Channel Modeling Activities of International Standardization on IEEE 802.15 TG6ma for Human and Vehicle Body Area Networks

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***Abstract*—As an international standard for the short-range wireless communication and body area network, IEEE 802.15.6 has been standardized in 2012. Body area networks (BAN) is targeting higher dependability of the wireless network such as lower error late and less latency. Currently, authors are promoting to make a revision of original 802.15.6-2012 in Task Group 15.6ma. In this revision, BAN is extended into several additional application such as brain-machine interface and vehicle body area networks (VBAN) including new MAC proposals. In order to evaluate the performance of proposals, channel models correspond to these new use cases are required. In this paper, channel modeling activities on this revision TG6ma are introduced.**

Keywords—International Standardization, IEEE802.15.6, Body Area Network, Channel Model

I. Background

Original International standard IEEE802.15.6-2012[1] has been developed in 2012 for body area networks (BAN). This standard mainly focused on dependable wireless communication for life critical applications such as medical applications.

IEEE802.15.6 defines 3 different physical layer (PHY) modulation method as

- Ultra-Wide Band (UWB) PHY,
- Narrow band (NB) PHY,
- Human Body Communication (HBC) PHY.

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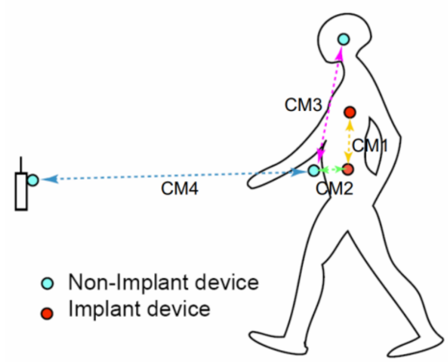


Fig. 1. Original IEEE802.15.6 Channel models[2].

From the point of view of dependable wireless communication, UWB-PHY can achieves lower error rate, lower latency, secure and robust communication than the other PHY modulation scheme.

To evaluate the performance of the systems, channel models of IEEE802.15.6 has been defined in channel model document [2] as shown in Fig. 1 and TABLE I.

Original IEEE802.15.6 has passed more than 10 years since it was developed. Since that was established, a lot of new applications requires more higher dependability than the other wireless systems such as WiFi and Bluetooth. Then, new standard of BAN with enhanced dependability using UWB communication is expected from medical, industrial and academic applications. The revision activity of IEEE802.15.6 has been started to achieve enhanced dependability and more wider applicability for the other use cases than the original IEEE802.15.6. Task Group 15.6ma (TG6ma) is a task group to make a revision of original standard.

TABLE I. ORIGINAL IEEE802.15.6 CHANNEL MODELS[2].

Scenario	Description	Frequency Band	Channel Model
S1	Implant to Implant	402-405 MHz	CM1
S2	Implant to Body Surface	402-405 MHz	CM2
S3	Implant to External	402-405 MHz	CM2
S4	Body Surface to Body Surface (LOS)	13.5, 50, 400, 600, 900 MHz 2.4, 3.1-10.6 GHz	CM3
S5	Body Surface to Body Surface (NLOS)	13.5, 50, 400, 600, 900 MHz 2.4, 3.1-10.6 GHZ	CM3
S6	Body Surface to External (LOS)	900 MHz 2.4, 3.1-10.6 GHZ	CM4
S7	Body Surface to External (NLOS)	900 MHz 2.4, 3.1-10.6 GHZ	CM4

From scientific point of view, channel models for UWB communication in frequency range of 3.2 to 10.6GHz which is defined in original IEEE802.15.6 has been provided by based on measurements[3],[4]. However, most of UWB channel modeling is focused on devices on human-body and indoor environment. Moreover, the other international standard such as IEEE802.15.4a and IEEE802.15.4ab also using UWB as PHY of them, nevertheless, these standards and channel models are not targeting vehicle environment and implanted applications. Thus, channel models for new applications of TG6ma such as vehicle application and implanted devices have scientific novelty as well as importance from the view point of industry. In this paper, TG6ma channel models for UWB communication in/around vehicle environment and implanted devices for BCI/BMI application are introduced.

II. CONCEPT OF REVISION ACTIVITY

Main purpose of the revision in TG6ma is development of revision of IEEE802.15.6. This revision including extension of target use cases and applications. Original IEEE802.15.6 focused only wireless communication in/on/around human body, and its main application is medical, healthcare, and the other applications which is required high dependability. However, in this revision, we are proposing several applications additionally.

