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

Submission Title: [IG DEP Necessity for Amendment of 15.6-2012 Medical BAN]

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Re: []

Abstract: [This document summarizes necessity and request for amendment of IEEE802.15.6 -2012 Medical Body Area Networks corresponding to increasing wide variety of use cases and satisfying dependability of BAN in PHY and MAC layers.]

Purpose: [information]

Necessity for Amendment of IEEE 802.15.6 Medical BAN with Enhanced Dependability

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Takumi Kobayashi (YNU)

Agenda

1. Review of WBAN Standard IEEE802.15.6
2. Extension and Amendment of BAN with Enhanced Dependability
3. Technical Challenges for Enhanced Dependability
4. Focused Amendment of std 15.6 BAN with Enhanced Dependability

1. Review of WBAN Standard IEEE802.15.6

1.1 Wireless BAN: Body Area Network

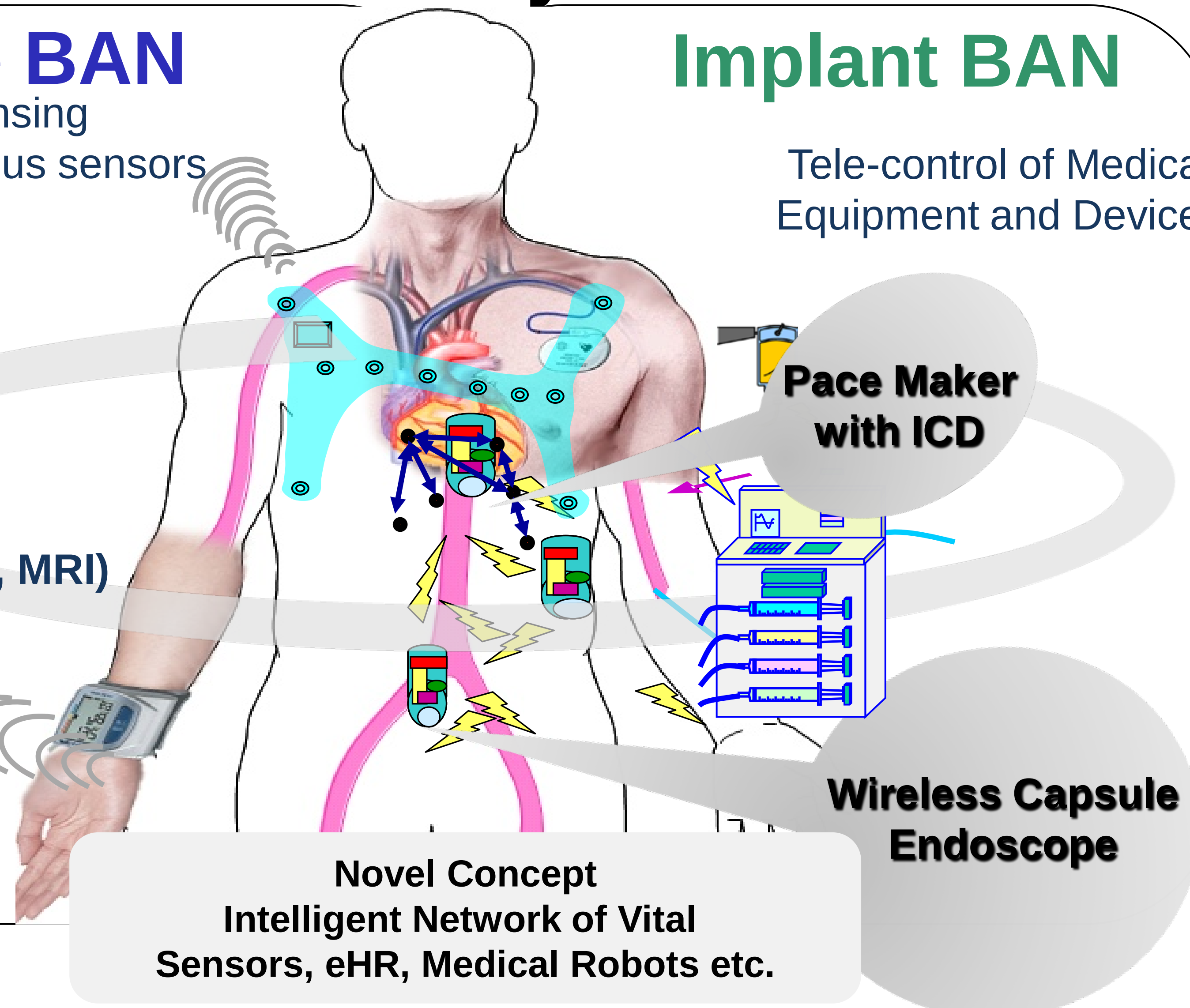
Wearable BAN

Tele-metering or sensing vital signs with various sensors

ECG
EEG
SPO2
Blood Pressure
Heartbeat
Body temperature
Glocuse level
Medical images(X-ray, MRI) and video

