New Revision of IEEE 802.15.6 Wireless Body Area Networks

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***Abstract*—Body Area Networks (BANs) is an active field of research and development because it offers the potential of significant improvement in the delivery and monitoring of healthcare, especially for senior people or patients with chronic conditions monitored at home.**

Other applications may include tracking the performance of athletes, and recently the potential integration to vehicles aided by Time Sensitive Networking (TSN) to deliver high-performance communication flows to 5G and Wi-Fi networks.

The standard IEEE 802.15.6™−2012 Wireless BANs aimed to solve the former issues. To address the latter, an amendment to such a standard is currently developed by the Task Group IEEE 802.15.6a. This amendment enhances the Ultra-Wideband (UWB) physical layer (PHY) and medium access control (MAC) to support dependability to human body area networks (HBAN) and adds support for vehicle body area networks (VBAN). VBAN operates under strict compliance to standards and limits for electromagnetic interference (EMI) from the vehicle's electric and electronic systems.

***Index Terms*—Body Area Networks, Vehicle, Area Networks, IEEE 802.15.6**

I. Introduction

The IEEE Std 802.15.6™−2012 Wireless Body Area Networks has completed a full life cycle and requires to be revised for another life cycle. Such procedure opens the entire Std for revision, meaning PHY and MAC technologies may be updated, deprecated or amended as the case may be.

The standard IEEE 802.15.62012 Wireless BANs was conceived to solve use cases related to Human Body Area Networks (HBAN). A proposed amendment is to support higher reliability in HBANs, extending the support for vehicle area networks (VBAN) and interaction with infrastructure.

Such revision is currently under development by the Task Group IEEE 802.15.6ma. The areas of enhancement include:

- operation and protection against interference from other BANs (intra-interference) or other wireless systems (inter-interference) operating in the UWB band.
- A simple and more reliable MAC protocol compared to IEEE 802.15.6-2012.
- Support for vehicle body area networks (VBAN), while complying with standardized limits for electromagnetic interference (EMI).
- Support for infrastructure protocols via a service access point to support better performance with interoperability to infrastructure such as Wi-Fi, 5G/6G APs. A potential solution is to incorporate Time-Sensitive Networking (TSN) protocols.

The purpose of the revision IEEE 802.15.6ma is to provide an international standard for short-range, low power, and highly reliable wireless communication for use in proximity to, or inside, a human body and a vehicle body. Technical features offer to satisfy an evolutionary set of entertainment, health care services and vehicle's wireless harness.

II. IEEE 802.15.6™−2012 in a Nutshell

The objective of IEEE 802.15.6-2012 Std is to provide an international standard for short-range, low-power, and reliable wireless communication for use in close proximity to, or inside, a human body. Such standard considers three PHYs and a common MAC with two modes.

- A narrowband PHY covers on-body BANs and in-body BANs (implant).
- A wideband PHY covers on-body BANs in the UWB band.
- A special case is Human Body Communications (UBC) as the communication link does not employ a radio wave, but rather an electromagnetic wave propagating through the skin.
- The MAC combines TDMA and polling (on-body communications) in one mode and polling and handshake (in-body communications) in another mode.

The network topology is a star with support for one-hop. In the first generation of BANs, nodes are sensors around or inside the human body, with a wireless interface for communication with a coordinator. Such coordinator could be placed on the body such as the waist or nearby a human body at a distance of up to 3m.

III. A case for enhanced dependability for IEEE 802.15.6-2012 Std

As the use of personal devices and gadgets in modern societies increases, BANs must coexist with other wireless systems operating in the UWB band. IEEE 802.15.6-2012 was not designed to cope with a plurality of devices and congested environments. It is necessary to introduce mechanisms to mitigate interference and performance degradation.

The new case of coexistence with other wireless systems includes other UWB systems and narrowband devices operating in the UWB band. For enhanced dependability, new mechanisms in the UWB PHY and MAC of IEEE 802.15.6-2012 must be introduced.

In addition, new use-cases appeared throughout the years. Such as wireless interfaces in vehicles, autonomous vehicles, not just infotainment, but control of sensors around a vehicle, integration to human BANs and infrastructure to offer stable and dependable communication flows via 5G for example.