Recently, brain-machine interface (BMI), brain-computer interface (BCI) technology are made advance. Especially, wireless implanted devices to get Electrocorticography (ECoG) or on-body devices to get electroencephalography (EEG) have been developed and expected to be put to practical use. In addition, capsule endoscopy devices also developed widely. These medical application needs to transmit detected biomedical data wirelessly. However, general consumer based wireless such as Bluetooth cannot cover required data rate and dependability.

In addition, as well known, most of recent vehicle, cars are controlled electrically and huge number of sensors are on the vehicle body. Mostly these actuator, sensors and controllers are connected by wired connection. From the point of view of ecology and environmental protection, weight of the cables to connect them cannot be ignored. Also car security application such as keyless entry system needs more secure wireless connection to protect from criminal jamming and intercept such as relay attacks. As mentioned above, car and vehicle systems requires secure and dependable wireless communication system. From these reasons, TG6ma discussing to extend the international standard to vehicle application as vehicle body area network (VBAN) as well as human BAN (HBAN) based on UWB PHY technology.

III. NEW TARGET USE CASES OF THE REVISION

A. *Capsule endoscopy*

1) Scenario 2.1: Implant to body surface(upper body) model

In the capsule endoscopy use cases, wireless communication from the capsule endoscopy device in gastrointestinal tract to body surface is required (Fig. 2). In order to achieve more higher data-rate transmission with higher dependability, UWB communication is expected to use to the application of capsule endoscopy. However, original standard IEEE802.15.6 channel model has been provided "implant to body-surface" model only for 402-405 MHz narrow band. Hence, in TG6ma, we consider to define a new channel models for implant to body-surface (upper body) as scenario 2.1(S2.1) and channel mode 2.1 (CM2.1) as shown in Fig. 2.

B. *Brain-Computer/Machine Interfaces*

Brain computer interface or brain machine interfaces (BMI/BCI) is a technology to connect brain and computer or machines directry to control the machines by signals from brain. These technologies achieve more seamless control of artificial arm, hand and legs as well as the other actuators. Additionally, BMI/BCI can be used for the feed back from the sensors to brain as well. For the BMI/BCI applications,

EEG which is detected from the surface of head skin is widely used because EEG can be measured non-invasively. However, EEG measurement has difficulty to detect clear electric signal from the brain because the electric signal is quite weak and the signal is attenuated by the biological tissues in between brain and EEG electrode such as skull bone and skin.

In contrast, ECoG is measured by the electrode which is located on the surface of the brain[7]. Although ECoG needs invasive operation to put the sensor electrodes on the brain, ECoG can measure electric signal from brain clearly with higher signal / noise ratio (SNR). Recently, BMI/BCI system using ECoG detected multiple sensor electrodes array has been studied[8].

BCI/BMI application using EEG or ECoG need to measure the electric signal by enough high resolution and sampling speed. Especially ECoG using multiple electrodes needs to transmit

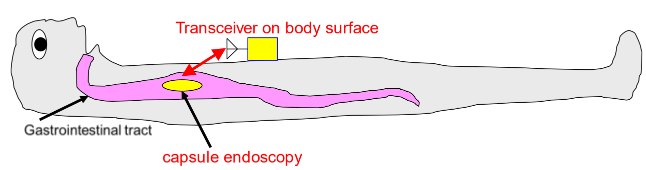


Fig. 2. Implant to body surface (upper body) model for UWB.

more than 50Mbps data. In order to transmit such a large number of signal, conventional narrow-band wireless cannot be applicable due to insufficient of bandwidth.

According to the requests from industrial, medical and academic to make an solution to wireless connection for the BMI/BCI as mentioned before, TG6ma, we considering to provide a solution of wireless transmission for the BMI/BCI as a new use-case.

As shown in TABLE I. channel models for implant device and device on body surface are provided in original IEEE802.15.6 channel models document[2]. However these already provided channel models are not calculated or simulated about the head part of the body. Biomedical tissues around head and the other part are totally different and electric characteristics as well. Then, TG6ma discussed and considered to add and define new scenarios and channel models for BMI/BCI applications in UWB frequency band BAN as follows.