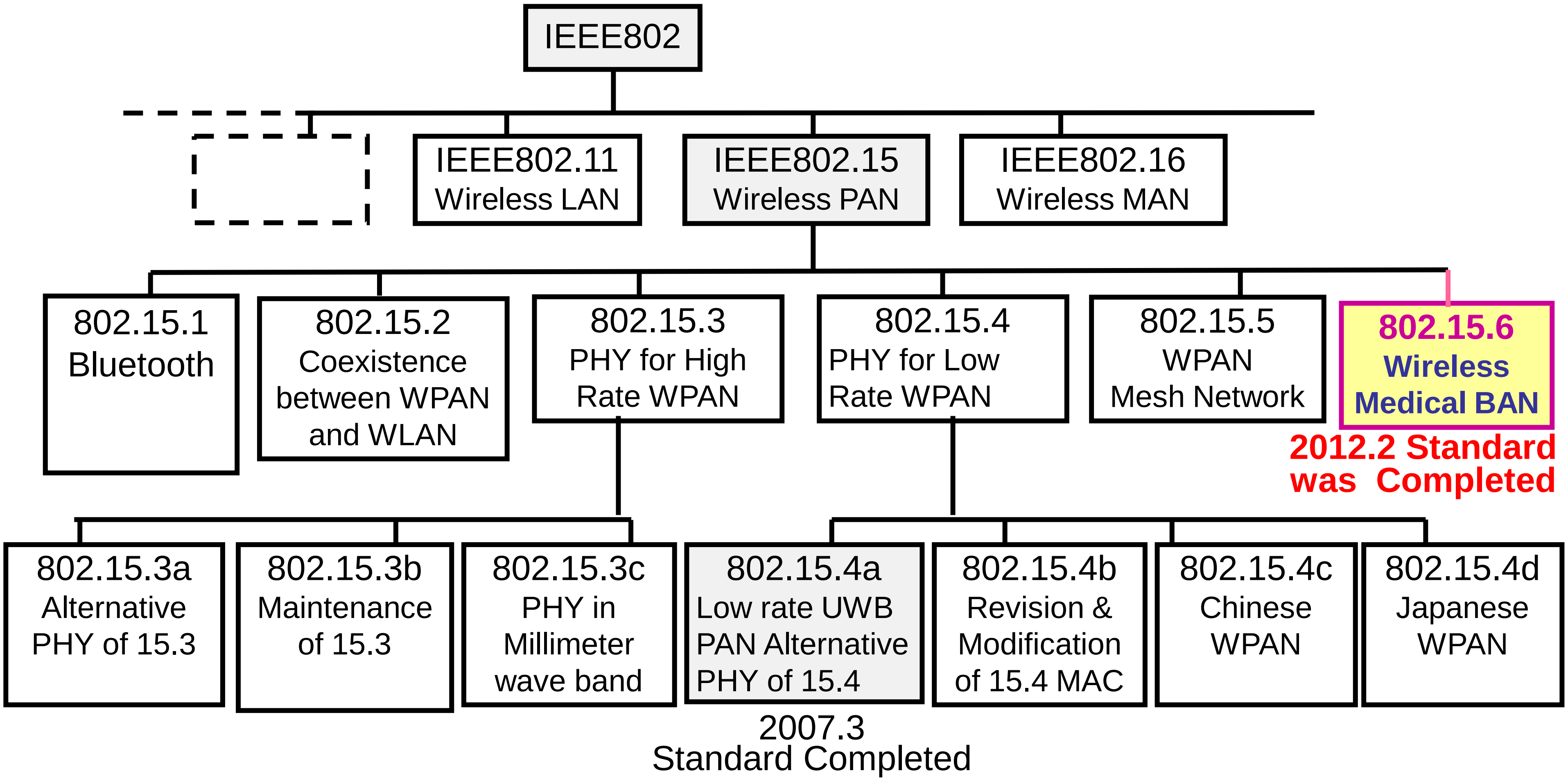
Implant BAN

Tele-control of Medical Equipment and Devices



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

1.2 Standard of Medical Wireless Body Area Network(BAN);IEEE802.15.6

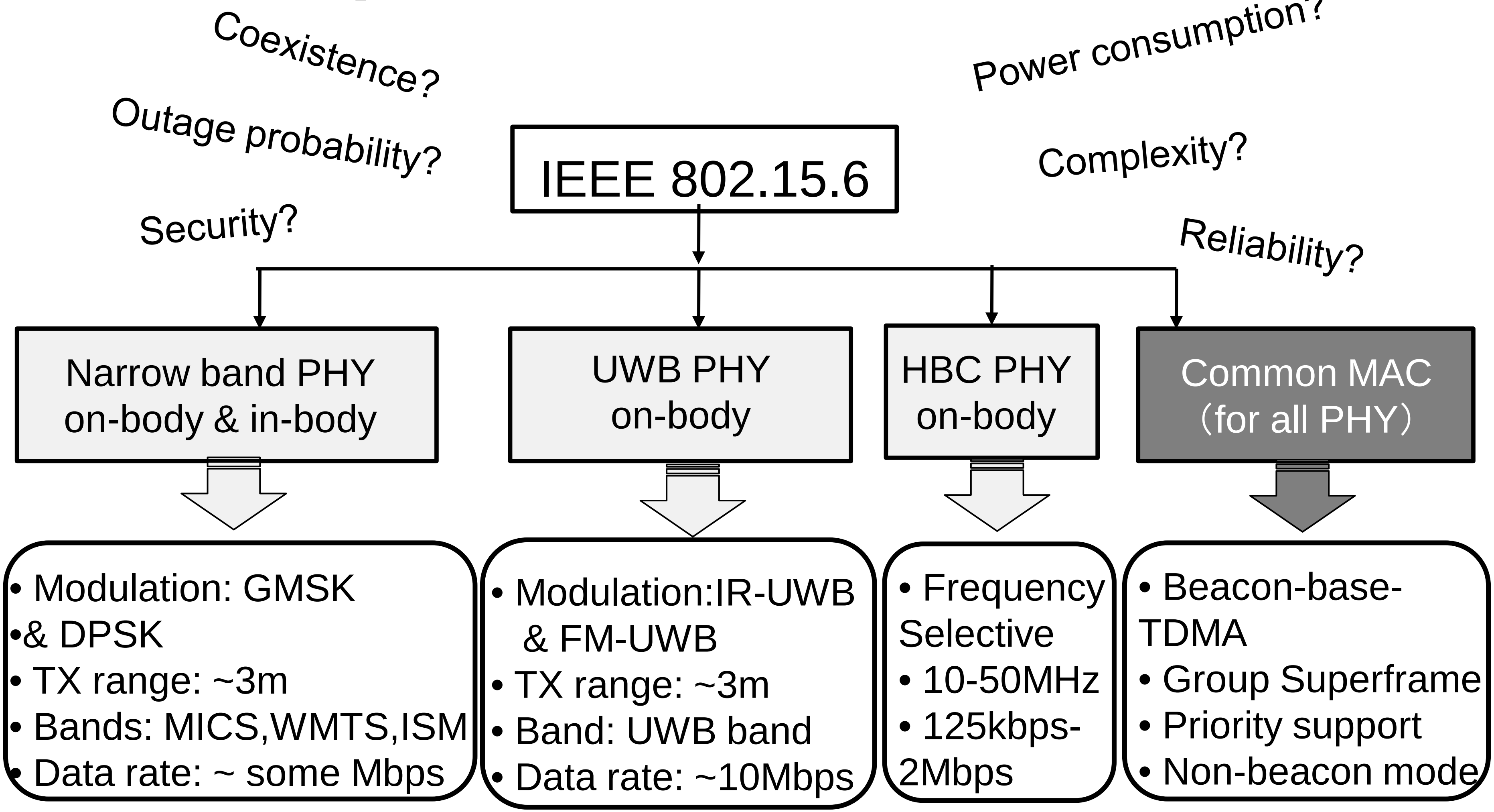


1.3 Main Contributors at TG6

- Casuh
- CEA-LETI
- CNU
- CSEM
- CUNY
- ETRI
- France Telecom
- Fujitsu Lab. Europe
- Fujitsu Lab.
- GE Global Research
- GE Healthcare
- IMEC
- Inha University
- KETI
- Korpa
- LG Electronics
- Meiji Univesity
- *Mitsubishi Electric Research Labs, USA*
- NICT
- NICTA
- NIST
- Olympus, USA
- Philips, USA
- Philips, EU
- Samsung
- Tensorcom
- Texas Instrument
- Thales
- Toumaz Technologies
- Yokohama National University
- Zarlink Semiconductor
- … …

Asia
Europe
USA

1.4 Top View of IEEE Std 802.15.6



UWB: Ultra-wideband
HBC: Human body communication

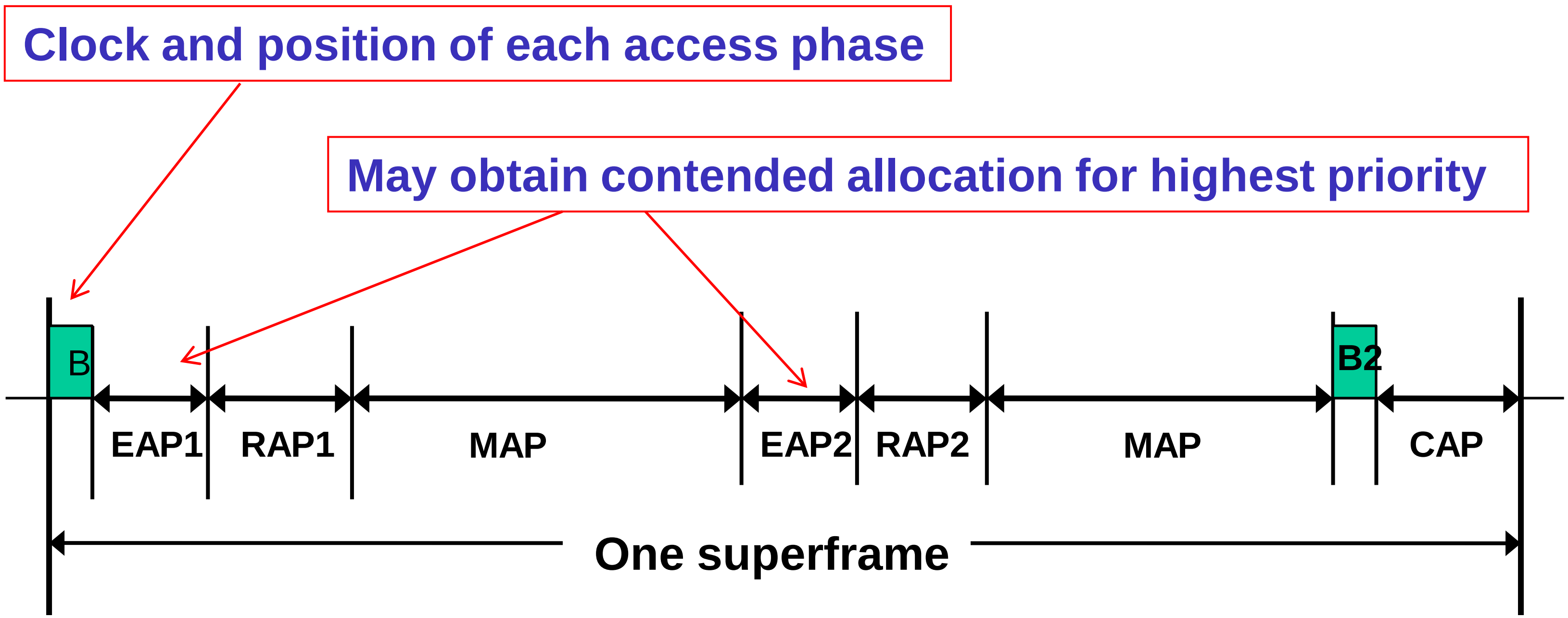
1.5 User Priority Mapping

Priority level	Traffic designation	Data type
7	Emergency or medical event report	Data
6	High priority medical data or network control	Data or management
5	Medical data or network control	Data or management
4	Voice	Data
3	Video	Data
2	Excellent effort	Data
1	Best effort	Data
0	Background	Data

