wireless System Clock in Micro Circuit & Network in Devices**

**Dependable Wireless System for Manufacturing (CIM)**

- **Car LAN & Wireless Harness**
- **Factory Automation (FA)**
Automatic Remote Sensing Glucose and Controlling Insulin Pump for Diabetes Patients Using Wireless BAN

Wireless Feedback Sensing and Controlling Loop for Diabetes Patients

Feedback Delay Loop Model with Motion Equation
1.8 Demand of BAN for Automotive Uses

A. Increasing Demands in a world:
   - New business promotion by applying wireless ICT to vehicle by huge alliance between automotive and telecom industries such as smart key, wireless harness
   - Autonomous car driving and safety controlling of elderly drivers by ICT and data science

B. Challenging but Feasible Solutions:
   - Provide Remote Sensing and Controlling Using ICT and AI
     ➔ Prevent Traffic Accidents, Jam, and Co2 Emission
   - Promote a New Global Business of Automotive, ICT, and Electronics

C. Approach:
   (1) R&D of Enable Technologies for Smart Vehicle and City
   (2) Promote International Standard of Wireless Body Network (BAN) and Integrated Platform of BAN/5G/AI for Global Marketing for both Medical and Automotive uses
   (3) Regulatory Compliance of Devices & Services to Ensure Safety, Reliability, Security, i.e. Dependability by Regulatory Science
1.9 Use of BAN for Autonomous Car Driving

Wireless Feedback Sensing and Controlling Loop for Autonomous Driving

Feedback Delay Loop Model with Motion Equation

Controller \[ u[k] \]

\[ r[k] \]

\[ K \]

\[ x[k] \]

\[ x[k] \]

\[ y[k] \]

\[ 1/S \]

\[ Ad \]

\[ Bd \]

Driver or AI

controller

Wireless channel

Axel/Brake

Radar

For Autonomous Driving

Own Car

Car Running Ahead

For Collision Avoidance and Inter-Vehicle Communication
1.10 Remote Localization and Rescue of Missing Victims Using Wireless Dependable BAN of Things/M2M

Wireless Feedback Sensing and Controlling Loop for Rescue of Victims

Feedback Delay Loop Model with Motion Equation

Controller

\[ r[k] \]

\[ u[k] \]

\[ u[k] \]

\[ x[k] \]

\[ x[k] \]

\[ r[k] \]

\[ K \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]

\[ x[k] \]
1.11 Body Area Network (BAN) of Vehicle Body

Motivation to extend human BAN (HBAN) to VBAN is to promote much dependable services by interaction between HBAN and VBAN.

Use case of Vehicle Body Area Network (VBAN) for Engine Room

1. Engine diagnostic sensor and controller
2. Air pressure sensor, wheel health sensor and controller
3. Transmission monitoring sensor and controller

Use case of Vehicle Body Area Network (VBAN) for Cabin Room

4. Cabin environment sensor (temperature, brightness, humidity etc.)
5. Sheet sensor, health care sensors for driver
6. Sheet sensor, health care sensors for passenger

https://media.istockphoto.com/photos/transparent-car-design-wire-model3d-illustration-my-own-car-design-picture-id594040008?k=6&m=594040008&s=612x612&w=0&h=XE8LiBjpM51aB4pH2CFt6-MT61vALRPnIxPcac0RXhg=
1.12 Use case in Factory Manufacturing Line; Detection of Twist and Cut of Cables

In order to improve QoS of controlling robots in factory lines, real-time sensing and controlling with permissible feedback control loop must be important requirement.

Prediction and Real-time Detection of twist and cut in signal and power cables.
2. Short Review of WBAN Standard
IEEE802.15.6-2012
2.1 Standard of Medical Wireless Body Area Network (BAN); IEEE802.15.6

IEEE802

- IEEE802.11 Wireless LAN
- IEEE802.15 Wireless PAN
- IEEE802.16 Wireless MAN

802.15.1 Bluetooth
802.15.2 Coexistence between WPAN and WLAN
802.15.3 PHY for High Rate WPAN
802.15.4 PHY for Low Rate WPAN
802.15.5 WPAN Mesh Network