1) Scenario 2.2: Implant(head) to on-body model

When ECoG is used for the BMI/BCI applications, sensing electrodes is put under the skin of head. From the point of view of to prevent the infection, all the components (electrodes, antennas and transmitter) are better to put inside the skin in ideal(Fig. 3). In such case, detected ECoG should be transmit to outside of the body wirelessly. Original IEEE802.15.5 channel model does not have channel models for the in head and head surface environment. Hence, in TG6ma, we consider to define a new channel model for implant to body-surface (head) as S2.2 and CM2.2 (Fig. 4).

2) Scenario 2.3: Implant(head) to external model

Another configuration of BMI/BCI use-case based on ECoG is an environment that transmitter is implanted in head and the receiver or BAN coordinator is at external. By this configuration, ECoG data can be transmitted to the off-body coordinator directry. For the future scalability, we consider to define a new channel model for implant to external as S2.3 and CM2.3 (Fig. 5).

3) Scenario6.1: On-body(head) to external model

When EEG is used for the BMI/BCI applications, electrodes are placed on the surface of head. In such a situation, if electrodes and signal detector or amplifier are connected by wire, a lot of wires are needed. From the view point of usability, wireless connection between EEG electrodes and computer is required. BAN based on UWB can be applicable such a use-case by its ultra-wide bandwidth and data transmission capacity. Hence, TG6ma, consider to define a new channel model for body surface (head) to external for UWB as S2.2 and CM2.2 (Fig. 6).

4) Coordinator to coordinator model

As a new use-cases, TG6ma discussing a situation that more than two HBAN users exist closely. In this case, HBAN coverage range are overlap and each coordinator or devices can connect each other. At the same time, each devices in different BAN could be interfered from the other device. From the view point of coordinator to coordinator link and co-existence view point, TG6ma consider to define a new channel model for body-surface to the other body surface model as S2.3 and CM2.3 (Fig. 7).

C. Vehicle applications

In TG6ma, as an extension of application using enhanced dependable BAN, we are considering to use BAN to vehicle

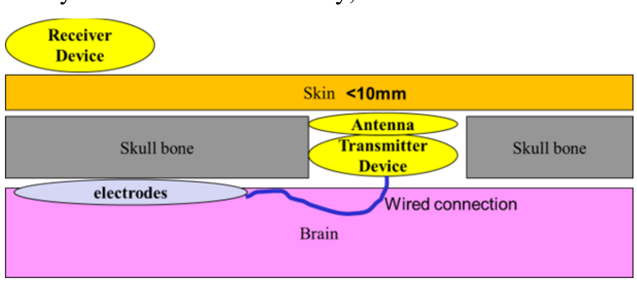
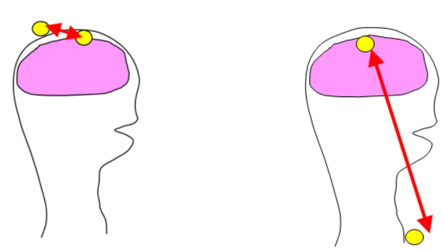


Fig. 3. An example of ECoG implanted devices configulation.



(a) head to body surface (head) (b) head to body surface (arm)

Fig. 4. Implant (head) to body surface models for UWB.

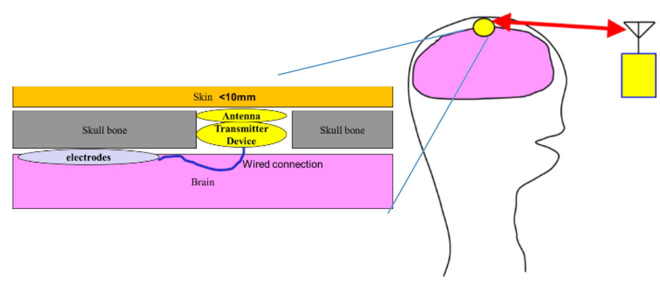


Fig. 6. Implant (head) to external model for UWB

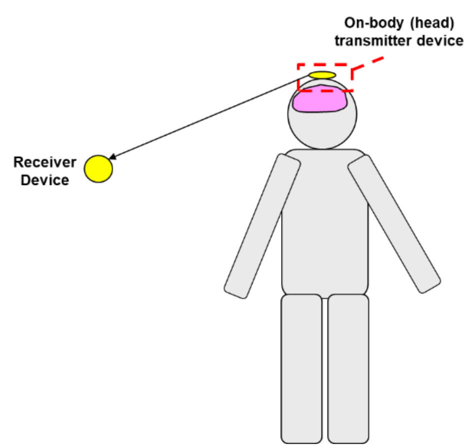


Fig. 5. Body surface (head) to external model for UWB.