1.6 Three Channel Access Modes

Channel access mode	Time reference-based (superframe structure)	Beacon	Notes
I	Yes	Yes	Coordinator sends beacon in each superframe except for inactive superframes.
II	Yes	No	Coordinator establishes time reference but doesn’t send beacon.
III	No	No	There is not time reference.

1.7 Time-referenced Superframe w/ Beacon



EAP: exclusive access phase

RAP: random access phase

MAP: managed access phase

CAP: contention access phase

1.8 Main Features of the Three PHYs

	Frequency band (MHz)	Data rate (kbps)	Note
NW-PHY	400, 600, 800, 900, 2400	75.9 --- 971.4	Interference with other systems operate at the same bands
UWB-PHY	6000-10600 3100-4800	390 --- 12600	Worldwide common band is 7.25 – 8.5 GHz
HBC-PHY	21	164 --- 1312.5	Strong concern on the effect to implant devices

1.9 Main Specifications of NB-PHY

Frequency bands (MHz)	Modulations		Data rates (kbps)	Number of channel	Notes
	PLCP header	PSDU			
402-405	π/2-DBPSK	π/2-DBPSK, π/4-DQPSK π/8-D8PSK	75.9/151.8/ 303.6/455.4	10	Majority of countries
420-450	GMSK	GMSK	75.9/151.8/187.5	12	Japan
863-870	π/2-DBPSK	π/2-DBPSK, π/4-DQPSK π/8-D8PSK	101.2/202.4/ 404.8/607.1	14	EU
902-928	π/2-DBPSK	π/2-DBPSK, π/4-DQPSK π/8-D8PSK	101.2/202.4/ 404.8/607.1	60	North America, Australia
950-958	π/2-DBPSK	π/2-DBPSK, π/4-DQPSK π/8-D8PSK	101.2/202.4/ 404.8/607.1	16	Japan
2360-2400	π/2-DBPSK	π/2-DBPSK, π/4-DQPSK	121.4/242.9/ 485.7/971.4	39	USA
2400-2483.5	π/2-DBPSK	π/2-DBPSK, π/4-DQPSK	121.4/242.9/ 485.7/971.4	79	Worldwide

1.10 Main Specifications of UWB-PHY

Mode	Modulation	Data rate (Mbps)	Waveform
IR-UWB (I)	OOK	0.49 – 15.6	Chirp pulse, chaotic pulse, SRRC-like pulse, or others.
IR-UWB (II)	DBPSK/DQPSK	0.49 – 15.6	
FM-UWB	Continuous-phase 2FSK (sub carrier) combined with FM	≦0.25	Gaussian (default)

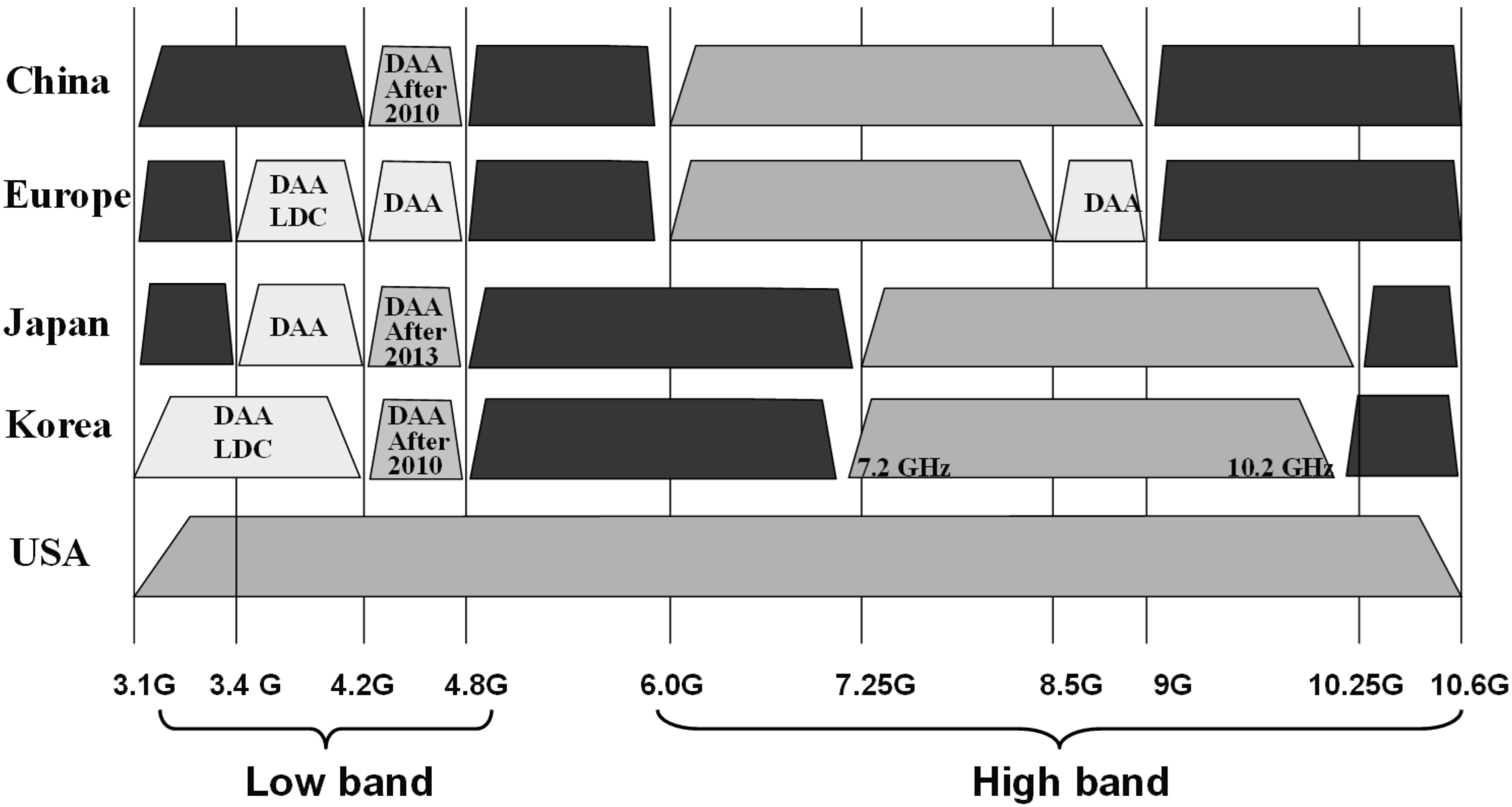
- **FM-UWB is an optional mode**
- **High QoS mode**
  - **Hybrid Type II ARQ**

1.11 Main Specifications of HBC PHY

- **HBC frequency band**
  - **center frequency:21MHz (3dB_BW=5.25MHz)**
- **Transmission method**
  - **Frequency Selective Digital Transmission**
- **Data rate**
  - **164, 328, 656, 1312.5 kbps**