IV. Vehicle Area Networks

1) Coexistence with multiple BANs: IEEE 802.15.6-2012 Std was not designed to manage interference among overlaid BANs operating nearby. The denser the number of BAN devices, the more collisions and inference cause performance degradation. Hence, amendment 15.6a aims to resolve these issues.
2) Coexistence with other radios: Changes in the regulation of the UWB band, other wireless systems were allowed to operate. More significantly, Wi-Fi and Cellular systems. Hence, 15.6a should upgrade mechanisms for interference mitigation and coexistence with other wireless systems.
3) Sensing and controlling loop Remote medical diagnosis, vital signs sensing, therapy and control actuators, and robotics need more dependable and efficient radio interfaces via BAN.
4) Usability in new vehicle use cases: The BAN paradigm extends to land vehicles. Indeed, BAN is specifically designed for vehicles with sensors and actuators in the vehicles' cabin, engine compartment, trunk. The idea is to interact with an HBAN to monitor vital signs and other health indicators in the vehicle's control system. Hence, HBAN is another input to vehicle control for navigation, cruise control, and emergency situations. Moreover, VBAN provides a hub for the connection to other networks such as Wi-Fi or Cellular with the possibility to connect Time-Sensitive Networking domains to support highly dependable communication flows.
5) The idea of interacting with an HBAN is to monitor vital signs and other health indicators in the vehicles control system. Hence, HBAN is another input to vehicle control for navigation, cruise control, and emergencies.
6) New business opportunities by the adoption of wireless technologies to vehicles like a smart-key, wireless harness, infotainment, monitoring drivers health conditions, to name a few.

V. Computer Brain Interface

Brain-computer interface (BCI) acquires brain signals, analyze them, and translate them into commands relayed to devices and actuators that carry out desired actions. BCI was originally conceived to replace neuromuscular disorders in disabled people. However, BCI has the potential to be a key element in virtual and augmented reality applications.

Indeed, until recently, the dream of controlling one's environment through thoughts had been in the realm of science fiction. However, the advance of technology has brought a new reality. We can use the electrical signals from brain activity to interact with the user's environment. CBI interface requires collecting signals from the brain; sending them to a control unit from which those are transmitted wirelessly to an Access Point (AP). Such AP supports a 15.6a interface. The reason to use UWB signaling in such an interface is the requirement to use a 64 Mb/s information data rate to support the BCI interface from NICT [**?**].

VI. Coexistence

The proliferation of wireless systems has produced scenarios in which multiple BANs must coexist as well as with other wireless systems operating in the UWB band. The Std IEEE802.15.6-2012 was not designed to manage such levels of interference that ultimately causes performance degradation. IEEE 802.15.6ma aims to solve coexistence with BANs and other wireless systems operating in the UWB band.

Interference mitigation mechanisms are required at the PHY and MAC levels to deal with the coexistence of multiple BANs and other wireless systems.

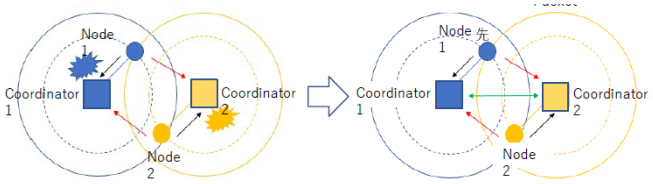

Fig. 1. Concept of coordinator-to-coordinator interference mitigation.

An innovation of the amendment is to coordinate interference and collisions among coordinators within communication range. Conventional 802.15.6 BAN coordinators operate independently of one another. The amendment aims to increase dependability and performance. Hence, 15.6a BAN coordinators may interact to mitigate interference and collisions. Coordinator-to-coordinator (C2C) communication performs via a dedicated link between BAN coordinators.

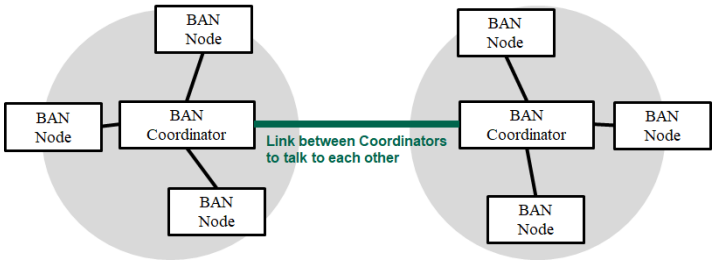

Fig. 2. coordinator-to-coordinator communications.

VII. Interaction with infrastructure

An aspect of the revision is to address the interoperability of HBAN and VBAN with other wireless systems such as Wi-Fi, 5G to extend the use cases to communicate with hospitals,

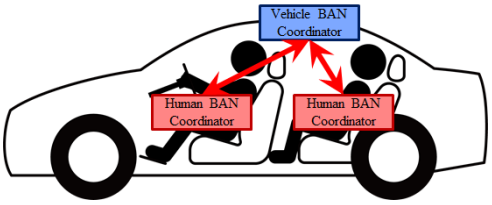

Fig. 3. Interaction of HBAN and VBAN.

emergency services, and control centers for vehicles. The communication flows should guarantee reliable communication links and latency constraints. A potential solution is to adopt mechanisms for communication flows between networks above the MAC layer. The IEEE 802.1 WG has established a series of Stds dealing with those scenarios. In particular, Time-Sensitive Networks [**?**]. TSN is a series of 802.1standards that provide deterministic data transfer in packet networks at layer 2.