802.15.3a Alternative PHY of 15.3
802.15.3b Maintenance of 15.3
802.15.3c PHY in Millimeter wave band
802.15.4a Low rate UWB PAN Alternative PHY of 15.4
802.15.4b Revision & Modification of 15.4 MAC
802.15.4c Chinese WPAN
802.15.4d Japanese WPAN

2007.3 Standard Completed
2012.2 Standard was Completed

Ryuji Kohno, Takumi Kobayashi (YNU/YRP-IAI)
2.2 Top View of IEEE Std 802.15.6

IEEE 802.15.6

Narrow band PHY on-body & in-body
- Modulation: GMSK & DPSK
- TX range: ~3m
- Bands: MICS, WMTS, ISM
- Data rate: ~ some Mbps

UWB PHY on-body
- Modulation: IR-UWB & FM-UWB
- TX range: ~3m
- Band: UWB band
- Data rate: ~10Mbps

HBC PHY on-body
- Frequency Selective
  - 10-50MHz
  - 125kbps-2Mbps
- Beacon-base-TDMA
- Group Superframe
- Priority support
- Non-beacon mode

Common MAC (for all PHY)

UWB: Ultra-wideband
HBC: Human body communication
### 2.3 User Priority Mapping

<table>
<thead>
<tr>
<th>Priority level</th>
<th>Traffic designation</th>
<th>Data type</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Emergency or medical event report</td>
<td>Data</td>
</tr>
<tr>
<td>6</td>
<td>High <em>priority</em> medical data or network control</td>
<td>Data or management</td>
</tr>
<tr>
<td>5</td>
<td>Medical data or network control</td>
<td>Data or management</td>
</tr>
<tr>
<td>4</td>
<td>Voice</td>
<td>Data</td>
</tr>
<tr>
<td>3</td>
<td>Video</td>
<td>Data</td>
</tr>
<tr>
<td>2</td>
<td>Excellent effort</td>
<td>Data</td>
</tr>
<tr>
<td>1</td>
<td>Best effort</td>
<td>Data</td>
</tr>
<tr>
<td>0</td>
<td>Background</td>
<td>Data</td>
</tr>
</tbody>
</table>
### 2.4 Three Channel Access Modes

<table>
<thead>
<tr>
<th>Channel access mode</th>
<th>Time reference-based (superframe structure)</th>
<th>Beacon</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Yes</td>
<td>Yes</td>
<td>Coordinator sends beacon in each superframe except for inactive superframes.</td>
</tr>
<tr>
<td>II</td>
<td>Yes</td>
<td>No</td>
<td>Coordinator establishes time reference but doesn’t send beacon.</td>
</tr>
<tr>
<td>III</td>
<td>No</td>
<td>No</td>
<td>There is not time reference.</td>
</tr>
</tbody>
</table>
2.5 Time-referenced Superframe w/ Beacon

Clock and position of each access phase

May obtain contended allocation for highest priority

One superframe

EAP: exclusive access phase
RAP: random access phase
MAP: managed access phase
CAP: contention access phase
2.6 Worldwide UWB Regulations in 2012

China

Europe

Japan

Korea

USA

3.1G 3.4G 4.2G 4.8G 6.0G 7.25G 8.5G 9G 10.25G 10.6G

Low band

High band
2.7 Radio Outdoor Uses in the Frequency Band 7.25-9.00GHz (January 2021)

- **Red lines** indicate channels defined by IEEE802.15.4a.
- Although Ch 9 in 7.587-8.4GHz **Blue line** was allowed for outdoor use in May 2019, MIC has started investigation to allow wider band 7.25-9.00GHz **Green line** and it is expected to allow it for outdoor use in January 2021.
2.8 Summary of IEEE802.15.6-2012

- A standard, IEEE Std 802.15.6™ was completed and published in Feb. 2012. In which, specifications of three PHY and common MAC are defined to support various medical and non-medical consumer applications.

- Commercial products of BAN have been sold as an enable technology supporting personal healthcare as a consumer electronics but not much approved for medical equipment.

- In PHY, ultra-wide band(UWB) is applied for high QoS use case but radio regulation for UWB results in restricting use cases.