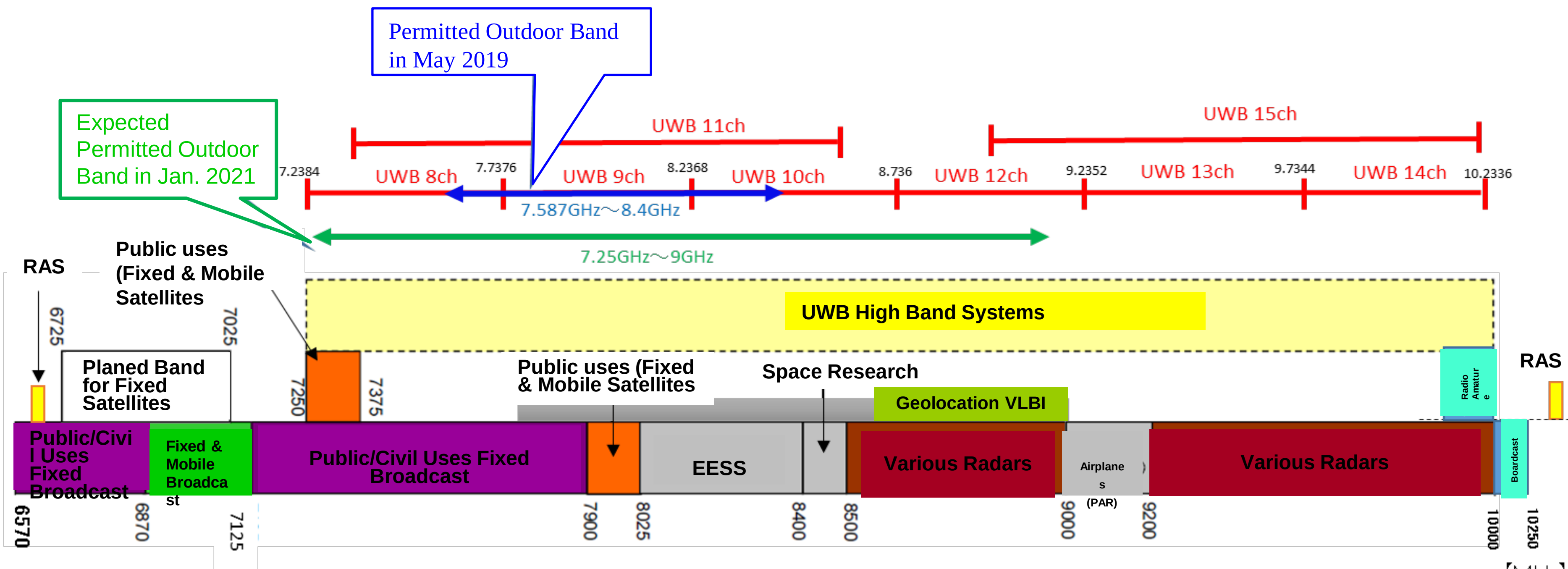
The electrode in contact with the body is used for transmitting or receiving an electrical signal through the body to a device

1.12 Worldwide UWB Regulations in 2012



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 wand it is expected to allow it for outdoor use in January 2021



1.13 Specifications of High Band UWB

Items	Specifications
Frequency band	7.25 – 10.25 GHz
Average e.i.r.p.	≤ -41.3 dBm/MHz
Peak e.i.r.p.	≤ 0 dBm/50MHz
Average unwanted radiation	≤ -70 dBm/MHz
Peak unwanted radiation	≤ -64 dBm/MHz
Pulse rate	~ 50 Mpps
Communication range	~ 3m

1.14 Summary of IEEE802.15.6

- 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 Body area network (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.

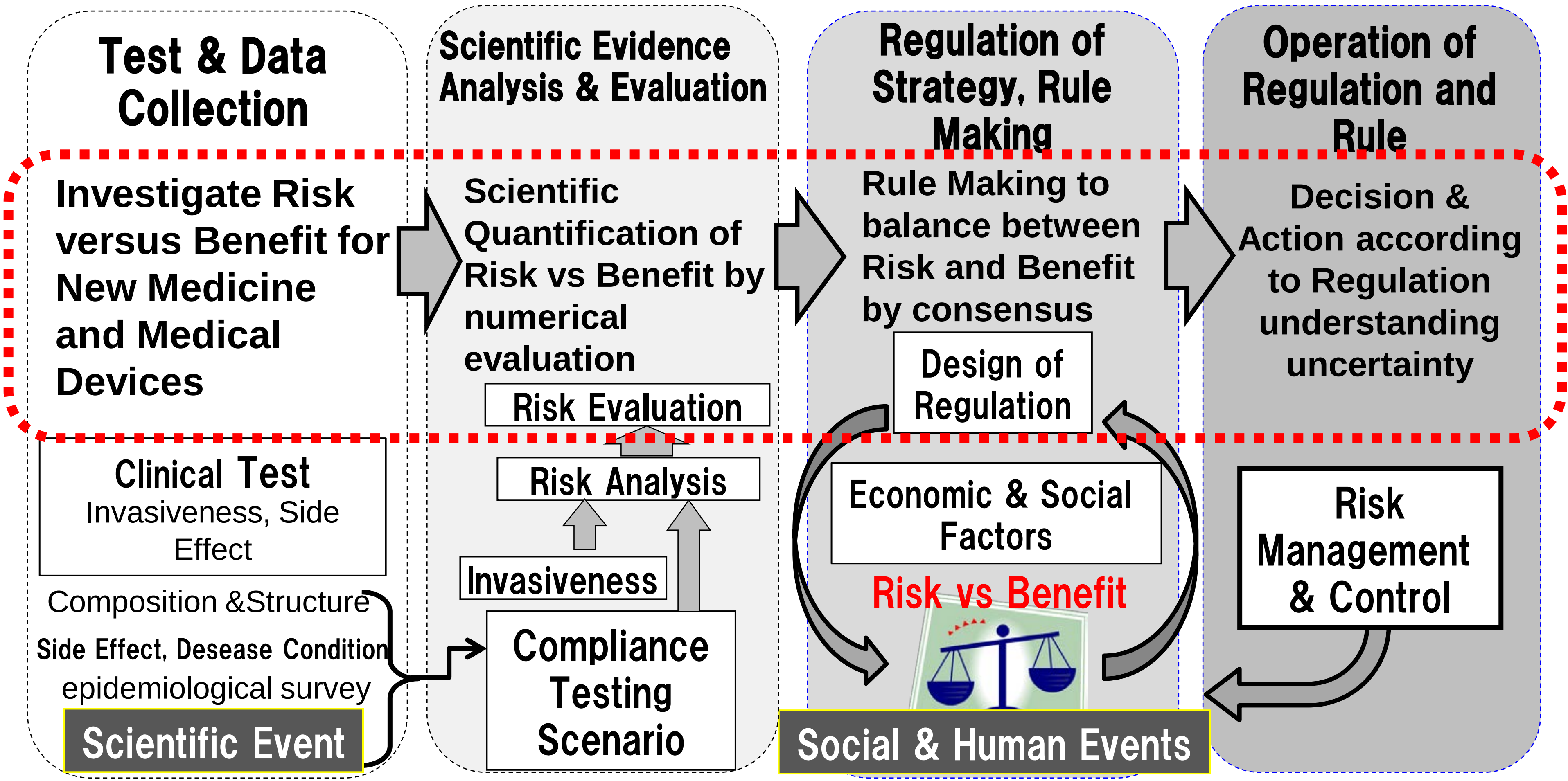
- In MAC, hybrid contention base and free protocol can perform flexible delay and throughput for QoS levels of packets but its implementation complexity is too high for its complete protocol.

