Abstract: This document summarizes standardization activity of IEEE802.15 Task Group(TG)6ma for revision of IEEE802.15.6-2012 Medical Body Area Network(BAN) corresponding to increasing for enhanced dependability in wireless sensing and controlling human and vehicle bodies for medical healthcare and automotive uses. After quick overview of IEEE802.15.6-2012, necessity of the revision 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 networks in some overlaid frequency band etc. Extension of BAN from human body for medical healthcare to car body for automotive uses and their combination makes a larger market and a new application in medical and automotive industries with a common standard.

Purpose: [information]

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Overview of Activity of IEEE 802.15 TG15.6ma for Revision of IEEE 802.15.6-2012 Wireless BAN with Enhanced Dependability

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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 Revision of BAN with Enhanced Dependability
4. Channel and Environment Models for Focused Use Cases for Revision of std 15.6-2012 for Human and Vehicle BANs with Enhanced Dependability TG16.6ma
5. Requirement for Revision of 15.6 MAC for Human and Vehicle BANs with Enhanced Dependability TG16.6ma
6. Available Technologies in PHY and MAC Layers for the Focused Use Cases for Revision of std 15.6-2012 for Human and Vehicle BANs with Enhanced Dependability TG16.6ma
7. Timeline of TG6ma
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:
  - Persistent chest pain
  - Blotches on skin
  - Decreased white blood cells
  - Kidney failure
  - Blood clotting
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
- Brain-Machine Interface (BMI)
- Pace Maker with ICD
- Wireless Capsule Endoscope

**Novel Concept**
Intelligent Network of Vital Sensors, eHR, Medical Robots etc.
1.4 BAN- Use Cases for Remote Medical Services

Medical support for developing countries

Satellite Link

Medical Data Server for Data Mining with Machine Learning

Satellite Networks

Big Data

Network Cloud

Internet

Cellular Network

Network Cloud

Medical Data Server for Data Mining with Machine Learning

Medical Center and General Hospitals

Data mining
1.5 BAN-base Universal Platform with Network Cloud, Data Mining Server for Medical Healthcare

Data mining or Analysis \textit{like Watson} → Data storage server; DBMS

Network cloud (5G. 6G) → Gateway → Hospital, Rehabilitation center, or Clinicians

Body Area Network (BAN) → Coordinator

Coordinator → Node

Node → physical assistant and surgery robots

Node → Elderly people

Node → Therapist, Nurses, Care givers
1.6 Universal Platform Based on BAN, Cloud Network, and AI Data Server for General Social Infrastructure beyond Medical Services
1.7 Extension of Use Cases of BAN beyond Medical Healthcare

- **Wearable BAN**
  - Tele-metering vital data
  - EEG, ECG, Blad Pressure, Temperature, MRI images, etc.
- **Implant BAN**
  - Tele-controlling implant devices
  - Pacemaker with IAD
  - UWB can solve such a problem that radio interferes with a human body and medical equipments
- **Dependable Network among vital sensors, actuators, robots**
- **Dependable BAN for Medical Healthcare**
- **Car Navigation & Collision Avoidance Radar**
- **Road to car networks**
- **Inter-vehicle networks**
- **Factory Automation (FA)**
  - Dependable Wireless Sensing & Controlling for Manufacturing (CIM)
- **Collision Avoidance Using inter-vehicle and roadside networks**
- **Dependable Wireless Networks for Transportation**
  - Car LAN & Wireless Harness
- **Inter-module wireless Networks**
- **Silicon Base**
- **Micor Machine Fablication**
- **Multi-layer BCB**
- **On Chip Antenna and Wireless Network in chio**
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

Data Collection and Analysis

Cloud Remote Monitoring Service

Without Clinical Staffs, health condition of COVID-19 patents can be monitoring and rescue them immediately.

Real-time remote monitoring and care

Family

Analyzed results for health condition

Integrated Data

Remote Therapy and mental care keeping distance

Analyzed results for health condition

Comman d for care of patients

Medical Care Center and Government Control Center

Dialog

Display

Data Input

BAN Coordinator

Environmental Data

Vital Sensors for SpO2, ECG, Temperature etc.