- In MAC, hybrid contention base and free protocol can perform flexible delay and throughput for variable QoS levels of packets but its implementation complexity is too high for its complete protocol.
3. Necessity and Uniqueness for Amendment of BAN with Enhanced Dependability
3.1 Necessity for Enhanced Dependability in std 15.6 BAN

1. In case of coexistence of multiple BANs
   - Current existing standard IEEE802.15.6 has not been designed to manage contention and interference among overlaid BANs. The more BAN uses in dense area, the more contention and inference cause performance degradation.
   - Amendment of PHY and MAC for resolving these problems in coexistence of BANs is necessary.

2. In case of coexistence with other radios
   - For enhanced dependability, UWB PHY of BAN should be updated to avoid performance degradation due to interference with coexisting other narrow band and UWB networks in overlapped frequency band.

3. In case of feedback sensing and controlling loop
   - Remote medical diagnosis with vital sensing and therapy and control actuators and robotics need more dependable and efficient protocol.

4. Usability and Implementation Complexity
   - Interoperability with other radio networks, more flexible network topology,
   - Transparency with other standards such as ETSI SmartBAN
   - Capability of ranging and positioning in UWB is required for mobility and security.
3.2 Technical Challenges for Enhanced Dependability

- First of all, we should recognize that any technology in PHY and MAC cannot guarantee full dependability in every use case.
- However, we can design a new standard which can guarantee a certain level of enhanced dependability in a specific defined use case.
- As an analogy of informed consent in medical doctor to a patient, a manufacturer of a dependable wireless network can describe such a specific defined use case that *the manufacture can guarantee a defined level of dependability showing necessary cost and remained uncertainty*. This is an honest manner and much better than no guarantee for any use case.
- Therefore, an expecting standard describes a specific use case in which *worst performance can be guaranteed enough high while most of exiting standards have been designed with average performance base*.
- Technical requirement for the specific use case can be guaranteed.
3.3 Uniqueness different from existing standards (1/2)

1. MAC protocol for around packets and recursive access for feedback loop in remote sensing and controlling;

2. Level of dependability can be defined with showing necessary cost and remained uncertainty. This is an honest manner and much better than no guarantee for any use case.

3. Worst performance can be guaranteed enough high while most of exiting standards have been designed with average performance base.

4. Others
3.3 Uniqueness different from existing standards (2/2)

2. PHY technologies to satisfy technical requirement for enhanced dependability in the focused use cases

A) In feedback loop for remote monitoring sensors or radars and feedback controlling actuators, real-time cognition of varying condition on site and adaptive reconfiguration in relatively messy, small, and dense areas are requested to guarantee worst performance with permissible delay and errors.

B) Within a permissible limited feedback delay, propagation paths connecting between nodes and coordinator should be found to keep connectivity by diversity, channel switching etc.

C) For such a dynamic environment and QoS requirement changing situation, sophisticated PHY technologies are requested to guarantee minimum requirement of performance.
3.4 Focused Issues in Amendment of std 15.6 BAN with Enhanced Dependability

1. MAC Protocol in case of coexistence of multiple BANs
   - Amendment of MAC for resolving these problems in coexistence of BANs is necessary.
   - Specified MAC protocol for feedback sensing and control loop between coordinator and nodes.

2. PHY Interference Mitigation In case of coexistence with other radios
   - For enhanced dependability, UWB PHY of BAN should be updated to avoid performance degradation due to interference with coexisting other narrow band and UWB networks in overlapped frequency band.

3. Usability and Implementation Complexity
   - Interoperability with narrow band and UWB PHY
   - more flexible network topology,
   - Transparency with other standards such as ETSI SmartBAN

4. Ranging and Positioning Capability of UWB-BAN
   - Mobile nodes and coordinator of BAN need ranging and positioning of UWB-BAN
4. Available Technologies in PHY and MAC Layers for the Focused Amendment of std 15.6 BAN with Enhanced Dependability
4.1 Intra and Inter System Interference among BAN and Other PANs

- **Inter-user interference**
  - IR-UWB uses the same pulse as all users signal in the same standard.
  - Other users signal and/or the other network signal would be interference.

- **Inter-system interference**
  - Interference from the other wireless system using overlapped frequency band. ⇒ Unknown

* 802.11a (wi-fi) (5GHz) overlaps
4.2 Approach for Intra and Inter System Interference among BAN and Other PANs

- **Sparate** and **Recognize** each interference from different source.
  - Apply suitable interference mitigation method according to source of interference.