VIII. Radio Channel and Environmental Models

The new VBAN use cases require the characterization of UWB propagation on vehicles and the interaction between HBAN and VBAN. The different use cases of channel characterization are named environmental models.

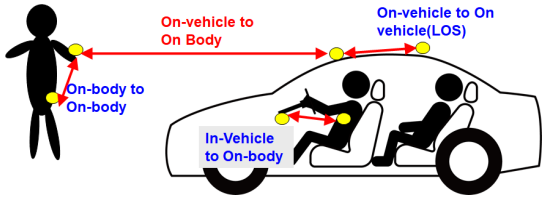

Fig. 4. Concept of channel models for HBAN and VBAN.

Such environmental models include interference from other wireless systems operating in the UWB band. Also, the EMI produce by the electric and electronic systems of vehicles.

An interesting use case is for a passenger bus with one or more VBAN coordinators coexisting with HBANs from passengers.

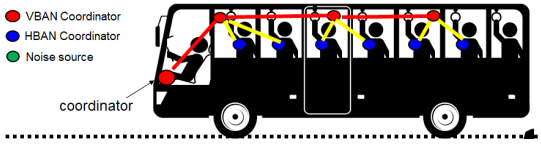

Fig. 5. Concept of VBANs and HBANs coexisting in a passanger bus.

IX. Functional Technical Requirements

A. Reference model

Currently, TG 15.6a holds discussions on the technologies to implement the reference model shown in Figure

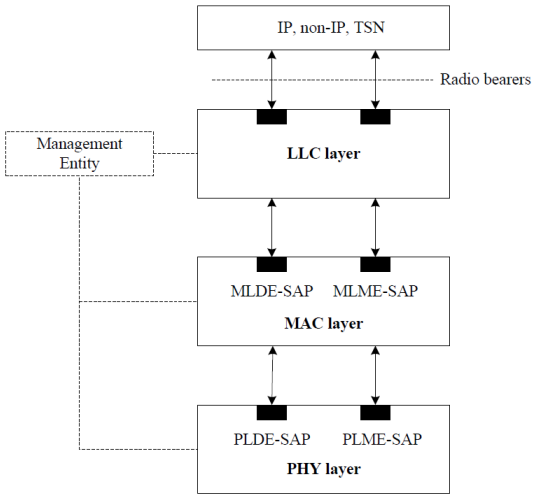

Fig. 6. Reference model.

B. PHY layer

The PHY layer includes, but not be limited to, mechanisms for synchronization, channel estimation, modulation, FEC, ranging, Clear Channel Assessment (CCA), interference mitigation.

C. MAC layer

The MAC layer includes, but not be limited to, mechanisms for QoS flow handling, security services included key management, privacy protection, segmentation, Automatic Repeat Request (ARQ), scheduling & priority handling, interference mitigation, Hybrid ARQ (HARQ). The MAC frame shall include an Ethertype field that indicates the network protocol encapsulated in the payload of the MAC frame.

D. System performance

1) Throughput measured at MAC SAP: The 802.15.6a amendment provides at least one mode of operation capable of achieving a throughput of at least 40 Mb/s, operating at a maximum mandatory data rate of 50 Mb/s assuming 500 MHz channel and under a PDR of 99%.

2) Transmission range: The 802.15.6a amendment provides at least one mode of operation that achieves the same transmission range for HBAN as the one provided by IEEE Std 802.15.6-2012 of 3m at the lowest data rate. the transmission range for VBAN is proposal-specific for cars, utility vehicles and passenger bus. Likewise, the transmission range between HBAN and VBAN is proposal-specific.

3) Transmission reliability: The 802.15.6a amendment should improve transmission reliability under congested communication environment compared to IEEE Std 802.15.6-2012 operating in UWB band, including interference from other wireless systems.

4) Latency: The 802.15.6a amendment should improve latency under congested communication environment compared to IEEE Std 802.15.6-2012 operating in UWB band including interference from other wireless systems.

5) Connection to infrastructure: The 802.15.6a amendment considers mechanisms for connecting to infrastructure (TSN domain) to improve performance and overall latency.

6) Positioning: The 802.15.6a amendment shall define procedures for at least one form of positioning.