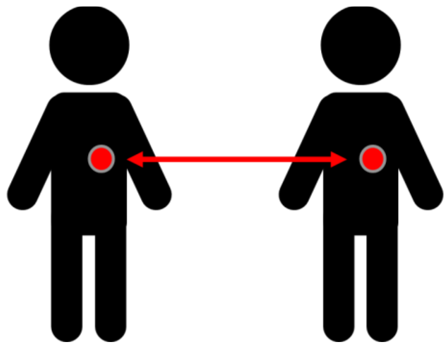


Fig. 7. On-body to on-body (the other body) model.

applications. Based on the higher dependability, extremely low error late, and low latency of BAN can cover the requirement of

life critical vehicle applications such as vehicle control, collision avoidance and vehicle security.

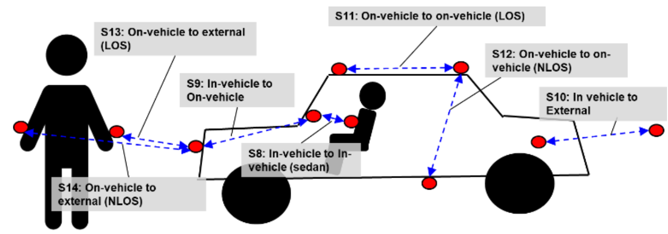
1) Pessenger vehicle models

For the VBAN applications, we discussed several typical use-cases for vehicle applications. From the discussions, TG6ma suppose following use-cases as typical applications using VBAN[12].

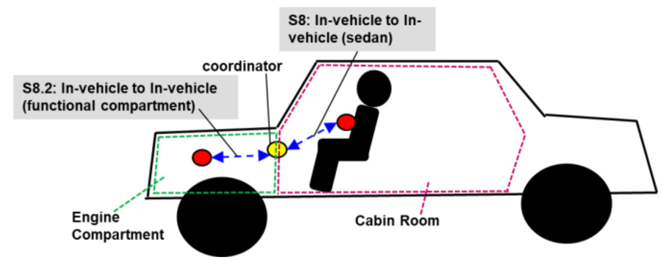
- Failure and deterioration detection of vehicle components.
  - Nodes are in engine compartment / coordinator is in engine compartment
- Sensing for safety driving support / Collision avoidance
  - Nodes are on outside surface of vehicle / coordinator is in engine compartment
- Entertainment for passengers
  - Nodes are in cabin / coordinator is in cabin.
- Key-less entry system
  - Node is around user outside of vehicle / coordinator is in engine compartment
- Communication between user on pedestrian and vehicle
  - Node is around user outside of vehicle / coordinator is on outside surface of vehicle (vehicle moves at walking speed (<5km/h))
- Vehicle controlling / Wireless herness
  - Coordinator and nodes are in between cabin and chassis of vehicle.
- Driver's health problem detection
  - Coordinator in engine compartment / nodes are on human (driver) body.
- Driver's and passenger's healthcare application
  - Nodes and coordinator are on human body.

Based on the discussion about use-cases as mentioned above in TG6ma, TG6ma is considering following new scenarios and channel models (Fig. 8 (a)).

- S8 In-vehicle to In-vehicle (sedan)
- S8.1 In-vehicle to In-vehicle (passenger bus)
- S8.2 In-vehicle to In-vehicle (functional compartment)
- S9 In-vehicle to On-vehicle
- S10 In vehicle to External



(a) Geometrical overview of scenarios S.8 – S.14



(b) Scenario S8.2 for Functional compartment model

Fig. 8. Channel models for VBAN for passengers vehicle.

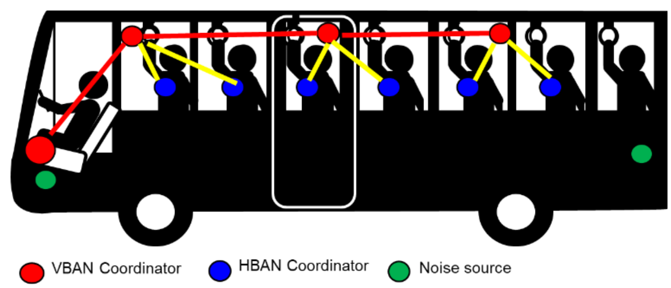


Fig. 9. Multiple passengers vehicle (bus) model (Scenario S8.1).