Smartphone, Tablet, Camera, Display, Microphone, Speaker


September 2023

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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
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]

K

u[k]

^\dot{x}[k]

Wireless channel

u[k]

Wireless channel

Bd

1/S

Ad

y[k]

x[k]

UAVs/Drones Model and Localizing System

For Remote Controlling UAVs

Navigation

Localization

By Using GNSS and Localization of UAVs/Drones

UAVs/Drones

Missing Victims

Rescue Team
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=XE8LiBjpm51aB4pH2CFt6MT6lALRPnIxPcac0RXhg=
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); IEEE 802.15.6

IEEE 802

IEEE 802.11 Wireless LAN
IEEE 802.15 Wireless PAN
IEEE 802.16 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

802.15.6 Wireless Medical BAN

September 2023
doc.: IEEE 802.15-23-0455-00-06ma

Slide 20
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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

Common MAC
(for all PHY)

• Beacon-base-TDMA
• Group Superframe
• Priority support
• Non-beacon mode

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 priority 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**: DAA After 2010
- **Europe**: DAA LDC, DAA
- **Japan**: DAA, DAA After 2013
- **Korea**: DAA LDC, DAA After 2010
- **USA**: 3.1G-4.8G (Low band), 6.0G-10.6G (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 7.25-9.00 GHz 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 Revision of BAN with Enhanced Dependability
3.1 Necessity for Enhanced Dependability in 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 interference 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)

Physical (PHY) layer 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. Channel and Environment Models for Focused Use Cases for Revision of std 15.6-2012 for Human and Vehicle BANs with Enhanced Dependability TG16.6ma
### 4.1 Channel models and scenarios in IEEE802.15.6ma

- **Path loss (Mandatory)
- Optional:
  - Fading (Small scale/large scale)
  - Shadowing

#### Specific use cases
- Implant to Body Surface for BCI
- Implant to External for BCI
- Body surface to body surface for BCI
- Body Surface to External for BCI
- Implant to body surface for capsule endoscopy

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Frequency Band</th>
<th>Channel Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>S2</td>
<td>Implant to Body Surface</td>
<td>402-405 MHz, 3.1-10.6 GHz UWB</td>
<td>CM2</td>
</tr>
<tr>
<td>S2.1</td>
<td>Implant (upper body) to Body Surface</td>
<td>3.1-10.6 GHz UWB</td>
<td>CM2.1</td>
</tr>
<tr>
<td>S2.2</td>
<td>Implant (head) to Body Surface</td>
<td>3.1-10.6 GHz UWB</td>
<td>CM2.2</td>
</tr>
<tr>
<td>S3</td>
<td>Implant to External</td>
<td>402-405 MHz, 3.1-10.6 GHz UWB</td>
<td>CM2</td>
</tr>
<tr>
<td>S4</td>
<td>Body Surface to Body Surface (LOS)</td>
<td>400, 600, 900 MHz, 2.4, 3.1-10.6 GHz</td>
<td>CM3</td>
</tr>
<tr>
<td>S4.1</td>
<td>Body Surface to Body Surface (LOS)</td>
<td>3.1-10.6 GHz CM4.1</td>
<td>CM4.1</td>
</tr>
<tr>
<td>S5</td>
<td>Body Surface to Body Surface (NLOS)</td>
<td>400, 600, 900 MHz, 2.4, 3.1-10.6 GHz</td>
<td>CM3</td>
</tr>
<tr>
<td>S6</td>
<td>Body Surface to External (LOS)</td>
<td>900 MHz 2.4, 3.1-10.6 GHz</td>
<td>CM4</td>
</tr>
<tr>
<td>S6.1</td>
<td>Body Surface (head) to External (LOS)</td>
<td>3.1-10.6 GHz</td>
<td>CM6.1</td>
</tr>
<tr>
<td>S7</td>
<td>Body Surface to External (NLOS)</td>
<td>900 MHz 2.4, 3.1-10.6 GHz</td>
<td>CM4</td>
</tr>
</tbody>
</table>
4.2 Brain-Machine-Interface (BMI): Wireless Body Area Network (BAN) with AI Machine-Learning and User-Interface

Brain-Computer-Interface (BCI) for Understanding Human Contention and Machine Control.
4.2 BMI with Wireless BAN with AI Machine-Learning and User-Interface

ECoG (Electrocorticogram) detected with implanted thousands of electrodes is transmitted in wireless by BAN with high capacity and dependability.