- Using both of Spatial and Temporal signal processing.

**Inter-user** interference
“IUI” in this presentation
Interference from a system using the same pulse

**Inter-system** interference
“ISI” in this presentation
Interference from a system using overlapped frequency

**Known**
Recognize and demodulate
Pulse shape multiple access
Multi-user detection

**Unknown**
Remove
Interference canceller
4.3 Time Domain Interference Mitigation

OMF; orthogonal matched filter

- Consists a matched filter (MF$_1$) and MF Group (MFG)
- Tap coefficients of MF$_1$ are the same as sequence of desired signal.
- Coefficients of MF$_1$ and each MF$_k$ that constituting MFG are orthogonal.
- Desired signal does not through MF$_2$ to MF$_{K-1}$ because orthogonality.
  → Only interference can through.
- MFG makes replica of interference signal by linear combination with weight vector w of linear combiner; LC.
- Subtract interference replica from the output of MF$_1$.

**OMF can remove interference without any pre-knowledge of interference.**
4.4 Space Domain Interference Mitigation

TDL-AA; Tapped delay line array antenna

- Array antenna by using multiple antenna elements and tapped delay line.
- Each antenna branch has coefficients.
- Transfer function of this antenna has parameters of signal incoming angle; $\theta$ and frequency; $\omega$.

$\Rightarrow$ has characteristics of both of spatial and time domain.

$$\tau_n = n \frac{d}{c} \sin \theta,$$

$$y(t) = \exp(j\omega t) \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} \exp(-j\omega(\tau_n + mT_0))w_{n,m},$$

$$= \exp(j\omega t) \times H(\theta, \omega),$$

$$H(\theta, \omega) = \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} w_{n,m} \exp(-jm\omega T_0) \exp(-jn\omega \frac{d}{c} \sin \theta).$$

TDL-AA can work as interference canceller on both of time and space domains.
4.5 Interference Mitigation among Other Radios

(a) Time Waveform of Pulse (right figure) and its Frequency Spectrum with notches in 2.4 and 5.2GHz for WLAN (left figure)

(b) Time Waveform of Pulse (right figure) and its Frequency Spectrum satisfying spectrum mask (left figure)

4.6 Integrated Terminal to Avoid Mutual Interference in case of overlaid coexisting BAN and other Radios such as UWB-BAN and 4G/5G

Integrated Terminal
= (Cellular Terminal + BAN Coordinator)
= (Primary User + Secondary BS)

4.7 ICT & Data Science Platform for Infrastructure with BAN, 5G/6G Cloud, and Data Servers Based on Regulatory Science

BAN for User 1
- ECG Sensor
- Glucose Sensor
- Rehabilitation Robot & Wheel Chair

BAN for User 60
- ECG Sensor
- Multiple Sensor (SpO2, EEG, etc.)
- Surgery Robot

Coordinator
- IEEE802.11
- Windows

Coordinator
- IEEE802.15
- Android

Local 5G
- iOS

Cloud Network
- 3G, 4G, 5G and 6G Cellular
- Wi-Fi
- WiMAX etc.

Data Mining
Network Operator
For 4G, 5G, and 6G
Cloud Server/Data Center
System Operation

Data Server & repository
For Data Mining with AI
C-data Science Center

General Hospital
Remote Diagnosis & Therapy

Regulatory Science Center
Regulatory Compliance Test, R&D, Standardization of Healthcare

IEEE802.15
Coordinator Windows

IEEE802.11
Coordinator Android

Three PHY with a common MAC in IEEE802.15.6
4.8 Contention among Overlaid BANs

**Issue**
- Interference problem in the case where multiple BANs overlap (specifically, situations where people with BAN approaching)
  - Because the schedule adjustment between the coordinators has not been done

**Solution**
- Negotiation between coordinators, scheduling between different BANs, to prevent deterioration due to inter-BAN interference

---

Ref. R. Kohno, S. Ogawa, “MAC Protocol with Interference Mitigation Using Negotiation among Coordinators in Multiple Wireless Body Area Networks (BANs),” IEEE802.15 doc.#15-19-0119-00-0dep-ig-dep, Vancouver, Canada, March 12, 2019
5. Technical Requirement for the Amendment of Std. 15.6 to Enhance Dependability
5.1 Update of Technical Requirements for Amendment of BAN