2. Extension and Amendment of BAN with Enhanced Dependability

2.1 Dependablity in Wireless Networks

- **Meanings of Dependability:**
  - "**Dependability in network**" means to guarantee lowest performance enough high in a sense of highly reliable, safe, secure, fault tolerant, robust services by showing numerical worst and average performances with remained uncertainty in specific defined classes of environment.
  - This is based on the concept of "**regulatory science**."
- **Demand for Dependable Networks:**
  - Highly dependable communications for **IoT/M2M** sensing and controlling medical healthcare, car, UAV, robotics and others is necessary in smart car, factory, and city as well as emergency environment such as natural disasters.
  - Numerical parameters to evaluate advantage and drawback of technologies are defined and their permissible ranges by showing remained uncertainty are agreed by all stakeholders such as users and manufactures, i.e. **the concept of regulatory science.**

Regulatory Science to Guarantee Dependability and Compliance in case of Medicine and Medical Devices



To enhance dependability of wireless systems, Regulatory Science is useful while showing risk vs benefit with cost and remained uncertainty because it can protect not only users but also manufactures

Human Impact vs BER according to Radio Emission Power

Pennes's Thermal Propagation Equation

$$c\rho\frac{\partial T}{\partial t} = \nabla\cdot(\kappa\nabla T) + A_0 + Q_v - b(T - T_b) \Rightarrow \kappa\nabla^2 T + \rho SAR - \rho\rho_b c_b F(T - T_b)$$

SAR(Specific Absorption Rate)

1st term; Thermal Propagation

2nd Term; Thermal Radiation to keep proper temperature

3rd Term; Thermal Volume by Millimeter wave

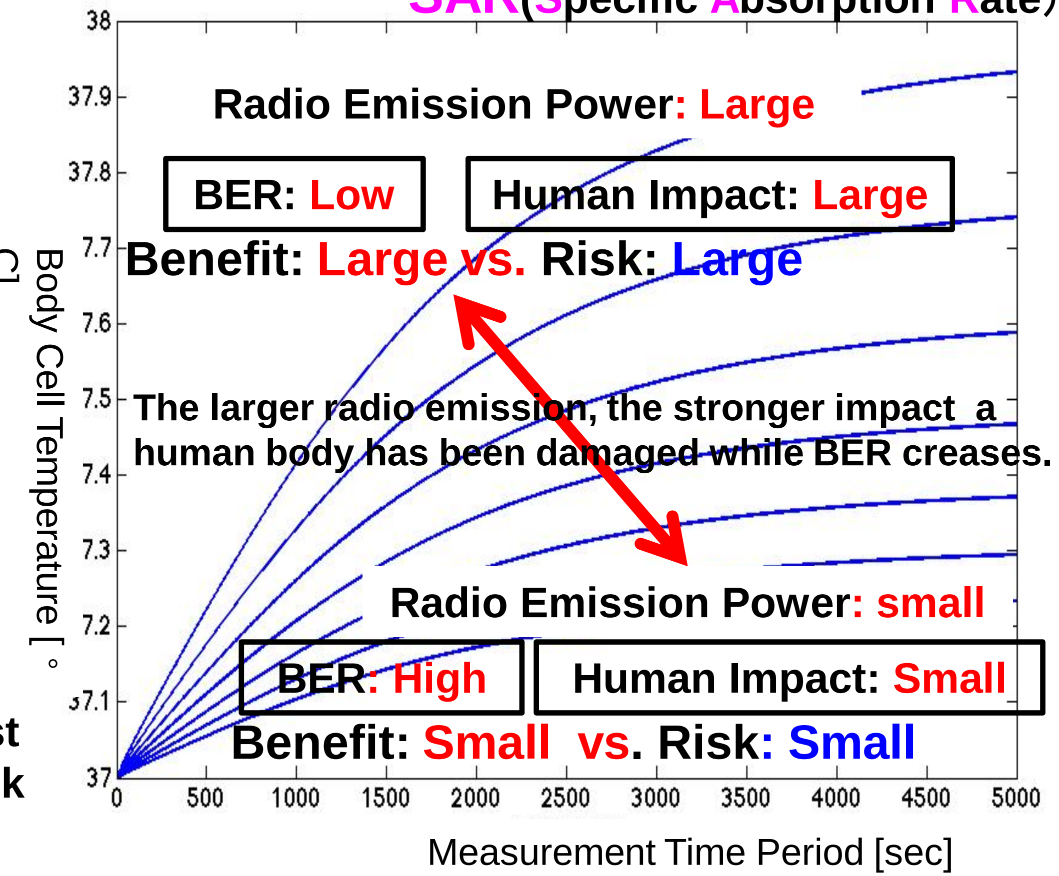
4th term; Thermal Change due to Blood Stream

EIRP of Emission Power P_t and Antenna Gain G_t for a distance R

$$E = \frac{\sqrt{49P_tG_t}}{R}$$

$$SAR \propto Pt \propto E^2$$

Then, radio emission power or SAR must be a numerical parameter to evaluate risk versus benefit of radio medical devices.



2.2 Demands for BAN Extension

1. BAN for Car and Other Bodies beyond Human Body

- Reliable performance of medical BAN for human body could be widely applicable for remote maintenance of car body and other bodies in IoT/M2M use cases.
- Demands for More flexible and widely applicable BAN in cars, robotics, UAVs and others are increasing for autonomous remote sensing and controlling.

⇒ **current IEEE802.15 IG-Dependability**

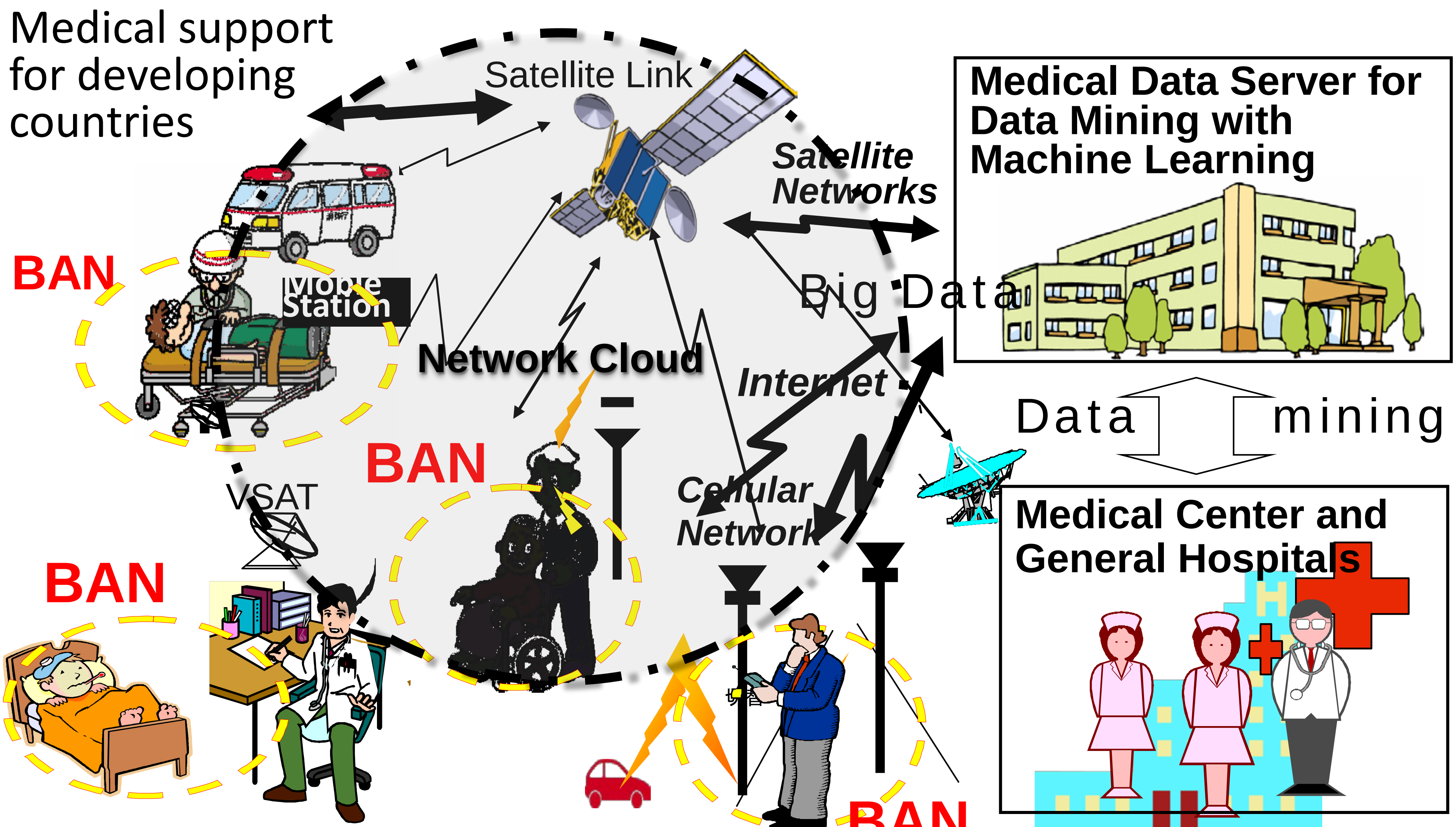
2. BAN-base Infrastructure Platform for Medical Healthcare

- BANs in end users are connected through Cloud Network and Edge Computer with AI Data Mining Server and Repository for medical healthcare platform by integration between ICT and data science.
- Enhanced dependability is required for end-to-end reliability and security.