7) Coexistence and interoperability: The 802.15.6a amendment provides coexistence and fairness with devices operating in the UWB band. Mechanisms for interference mitigation must be provided.

8) Privacy and security: The 802.15.6a amendment considers mechanisms to enhance security and privacy protection.

E. Topology

Individually, HBAN and VBAN supports the star topology with one coordinator suitable for 100 nodes. Nodes may support 1, 2 relaying hops. Coordinator and nodes may be on the human body or vehicles cabin. In the case of HBAN, nodes may include implant devices. In the case of HBAN, nodes may include implant devices.

1) Coordinator to coordinator topology:

1) A VBAN coordinator supports a star topology with 5 HBAN coordinators for a passenger vehicle, i.e., sedan, pickup, SUV, utility vehicle.
2) One or two VBAN coordinators supports a star topology with 15 HBAN coordinators for a passenger bus.
3) Coordinators of HBANs operating within the transmission range of one another may support Peer-to-Peer (P2P) topology.

2) Multiple access: HBAN and VBAN shall support contention access, contention-free access or a hybrid form of contention access and contention-free access.

3) Handover:

1) In the passenger bus use case with one or two VBAN coordinators, HBAN coordinators may support handover to alleviate congestion.
2) A given device associated with an HBAN approaching a VBAN may be disassociated from the HBAN and immediately associated with the VBAN via handover.

4) Priority traffic: Priority traffic should be compatible with IEEE 802.15.6-2012 with eight possible levels of priority. Proposals may include their classification of priority traffic, indicating justification and traffic discriminator.

5) Mobility: HBAN walking speed 3 miles/h or 4.8 km/h.

6) Antenna configuration: A 15.6a device may be equipped with multiple antennas configuration to support a higher data rate.

7) Interference management: Interference is defined as unwanted emissions from coordinated or uncoordinated wireless systems operating in the UWB band.

1) 802.15.6a devices supports the functionality to control the transmit power to minimize interference to other systems and power consumption.
2) 802.15.6a devices supports the functionality to mitigate interference from other wireless systems operating in the UWB band.
3) VBAN operating in coordination with other HBANs should support the functionality to control and mitigate interference.
4) Electromagnetic Interference (EMI) is defined as unwanted emissions from electromagnetic sources such as electric systems, alternators, fast digital switches unproperly shield.

F. Performance metrics

To evaluate proposals, TG 15.6a provides the metrics for evaluation.

1) Packet delivery ratio: Packet Delivery Ratio (PDR) is computed as the ratio of packets successfully received at the MAC-SAP of the receiver (receivedPackets) to the total number of packets sent to the PHY-SAP of the transmitter. It indicates the efficiency and reliability of the proposal to successfully deliver packets to its destination under given conditions. Proposals should provide 99% of PRD under congested communication environment.The Packet Error Rate (PER) is the complement of PDR.

2) Throughput: Throughput denotes the effective transfer of information data rate (without overhead) in b/s measured at the MAC-SAP during a communication flow. It involves losses in the radio link due to congestion, transmission range, interference, and protocol communication exchanges. Requirement: Proposals should provide at least one mode of operation capable of achieving a throughput of at least 40 Mb/s, operating at a maximum mandatory data rate of 50 Mb/s in the high band of UWB (500 MHz channel) in a low mobility channel environment (3 miles/h or 4.8 Km/h) under congested communication environment and under a PDR of 99

3) End-to-end latency: End-to-end latency represents the time interval between the time instant the transmitter's MAC delivers the first bit of a MAC packet to the PHY-SAP for transmission to the time instant of the last bit of such MAC packet received by the MAC-SAP at the receiver. End-to-end latency involves processing delay at the transmitter, propagation delay, and processing delay at the receiver. It includes all mechanisms at the PHY and MAC levels, like scheduling to access the medium, retransmissions, signal processing, etc. Requirement: Proposals should include end-to-end latency in the interval [250 msec, 1 sec].

G. Evaluation methodology

Parameters set up for simulation and scenarios are still a work in progress as the TG 15.6ma is in its early stages.

X. Conclusions

The paper describes the current activities of the IEEE 802.15.6ma TG with the task to revise the IEEE 802.15.6-2012 Std with enhanced dependability and the extension to VAN. IEEE 802.15.6a will provide the guidelines for implementations targeting medical and non-medical applications of

BANs with the necessary mechanisms for interoperability and coexistence.

Implementations of HBAN and VBAN applications are open to the research community and industry. That is solutions such as receiver's algorithms, hardware implementations, and applications.

We expect the new BAN standard under IEEE 802.15.6ma will address an important segment of the mass market for health care applications and autonomous vehicles.

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