Brain-Machine-Interface (BMI) systems for Clinical Support to Disability such as autonomous robot hand control and communication assistance.
4.2 Channel models and scenarios in use case of BMI and BCI (Brain-Computer-Interface)

We will define what is BCI and BMI.

- Implant to Body Surface for BCI
- Body Surface to External on-body surface for BCI
- Implant to External for BCI

Specific use cases

<table>
<thead>
<tr>
<th>Use Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implant to Body Surface for BCI</td>
</tr>
<tr>
<td>Implant to External for BCI</td>
</tr>
<tr>
<td>Body surface to body surface for BCI</td>
</tr>
<tr>
<td>Body Surface to External for BCI</td>
</tr>
<tr>
<td>Implant to body surface for capsule endoscopy</td>
</tr>
</tbody>
</table>

Simulation and measured models of implant transmitters
4.3 Channel models and scenarios for capsule endoscopy

<table>
<thead>
<tr>
<th>Specific use cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implant(head) to on-body for BCI</td>
</tr>
<tr>
<td>Implant to External for BCI</td>
</tr>
<tr>
<td>Body surface to body surface for BCI</td>
</tr>
<tr>
<td>Body Surface to External for BCI</td>
</tr>
<tr>
<td><strong>Implant to body surface for capsule endoscopy</strong></td>
</tr>
</tbody>
</table>

Transceiver on body surface

Gastrointestinal tract

capsule endoscopy

Implant to Body Surface for Capsule Endoscopy
September 2023

4.4 Channel and Environmental models of VBAN

Common Standard of Dependable BAN IEEE802.15.6ma for human and car bodies makes a new market for both medical devices and automotive industries. For instance, autonomous car safety control for elderly divers’ driving failure to avoid accidents.
4.4 Use Case of Coexisting Multiple HBAN and VBAN

Nodes and coordinator are in cabin room

Geometrical configuration

Original channel models, common channel model to IEEE 802.15.4a and IEEE802.15.6-2012

Use case
- Entertainment for passengers
  - Nodes are in cabin room / coordinator is in cabin room.

<table>
<thead>
<tr>
<th>scenario</th>
<th>Sedan/RV / SUV with engine</th>
<th>Sedan/RV / SUV without engine</th>
<th>Bus</th>
<th>Cargo / pickup</th>
<th>Special purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1v</td>
<td>VBAN coordinator and VBAN coordinator</td>
<td>Case 3.1a</td>
<td>Case 3.1a</td>
<td>Same as 3.1a</td>
<td>---</td>
</tr>
<tr>
<td>8.1v h</td>
<td>VBAN coordinator and HBAN coordinator</td>
<td>Case 3.1b</td>
<td></td>
<td></td>
<td>---</td>
</tr>
</tbody>
</table>
4.4 Channel models and scenarios in IEEE802.15.6ma

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Frequency Band</th>
<th>Channel Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>S8</td>
<td>In-vehicle to In-vehicle (sedan)</td>
<td>2.4, 3.1-10.6 GHZ</td>
<td>CM8</td>
</tr>
<tr>
<td>S8.1</td>
<td>In-vehicle to In-vehicle (passenger bus)</td>
<td>2.4, 3.1-10.6 GHZ</td>
<td>CM8.1</td>
</tr>
<tr>
<td>S9</td>
<td>In-vehicle to On-vehicle</td>
<td>2.4, 3.1-10.6 GHZ</td>
<td>CM9</td>
</tr>
<tr>
<td>S10</td>
<td>In vehicle to External</td>
<td>2.4, 3.1-10.6 GHZ</td>
<td>CM10</td>
</tr>
<tr>
<td>S11</td>
<td>On-vehicle to on-vehicle (LOS)</td>
<td>2.4, 3.1-10.6 GHZ</td>
<td>CM11</td>
</tr>
<tr>
<td>S12</td>
<td>On-vehicle to on-vehicle (NLOS)</td>
<td>2.4, 3.1-10.6 GHZ</td>
<td>CM12</td>
</tr>
<tr>
<td>S13</td>
<td>On-vehicle to external (LOS)</td>
<td>2.4, 3.1-10.6 GHZ</td>
<td>CM13</td>
</tr>
<tr>
<td>S14</td>
<td>On-vehicle to external (NLOS)</td>
<td>2.4, 3.1-10.6 GHZ</td>
<td>CM14</td>
</tr>
</tbody>
</table>
4.5 Classification of Channel and Environment Models for Human and Vehicle Body Area Networks (HBAN&VBAN)

**Note:**

- **HBAN-model:**
  - Environment with co-existing systems is not considered.