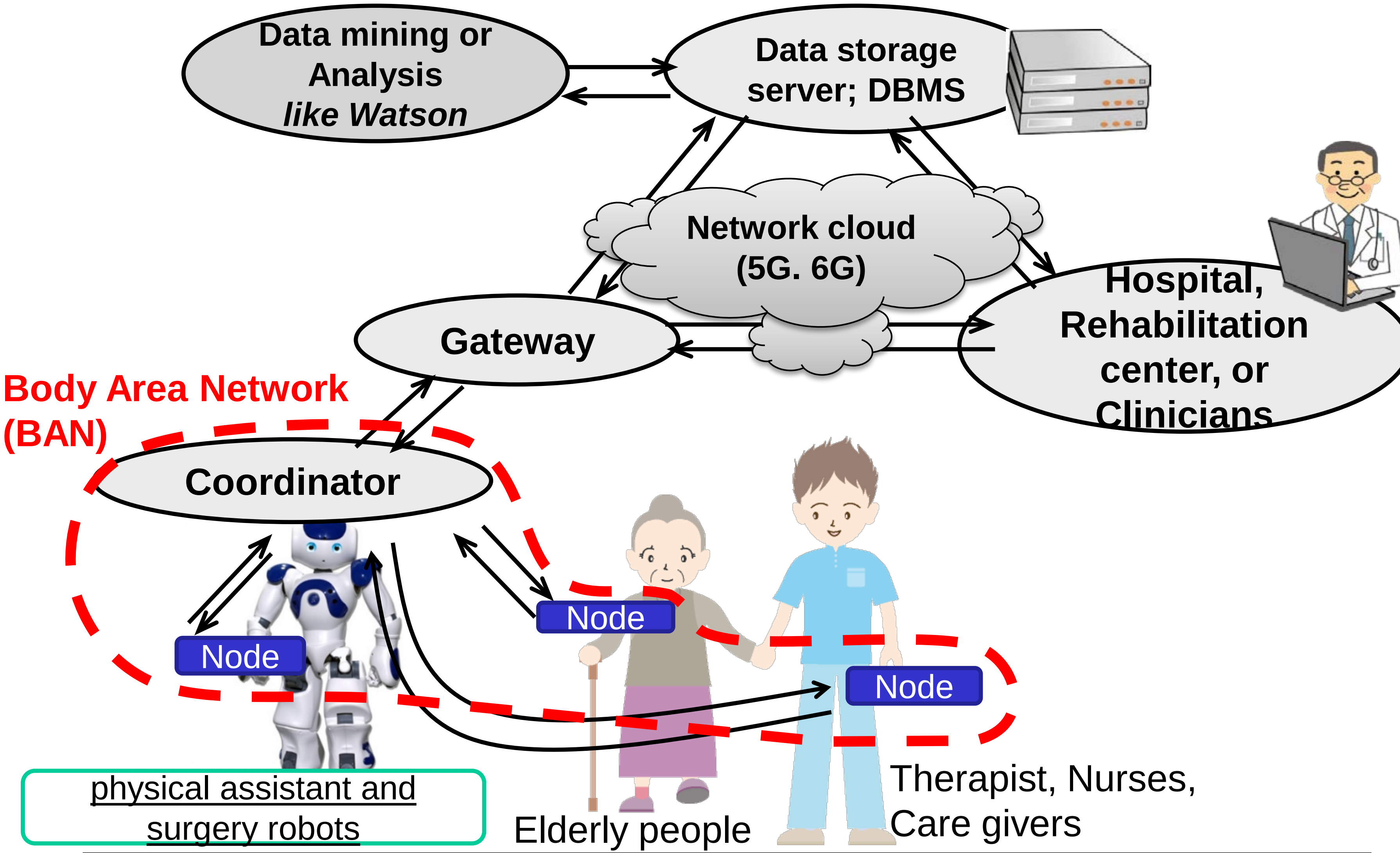
3. BAN-base Universal Platform for Medical and beyond Medical Infrastructures

- Emergency for natural disasters and terrorism, smart city with reliable maintenance of cars, buildings etc. need common dependable platform,

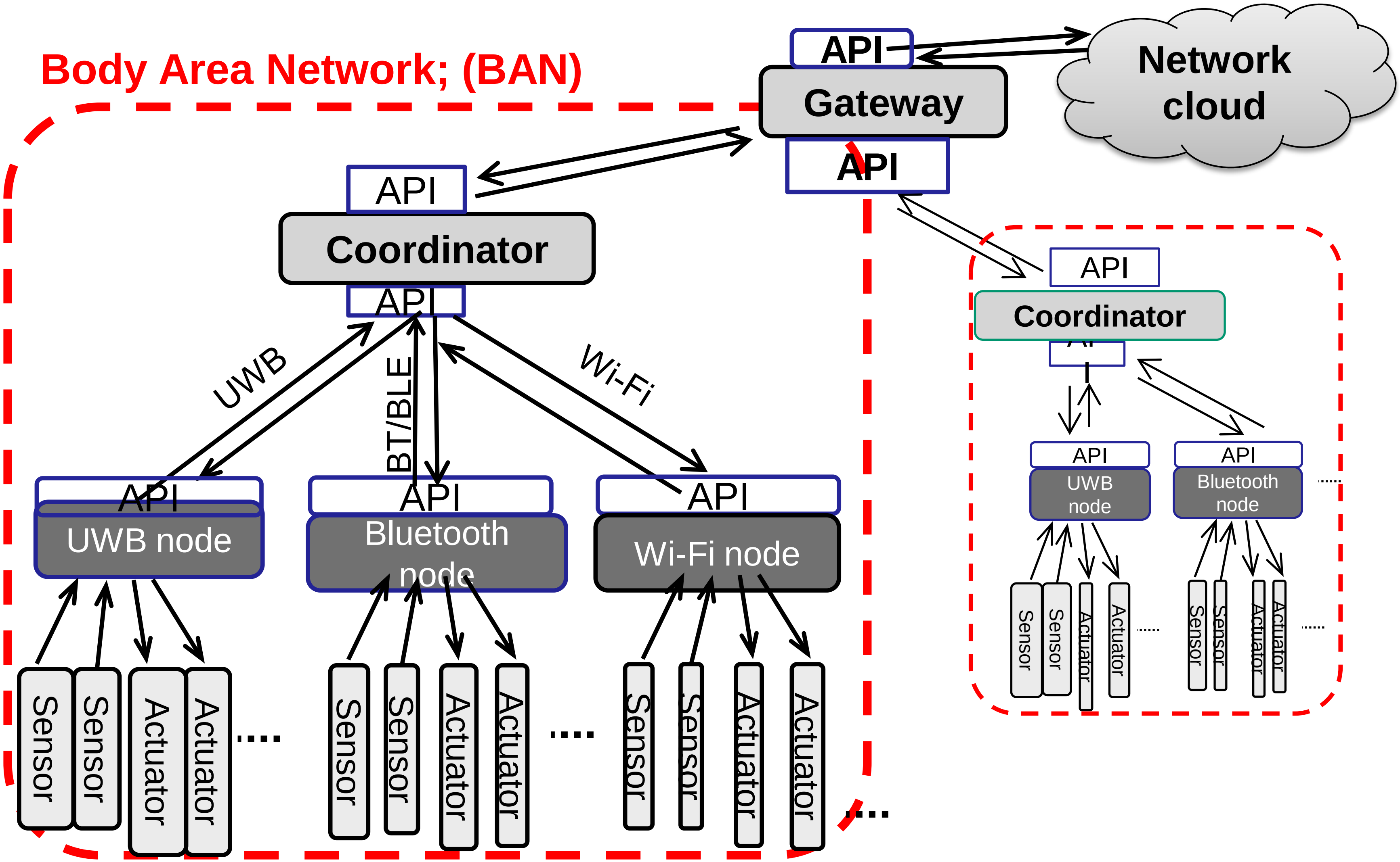
2.3 BAN- Use Cases for Remote Medical Services