- IEEE802.15.6 for Medical BAN was established in Feb. 2012 and has not been updated for successive applications.
- IG-DEP has been discussing with ETSI Smart BAN for digital healthcare and further medical applications.
- NICT Brain Machine Interface; BMI labs with medical community requests amendment of IEEE802.15.6 for much higher capacity and reliability in IG-DEP, particularly 2nd Generation of ECoG with much more electrodes beyond EEG using UWB technologies.
- IG-DEP has decided to include dependable medical BAN with higher capacity and reliability in focused applications.
- Then updated technical requirement has been discussed.
- The updated requirement will be summarized in next pages.
### 5.2 Updated Technical Requirements (1/5)

<table>
<thead>
<tr>
<th></th>
<th>Car</th>
<th>Factory automation</th>
<th>UAV(Drone)Sensing &amp;Control</th>
<th>High Data Rate BAN (HRP)</th>
<th>Low Data Rate BAN (LRP)</th>
<th>Dependable BAN including Car Body as well as Human and Robotic Body</th>
<th>Reference standard 802.15.6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of sensors</strong></td>
<td>Up to ten per network</td>
<td>Up to ten per network</td>
<td>Up to ten (ex. camera, GPS etc.)</td>
<td>Up to 4096</td>
<td>Up to 256</td>
<td>128, 64, 32, 16, 8, 4, 2 nodes for each unit. In case of Human body, 4 units can cover 256 nodes as the same as 15.6. In case of Car body, M&gt;4 units can cover 64xM nodes in layer structure. Class A; node transmitting periodical packets Class B: node doing non-periodical ones.</td>
<td>256 For 2nd G ECoG BMI 128x32, 64x64 32x128, 16x256, 8x512 4x1024, 2x2048</td>
</tr>
<tr>
<td><strong>Support for multiple network co-existence &amp; interoperability</strong></td>
<td>Less than 100</td>
<td>Up to 100</td>
<td>Up to ten (ex. at least 4 drones for relative localization)</td>
<td>Single</td>
<td>Up to 3 BANs</td>
<td>Less than 64 units. 1 unit contains 64 sensors. Includes multiple BANs overlaid. Other choices are 32 nodes/unit and max. no. of units is 100 Ref. 64 sensors x 64 Units = 4,096 sensors that is sufficient for 2nd G ECoG BMI</td>
<td>0 Not expected multiple BANs overlaid</td>
</tr>
<tr>
<td><strong>Topology</strong></td>
<td>Extended star</td>
<td>Star + bus</td>
<td>Star (dynamic allocation of coordinator)</td>
<td>Star (2pairs)</td>
<td>Star + multi hop</td>
<td>Star + multiple hop or Star + mesh Due to relationship with smart BAN and smart M2M Two layered cluster tree (extended) star+one hop</td>
<td></td>
</tr>
<tr>
<td><strong>Data rate</strong></td>
<td>Comparable to CAN, RIM</td>
<td>2 Mbps/sensor</td>
<td>Up to several ten Mbps/camera/drone</td>
<td>Up to 1KHzx12 = 12kbps/sensor</td>
<td>Aggregate rate up to 2Mbps</td>
<td>2 Mbps For high QoS (priority) packets, 1Mbps while shorter back-off time or delay For low QoS packets, 2 Mbps or higher while permissible delay longer</td>
<td>1 Mbps for narrow Band 11 Mbps for UWB in max</td>
</tr>
</tbody>
</table>
## 5.2 Updated Technical Requirements (2/5)