- **VBAN model:**
  - Key-less entry system
  - Localization in-body, on-body
  - Most dominant model should be defined and separatory defined as Mandatory and Optional.
5. Requirement for Revision of 15.6 MAC for Human and Vehicle BANs with Enhanced Dependability TG15.6ma
5.1 Coexisting Models; Interference among BANs and other Networks

- There would be cases where BANs or BAN and other networks are spatially collapsed.

Case 1: BANs, using same frequency bands

Case 2: BAN and PAN, using same frequency bands
When introducing a new radio system, R&D of technologies to avoid interference among coexisting systems is mandatory by regulation and necessary in standard.

Particularly, cognitive sensing, measuring, modelling, and interference mitigation technologies must be a common subject among URSI commissions.

Case 3: BAN and other piconets such as cellular network or Wi-Fi, some part of their frequency bands are overlapped.

Case 4: Coexisting Passive Radio Receiver Systems such as RAS, EESS etc.
## 5.3 Definition of Coexistence Environment Classes

<table>
<thead>
<tr>
<th>Coexistence Class</th>
<th>Coexisting system(s)</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>802.15.6ma</td>
<td>802.15.6-2012</td>
</tr>
<tr>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1 (1a)</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>2 (1b)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>4 (2a)</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>5 (2b)</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>6 (2c)</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

- The coexistence class has been redefined to 8 levels, which can be represented by 3 bits and would be suitable to include in PHY or MAC headers.
5.4 TSN Possibility in WBAN 15.6ma

• 802.15.6 has BAN coordinator (hub) which can perform MAC bridge which connects two separate networks as 802.1 TSN (Time Sensitive Network).

• A coordinator connects to nodes in its own network.
  – Not only same nodes operate on the same PHY, but also different PHYs.

• The revision may enable a coordinator to connect to other coordinators, to avoid interference and enhance dependability.
  – Unlike wired network, wireless network shares same medium and collision occurs which plays significant role in dependability.
5.4 Possible bridging in 802.15.6ma

- BAN coordinator may relay frames to outer network as a MAC Bridge.
5.5 Coordinator to Coordinator Bridging

As a MAC Bridge, BAN coordinator may relay frames to outer network. Those frames can be from other BAN coordinator.
5.6 TSN equipment to infrastructure

- LLC
- 15.6ma MAC interface to TSN
- TSN procedures
- WiFi, 5G MAC interface to TSN
- LLC or equiv. for 5G
- WiFi, 5G MAC

Wire or wireless link
## 5.7 TSN in the 15.6ma protocol stack

<table>
<thead>
<tr>
<th>Layer</th>
<th>Application</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1</td>
<td>15.6ma PHY</td>
<td></td>
</tr>
<tr>
<td>Layer 2</td>
<td>15.6ma MAC</td>
<td></td>
</tr>
<tr>
<td>Layer 3</td>
<td>802.1 TSN interface</td>
<td>LLC layer</td>
</tr>
<tr>
<td>Layer 4</td>
<td>Proprietary/Other</td>
<td>TCP/UDP</td>
</tr>
<tr>
<td>Layer 5, 6, 7</td>
<td>Payload</td>
<td>Payload</td>
</tr>
</tbody>
</table>

- **Layer 1**: 15.6ma PHY
- **Layer 2**: 15.6ma MAC
- **Layer 3**: 802.1 TSN interface
- **Layer 4**: Proprietary/Other
- **Layer 5, 6, 7**: Payload
5.7 TSN switch

15.6ma should focus on the MAC layer

Fortunately, there is no conflict with 802.1 MAC addresses.
6. Available Technologies in PHY and MAC Layers for the Focused Use Cases for Revision of std 15.6-2012 for Human and Vehicle BANs with Enhanced Dependability TG16.6ma
6.1 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
6.2 Approach for Intra and Inter System Interference among BAN and Other PANs

– **Separate** 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*
6.3 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 \(MF_{2\sim\ldots\sim K-1}\) 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.**
6.4 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.