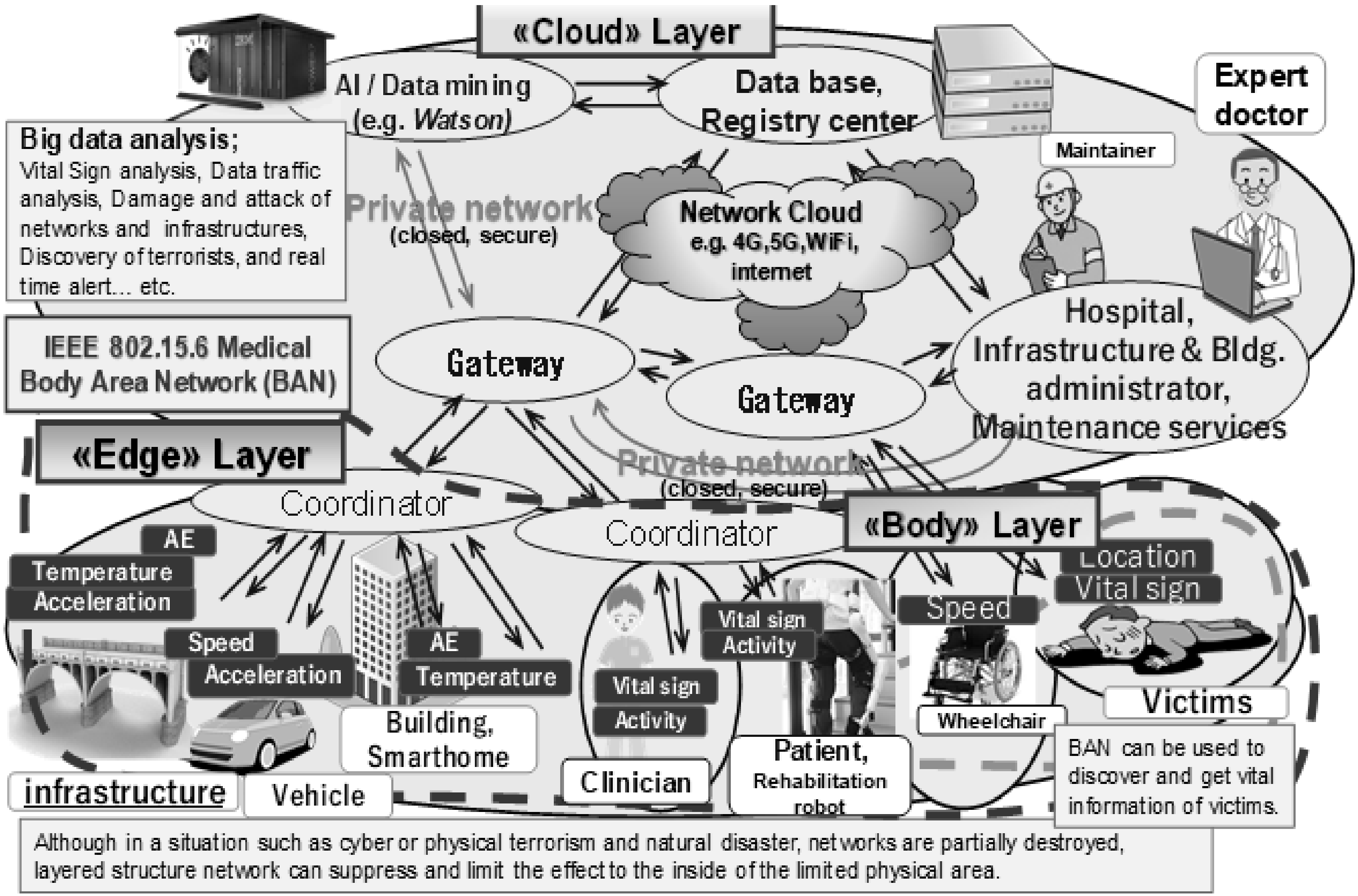
BAN-base Universal Platform with Network Cloud, Data Mining Server for Medical Healthcare



Medical Healthcare Data Mining and Networking Based on Universal Platform by Wireless BAN, Network Cloud, Data Server with AI Data Mining



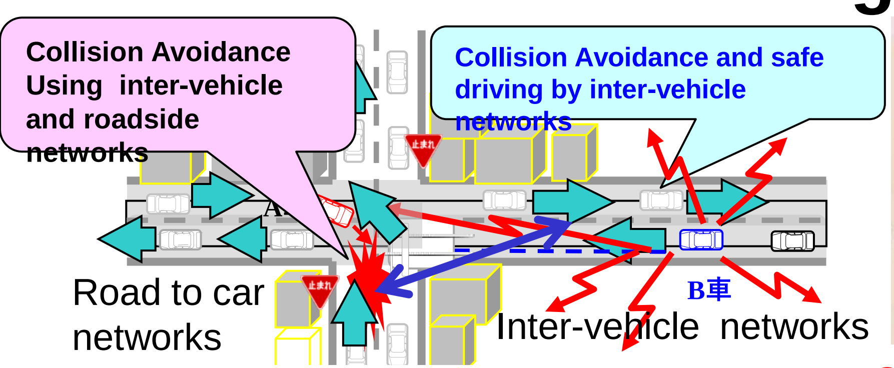
2.4 Universal Platform Based on BAN, Cloud Network, and AI Data Server for General Social Infrastructure beyond Medical Services



2.5 Scalable Applications of WBAN with Enhanced Dependability

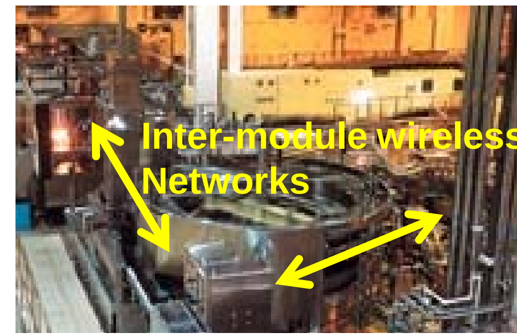
1. Remote healthcare monitoring and therapy
2. Remote sensing and controlling robots and UAVs for disasters
3. Recovering infrastructure networks after disasters
4. Resilient, reliable and robust IoT network against disasters
5. Vehicle internal sensing and controlling
6. Collision avoidance radar
7. Inter-vehicle communications and ranging
8. Wearable and implant wireless medical sensing and controlling
9. Wearable healthcare sensing
10. Dependable Brain-Machine Interface (BMI)
11. Wireless sensing system for Factory with feedback control
12. Dependable multi-hop inter-vehicle communications
13. Inter-navigation and inter-vehicle information sharing in normal and emergency conditions
14. Single wireless communication network solution that functions both in normal and in disaster environments
15. Disaster prevention, emergency rescue and recovery