<table>
<thead>
<tr>
<th>Aggregate data rate over interoperating networks</th>
<th>Car</th>
<th>Factory automation</th>
<th>UAV(Drone) Sensing &amp; Controlling</th>
<th>High Data Rate BAN (HRP)</th>
<th>Low Data Rate BAN (LRP)</th>
<th>Dependable BAN for Car Body as well as Human Body</th>
<th>Reference standard 802.15.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Few hundred Mbps</td>
<td>Few hundred Mbps</td>
<td>Up to 1 Gbps</td>
<td>Up to several Mbps/drone</td>
<td>50 Mbps</td>
<td>2 Mbps</td>
<td>6 hundred Mbps in case of 4 nits x 64 nodes/unit</td>
<td>N/A</td>
</tr>
<tr>
<td>Latency in normal operation</td>
<td>Comparabile to CAN, RIM or Flex Ray</td>
<td>250 ms to 1s</td>
<td>250 ms to 500 ms</td>
<td>Frame length 10-20 ms</td>
<td>Latency 10ms</td>
<td>10 ms to 20ms</td>
<td>Typical 50 to 100 ms Ref. 15.4e</td>
</tr>
<tr>
<td>Latency in critical situation</td>
<td>Comparabile to CAN, RIM or Flex Ray</td>
<td>Few ms to 15 ms *</td>
<td>Several 10 ms</td>
<td>5-10 ms</td>
<td>10 ms</td>
<td>100 ms</td>
<td>Less than typical case</td>
</tr>
<tr>
<td>Association delay</td>
<td>N/A</td>
<td>&lt; 1 s</td>
<td>&lt; 100ms</td>
<td>Same direction &lt; 30ms</td>
<td>&lt; 60 ms</td>
<td>&lt; 1 s</td>
<td>Less than 1s Optional requirement</td>
</tr>
<tr>
<td>Authentication and security delay</td>
<td>N/A</td>
<td>&lt; 1 s</td>
<td>N/A</td>
<td>Same direction &lt; 50ms</td>
<td>&lt; 100 ms</td>
<td>&lt; 1 s</td>
<td>Seconds Optional requirement</td>
</tr>
<tr>
<td>Delivery ratio requirement</td>
<td>&gt; 99.9%</td>
<td>&gt; 99%</td>
<td>&gt; 99.9%</td>
<td>&gt; 99.9%</td>
<td>&gt; 99%</td>
<td>&gt;95%</td>
<td>95%</td>
</tr>
</tbody>
</table>

### 5.2 Updated Technical Requirements (3/5)

<table>
<thead>
<tr>
<th></th>
<th>Car</th>
<th>Factory automation</th>
<th>UAV(Drone) Sensing &amp; Controlling</th>
<th>High Data Rate BAN (HRP)</th>
<th>Low Data Rate BAN (LRP)</th>
<th>Dependable BAN including Car Body as well as Human Body</th>
<th>Reference standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disconnection ratio (of time)</td>
<td>&lt; 0.01%</td>
<td>&lt; 0.01%</td>
<td>&lt; 0.001%</td>
<td>&lt; 0.01%</td>
<td>&lt; 2%</td>
<td>&lt; 1% to be considered use case of 2nd G ECoG BMI</td>
<td>?</td>
</tr>
<tr>
<td>Synchronization recovery time</td>
<td>&lt; 100 ms</td>
<td>&lt; 100 ms</td>
<td>&lt; 70 ms</td>
<td>&lt; 10 ms</td>
<td>N/A</td>
<td>&lt; 50 ms to be considered use case of 2nd G ECoG BMI</td>
<td>Seconds</td>
</tr>
<tr>
<td>Coverage range</td>
<td>6 m</td>
<td>5 m</td>
<td>100m (among drones) some km (with controller)</td>
<td>10cm</td>
<td>50cm</td>
<td>&lt; 10 m Much less coverage for 2nd G ECoG BMI</td>
<td>&lt; 10 m</td>
</tr>
<tr>
<td>Feedback loop response time</td>
<td>&lt; 10 ms</td>
<td>&lt; 1 s</td>
<td>&lt; 10 ms</td>
<td>&lt; 10 ms</td>
<td>&lt; 100ms</td>
<td>&lt; 50 ms Ref. to be considered use case of 2nd G ECoG BMI</td>
<td>&lt; 500 ms</td>
</tr>
<tr>
<td>Handover capability</td>
<td>N/A</td>
<td>&lt; 2 s</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Not defined</td>
</tr>
<tr>
<td>Data packet size</td>
<td>CAN &amp; RIM compatibility</td>
<td>10 to 1000 bytes</td>
<td>802.11 compatible</td>
<td>802.11 compatible</td>
<td>802.11 compatible</td>
<td>Up to 255 octets</td>
<td>Up to 255 octets</td>
</tr>
</tbody>
</table>
## 5.2 Updated Technical Requirements (4/5)