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

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

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

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

TDL-AA can work as interference canceller on both of time and space domains
6.5 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)

6.6 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)

6.7 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

What is interference at the MAC layer
Sensor nodes within the communication range try to transmit packets at the same timing, causing collisions, making it impossible to communicate correctly

---

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
6.8 QoS Levels of Packets corresponding to User Priority in IEEE802.15.6

- In Std.15.6 WBAN systems, a various data such as vital signs, skin temperature, blood pressure, ECG, EEG, ECoG, and vehicle controlling commons have different QoS levels corresponding to user priority.

- In 15.6ma for dependable WBAN for human and vehicles, data packet transmission should be dependable according to QoS levels even in various classes of coexistence environment.

- Therefore, appropriate sets of error controlling scheme with FEC and hybrid ARQ corresponding to QoS levels have been standardized in 15.6ma.

<table>
<thead>
<tr>
<th>User priority</th>
<th>Traffic designation</th>
<th>Frame type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Background (BK)</td>
<td>Data</td>
</tr>
<tr>
<td>1</td>
<td>Best effort (BE)</td>
<td>Data</td>
</tr>
<tr>
<td>2</td>
<td>Excellent effort (EE)</td>
<td>Data</td>
</tr>
<tr>
<td>3</td>
<td>Video (VI)</td>
<td>Data</td>
</tr>
<tr>
<td>4</td>
<td>Voice (VO)</td>
<td>Data</td>
</tr>
<tr>
<td>5</td>
<td>Medical data or network control</td>
<td>Data or management</td>
</tr>
<tr>
<td>6</td>
<td>High-priority medical data or network control</td>
<td>Data or management</td>
</tr>
<tr>
<td>7</td>
<td>Emergency or medical implant event report</td>
<td>Data</td>
</tr>
</tbody>
</table>
**6.9 Channel Coding Table #1**

<table>
<thead>
<tr>
<th>User priority</th>
<th>Inner code</th>
<th>Outer code</th>
<th>HARQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>15.4ab LDPC code (R=1/2)</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>15.4ab LDPC code (R=1/2)</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>15.4ab LDPC code (R=1/2)</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>15.4ab LDPC code (R=1/2)</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>15.4ab LDPC code (R=1/2)</td>
<td>(54, 46) shortened RS code</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>15.4ab LDPC code (R=1/2)</td>
<td>(54, 38) shortened RS code</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>15.4ab LDPC code (R=1/2)</td>
<td>(54, 28) shortened RS code</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>15.4ab LDPC code (R=1/2)</td>
<td>(54, 14) shortened RS code</td>
<td>-</td>
</tr>
</tbody>
</table>

- As an outer code, shortened Reed-Solomon (RS) codes with N=54 (original code length N=63) will be selected to correct burst errors due to interference from other WBANs and the coding rates are changed according to each QoS and channel condition.
- As an inner code, 15.4ab LDPC codes (K=324, 648, 972, R=1/2) will be selected for the coexistence of 15.6ma and 15.4ab.
- This updated concept table is considered as the first priority.

Common with IEEE802.15.4ab

Error-correcting codes corresponding to QoS levels

**User priority**  | **Inner code**                  | **Outer code**                        | **HARQ** |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>15.4ab LDPC code (R=1/2)</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>15.4ab LDPC code (R=1/2)</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>15.4ab LDPC code (R=1/2)</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>15.4ab LDPC code (R=1/2)</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>15.4ab LDPC code (R=1/2)</td>
<td>(54, 46) shortened RS code</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>15.4ab LDPC code (R=1/2)</td>
<td>(54, 38) shortened RS code</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>15.4ab LDPC code (R=1/2)</td>
<td>(54, 28) shortened RS code</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>15.4ab LDPC code (R=1/2)</td>
<td>(54, 14) shortened RS code</td>
<td>-</td>
</tr>
</tbody>
</table>
Evaluation of Channel Codes Assigned Corresponding to Different QoS Priority Levels

Bit error ratio of (54,46), (54,38), (54,28), (54,14) shortened RS codes and no encoding were evaluated under an AWGN channel and BPSK modulation.