- S11 On-vehicle to on-vehicle (LOS)
- S12 On-vehicle to on-vehicle (NLOS)
- S13 On-vehicle to external (LOS)
- S14 On-vehicle to external (NLOS)

2) Scenario 8.1: In-vehicle model for bus

TG6ma considers VBAN as an extension of HBAN for vehicles not only passenger car like sedan but also large vehicle like cargo and bus vehicles. For bus use-cases, TG6ma considers situation that multiple BAN users are in the same bus. This channel model has been defined as S8.1 and CM8.1 (Fig. 9).

3) Scenario 8.2: In-vehicle to in-vehicle (functional compartment) model

In the functional compartment of vehicle such as engine compartment or electric motor compartment for electric vehicle (EV) is totally different condition from the view point of radio propagation and electro-magnetic interference (EMI) or electro-magnetic compatibility (EMC). To apply VBAN in such condition, TG6ma consider defining a new scenarios and channel model as S8.2 and CM8.2 (Fig. 8 (b)).

TABLE II. HBAN SCENARIOS AND CHANNEL MODELS (TANTATIVE).

Scenario	Description	Frequency Band	Channel Model
S1	Implant to Implant	402-405 MHz,	CM1
S2	Implant to Body Surface	402-405 MHz,	CM2
S2.1	Implant (upper body) to Body Surface	3.1-10.6 GHz	CM2.1
S2.2	Implant (head) to Body Surface	3.1-10.6 GHz	CM2.2
S3	Implant to External	402-405 MHz, 3.1-10.6 GHz UWB	CM2
S4	Body Surface to Body Surface (LOS)	400, 600, 900 MHz 2.4, 3.1-10.6 GHz	CM3
S4.1	Body Surface to Body Surface (LOS)	3.1-10.6 GHz	CM4.1
S5	Body Surface to Body Surface (NLOS)	400, 600, 900 MHz 2.4, 3.1-10.6 GHz	CM3
S6	Body Surface to External (LOS)	900 MHz 2.4, 3.1-10.6 GHz	CM4
S6.1	Body Surface (head) to External (LOS)	3.1-10.6 GHz	CM6.1
S6.2	BAN Coordinator to BAN coordinator	3.1-10.6 GHz	CM6.2
S7	Body Surface to External (NLOS)	900 MHz 2.4, 3.1-10.6 GHz	CM7

IV. NEW CHANNEL MODEL DEFINITIONS (TENTATIVE)

As we mentioned above, TG6ma is considering to add several new scenarios and channel models for new use-cases and application of BANs. As a summary of tentative channel model document has been proposed as shown in TABLE II. and TABLE III. [11].

V. CONCLUDING REMARKS

In this paper, we described about standardization activities of TG6ma which is a revision of IEEE802.15.6-2012. As an extension of body area network applications, BMC/BCI applications and vehicle BAN applications have been described and channel models and scenarios correspond to these new use-cases have been described.

As future works, TG6ma will continuously consider about these new channel models and scenarios. In near future, the numerical models for new scenarios will be provided.

TABLE III. VBAN SCENARIOS AND CHANNEL MODELS (TANTATIVE).

Scenario	Description	Frequency Band	Channel Model
S8	In-vehicle to In-vehicle (sedan)	2.4, 3.1-10.6 GHZ	CM8
S8.1	In-vehicle to In-vehicle (passenger bus)	2.4, 3.1-10.6 GHZ	CM8.1
S8.2	In-vehicle to In-vehicle (functional compartment)	2.4, 3.1-10.6 GHZ	CM8.2
S9	In-vehicle to On-vehicle	2.4, 3.1-10.6 GHZ	CM9
S10	In vehicle to External	2.4, 3.1-10.6 GHZ	CM10
S11	On-vehicle to on-vehicle (LOS)	2.4, 3.1-10.6 GHZ	CM11
S12	On-vehicle to on-vehicle (NLOS)	2.4, 3.1-10.6 GHZ	CM12
S13	On-vehicle to external (LOS)	2.4, 3.1-10.6 GHZ	CM13
S14	On-vehicle to external (NLOS)	2.4, 3.1-10.6 GHZ	CM14

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