<table>
<thead>
<tr>
<th></th>
<th>Car</th>
<th>Factory automation</th>
<th>UAV(Drone) Sensing &amp; Controlling</th>
<th>High Data Rate BAN (HRP)</th>
<th>Low Data Rate BAN (LRP)</th>
<th>Dependable BAN including Car Body as well as Human Body</th>
<th>Reference standard 802.15.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jitter: typical max</td>
<td>5 ms</td>
<td>50 ms</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Dependent on Highest QoS</td>
<td>QoS dependent</td>
</tr>
<tr>
<td>Jitter: critical max: 5% outliers acceptable</td>
<td>5 ms</td>
<td>5 ms</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Dependent on Highest QoS</td>
<td>QoS dependent</td>
</tr>
<tr>
<td>Multi BAN Overlaid (A) Intra network interference</td>
<td>Driver/Passengers room: &lt;10</td>
<td>&lt;50 according to coverage range</td>
<td>&lt;10 according to no. of drones cluster</td>
<td>Single(2pairs) according to spacing between BANs</td>
<td>Up to 3 BANs according to covering range</td>
<td>&lt;64 Ref. to be considered use case of 2nd G ECoG BMI</td>
<td>By a few use case models, worst interference can be defined</td>
</tr>
<tr>
<td>Engine room: &lt;10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Different PANs (B) Inter network interference (number of coexisting networks)</td>
<td>Driver/Passengers room: &lt; 5</td>
<td>&lt;10 according to factory condition</td>
<td>&lt;5 according to no. of drones cluster</td>
<td>single Corresponding for interference mitigation technologies</td>
<td>Up to 3 PANS Corresponding to specification of coexisting PANs</td>
<td>&lt;10 Ref. to be considered use case of 2nd G ECoG BMI</td>
<td>By a few use case models, worst interference can be defined</td>
</tr>
</tbody>
</table>
## 5.2 Updated Technical Requirements (5/5)

<table>
<thead>
<tr>
<th>Channel model resilience</th>
<th>Car</th>
<th>Factory automation</th>
<th>UAV(Drone) Remote Sensing and Controlling</th>
<th>High Data Rate BAN (HRP)</th>
<th>Low Data Rate BAN (LRP)</th>
<th>Dependable BAN</th>
<th>Reference standard 802.15.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver/Passengers room:</td>
<td></td>
<td></td>
<td>Line of sight (LOS)</td>
<td></td>
<td></td>
<td></td>
<td>By a few use case models, worst interference can be defined</td>
</tr>
<tr>
<td>Light multipath</td>
<td></td>
<td></td>
<td>Dedicated short distance (DSRC) with line of sight (LOS)</td>
<td>No Line of sight (NLOS) with shadowing and multipath</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy multipath with</td>
<td></td>
<td></td>
<td>Compliance for safety guide line with SAR &amp; EMC</td>
<td>Compliance for safety guide line with SAR &amp; EMC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>shadowing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine room:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy multipath with</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>shadowing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

By a few use case models, worst interference can be defined.
5. Concluding Remark

- Corresponding request from ETSI smart BAN and smart M2M, IG-DEP and its successive SG15.6a have discussed to focus on internal car network for IoT/M2M connections that is focused on BAN for human and car bodies.
- As amendment of IEEE802.15.6, MAC for multiple BANs can be guaranteed to satisfy permissible delay or back-off time and throughput of high QoS packets for human and vehicle BANs while maintaining average performance.
- As amendment of IEEE802.15.6, PHY for UWB radios should be revised for updated UWB regulation. In particular, coexistence among different UWB radios of IEEE802.15 such as 15.4a, 15.4f, 15.4z can be supported. For instance, during CCA, types or features of these UWB radios can be analyzed to control access of packets from each radio.
- To include new use cases with enhanced dependability such as the 2nd Generation of ECoG for Brain-Machine-Interface(BMI), technical requirement has been updated to cover higher data rate and more units of ECoG sensors.
- We focus on amendment of IEEE802.15.6 for enhanced dependability in PHY and MAC and move on TG to complete the amendment.
- If you have any question and comment, you are welcome to discussion in SG15.6a and send content contributions to Ryuji Kohno <kohno@ynu.ac.jp> and Takumi Kobayashi <Kobayashi-takumich@ynu.ac.jp>