Performances were improved as the coding rate decreased.

LDPC simulator is currently checked and will be combined with the RS simulator.
## 6.9 Channel Coding Table #2

### User priority | Inner code | Outer code | HARQ
--- | --- | --- | ---
0 | - | 15.4ab LDPC code (R=1/2) | -
1 | - | 15.4ab LDPC code (R=1/2) | -
2 | - | 15.4ab LDPC code (R=1/2) | -
3 | - | 15.4ab LDPC code (R=1/2) | -
4 | 15.4a/z based convolutional code, R=4/5 | 15.4ab LDPC code (R=1/2) | ✓
5 | 15.4a/z based convolutional code, R=2/3 | 15.4ab LDPC code (R=1/2) | ✓
6 | 15.4a/z convolutional code, R=1/2 | 15.4ab LDPC code (R=1/2) | ✓
7 | 15.4a/z based convolutional code, R=1/4 | 15.4ab LDPC code (R=1/2) | ✓

- As an outer code, 15.4ab LDPC (K=324, 648, 972, R=1/2) codes will be selected for the coexistence of 15.6ma and 15.4ab.
- As an inner code, 15.4a/z based convolutional codes (which are almost the same of our proposed decomposable codes) will be selected, and the coding rates are changed according to each QoS and channel condition, which can be applied to hybrid ARQ.
- This table is considered as the second choice.
### 6.10 Specification of Error-Control Defined Corresponding Combination of 8 QoS Levels and 8 Coexistence Classes

<table>
<thead>
<tr>
<th>Coexistence Class</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>QoS Level</td>
<td>BCC</td>
<td>BCC+E</td>
<td>BCC+E</td>
<td>BCC+E</td>
<td>BCC+E</td>
<td>HARQ</td>
<td>HARQ</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>BCC</td>
<td>BCC+E</td>
<td>BCC+E</td>
<td>BCC+E</td>
<td>HARQ</td>
<td>HARQ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>BCC</td>
<td>BCC+E</td>
<td>BCC+E</td>
<td>BCC+E</td>
<td>HARQ</td>
<td>HARQ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>BCC</td>
<td>BCC+E</td>
<td>BCC+E</td>
<td>BCC+E</td>
<td>HARQ</td>
<td>HARQ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>BCC</td>
<td>BCC+E</td>
<td>BCC+E</td>
<td>BCC+E</td>
<td>HARQ</td>
<td>HARQ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>BCC</td>
<td>BCC+E</td>
<td>BCC+E</td>
<td>BCC+E</td>
<td>HARQ</td>
<td>HARQ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>BCC</td>
<td>BCC+E</td>
<td>BCC+E</td>
<td>BCC+E</td>
<td>HARQ/IM</td>
<td>HARQ/IM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>CFP/HARQ</td>
<td>CFP/HARQ</td>
<td>CFP/HARQ</td>
<td>CFP/HARQ</td>
<td>CFP/HARQ</td>
<td>CFP/HARQ</td>
<td>HARQ/IM</td>
<td>HARQ/IM</td>
</tr>
<tr>
<td>7</td>
<td>CFP/HARQ</td>
<td>CFP/HARQ</td>
<td>CFP/HARQ</td>
<td>CFP/HARQ</td>
<td>CFP/HARQ</td>
<td>CFP/HARQ</td>
<td>HARQ/IM</td>
<td>HARQ/IM</td>
</tr>
</tbody>
</table>
6.11 Dependable MAC for IEEE802.15.6ma

- To enhance dependability in MAC layer, IEEE802.15.6 has applied a **hybrid contention free and contention access MAC protocol** in which high QoS level of packets have transmit without delay in **contention free period (CFP)** while low QoS level of packets with permissible delay in **contention access period (CAP)**.

![Diagram of superframe]

- May obtain contended allocation for highest priority

**EAP**: exclusive access phase
**RAP**: random access phase
**MAP**: managed access phase
**CAP**: contention access phase (e.g. CSMA/CD, ALOHA)

**Contention Free Period (CFP)**, e.g. TDMA
7. Timeline of TG15.6ma
TG 6ma Timeline

- Tech Req Doc(TRD) - July 2022
- Presentaton of proposals - Nov 2022, Jan 2023
- Std Draft - V0 - May 2023
- WG pre-ballot - Sept 2023
- WG letter ballot (LB) - Jan. 2024
- SB recirculation - May 2024
- Revcom Submission - June 2024

- TRD, CMD Call Proposals - Sept 2022
- Harmonization of Proposals - Mar 2023
- Finish integration of technical proposals. Draft v1 - July 2023
- Comments and resolution for pre-ballot. - Nov 2023
- EC approval to SB, SB submission - Mar 2024
- SB recirculation if required - Jun 2024
- Revcom Approval - Jul 2024

Notes: SASB/RevCom scheduled for 2024 a guess
## Timeline details.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Deadline</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Requirements Document (TRD). Channel Model Document (CMD). Call for Proposals.</td>
<td>Sept. 2022</td>
<td>TRD describes the technical requirements baseline for the evaluation of proposals. The CMD contains the channel models for different use cases targeted by the Std. Announcement of call for proposals.</td>
</tr>
<tr>
<td>Due day for proposals</td>
<td>March 10th, 2023</td>
<td>Postponed from January 2023</td>
</tr>
<tr>
<td>Presentation of proposals</td>
<td>Nov. 2022, January, March 2023</td>
<td>Start of discussions for harmonization of proposals.</td>
</tr>
<tr>
<td>Harmonization of Proposals</td>
<td>March 2023</td>
<td>Agreements on key technologies.</td>
</tr>
<tr>
<td>Std Draft v.0</td>
<td>May 2023</td>
<td>Mostly editorial revisions and start integrating text of agreed proposals.</td>
</tr>
<tr>
<td>Std Draft v. 1</td>
<td>July 2023</td>
<td>Finish integration of technical proposals.</td>
</tr>
<tr>
<td>Std Draft v. 1 recirculation</td>
<td>August 2023</td>
<td>TG approval</td>
</tr>
<tr>
<td>WG pre-ballot</td>
<td>September 2023</td>
<td>WG pre-ballot submission.</td>
</tr>
<tr>
<td>Comments and resolution for pre-ballot.</td>
<td>November 2023</td>
<td>Finish resolutions to pre-ballot comments and recirculation.</td>
</tr>
<tr>
<td>WG letter ballot (LB)</td>
<td>January 2024</td>
<td>LB submission</td>
</tr>
<tr>
<td>LB recirculation</td>
<td>January 2024</td>
<td>Comment-resolutions to LB recirculation</td>
</tr>
<tr>
<td>Conditional approval for Sponsor Ballot (SB)</td>
<td>January 2024</td>
<td>Seek conditional approval</td>
</tr>
<tr>
<td>Final LB recirculation. EC approval</td>
<td>March 2024</td>
<td>Just before the March meeting.</td>
</tr>
<tr>
<td>EC approval to SB</td>
<td>March 2024</td>
<td></td>
</tr>
<tr>
<td>SB submission</td>
<td>March 2024</td>
<td></td>
</tr>
<tr>
<td>SB recirculation</td>
<td>May 2024</td>
<td>Resolutions to SB.</td>
</tr>
<tr>
<td>Conditional/unconditional approval to RevCom</td>
<td>May 2024</td>
<td>Submission to SASB agenda</td>
</tr>
<tr>
<td>SB recirculation if required</td>
<td>June 2024</td>
<td></td>
</tr>
<tr>
<td>RevCom submission</td>
<td>June 2024</td>
<td>RevCom approval</td>
</tr>
</tbody>
</table>

Note: the deadlines are subject to change.
8. 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 a revision 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 a revision 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, 4f, 4z, 4ab 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 a revision of IEEE802.15.6 for enhanced dependability in PHY and MAC, established and will complete the revision IEEE802.15.6ma. About an year later. If you have any question and comment, you are welcome to discussion in TG15.6ma and send content contributions to Ryuji Kohno <kohno@ynu.ac.jp>
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• Thank You!

• Any Questions?