Possible Use Cases of Dependable M2M and BAN for Sensing and Controlling



Car Navigation & Collision Avoidance Radar

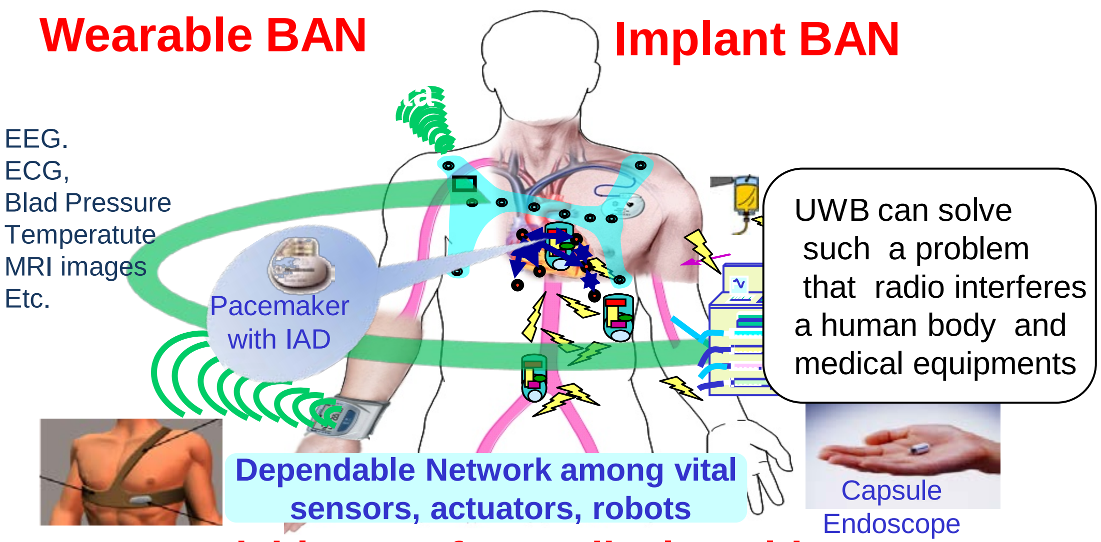
Car LAN & Wireless Harness



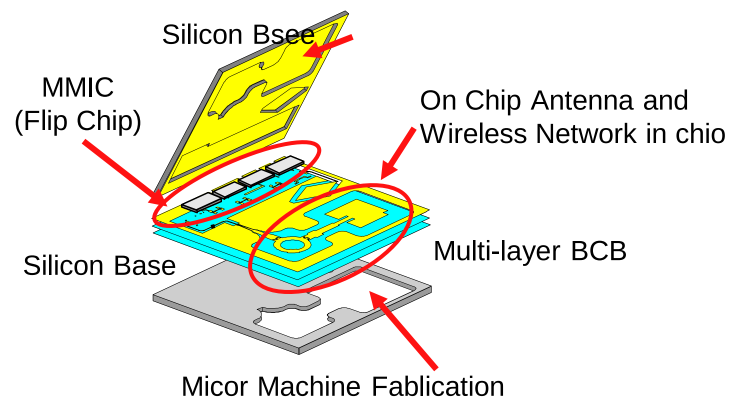
Factory Automation (FA)

Dependable Wireless Networks for Transportation

Dependable Wireless Sensing & Controlling for Manufacturing (CIM)

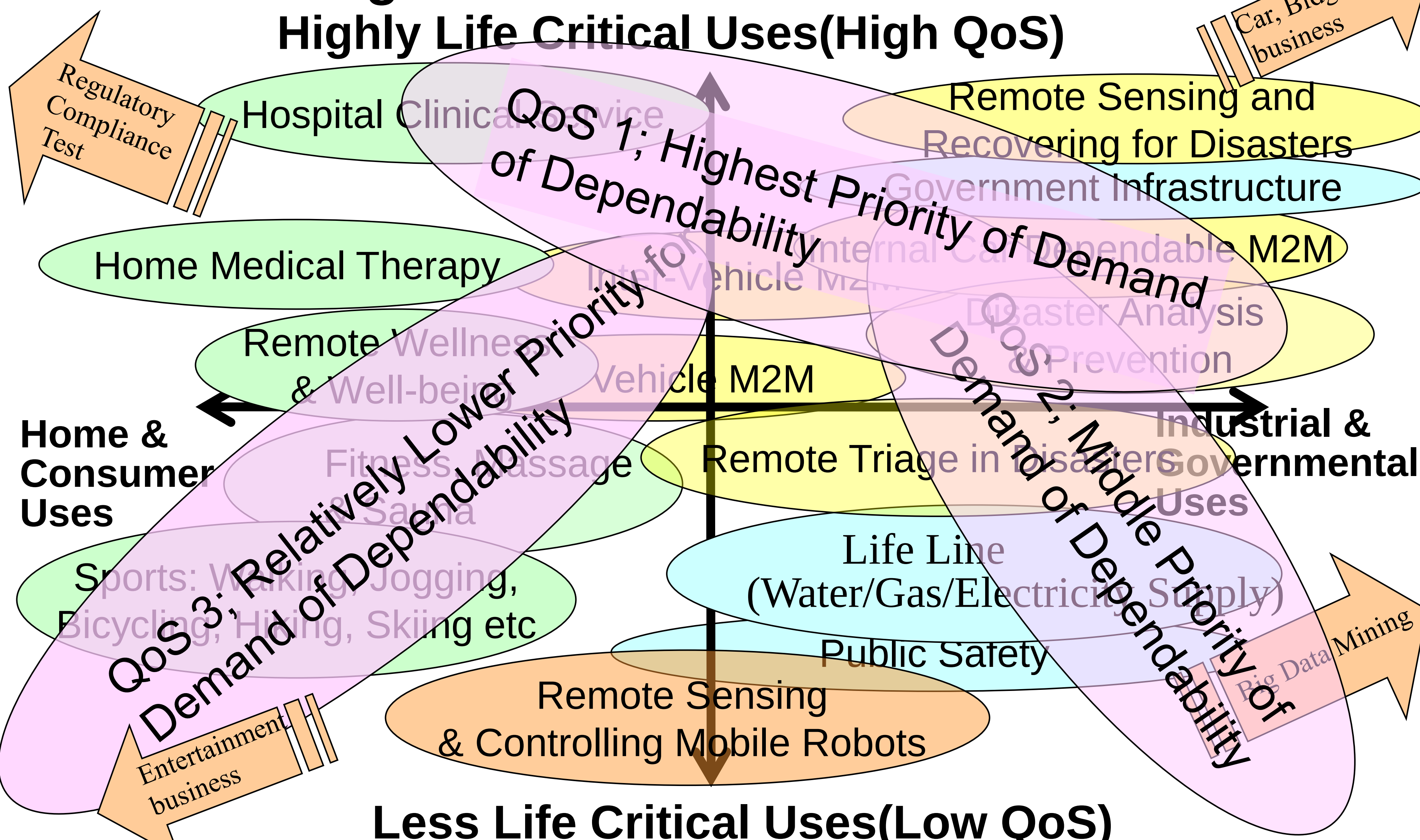


Dependable BAN for Medical Healthcare



Dependable Wireless System Clock in Micro Circuit & Network in Devices

Visualizing Portfolio of Focused Use Cases



Ryuji Kohno(YNU/CWC UofOulu), Takumi Kobayashi(YNU)

2.6 Three Classes of Focused Potential Use Cases

We have classified focused potential applications into three classes according to demands of dependability.

Class 1 QoS: Highest Priority Level for Demand of Dependability

- 1.1 **Remote Sensing and Control of Implanted and Wearable Medical Devices (ex. BMI etc.)**
- 1.2 **Remote Medical Diagnosis and Therapy**
- 1.3 **Vehicle Autonomous Driving**
- 1.4 **Remote Monitoring Infrastructure for Rescue in Disaster**

QoS 2 Class: Meddle Priority Level for Demand of Dependability

- 2.1 Personal Healthcare
- 2.2 Vehicle Wireless Harness
- 2.3 Lifeline Maintenance (Water/Gas/Electricity Supply)
- 2.4 Remote Maintenace of Infra(bridge/bldg./train)

QoS 3 Class: Low Priority Level for Demand of Dependability

- 3.1 Wellness, Wellbeing
- 3.2 Public Safety
- 3.3 Remote Sensing and Controlling Mobile Robots
- 3.4 Disaster Analysis and Prevention

2.7 Needs 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.

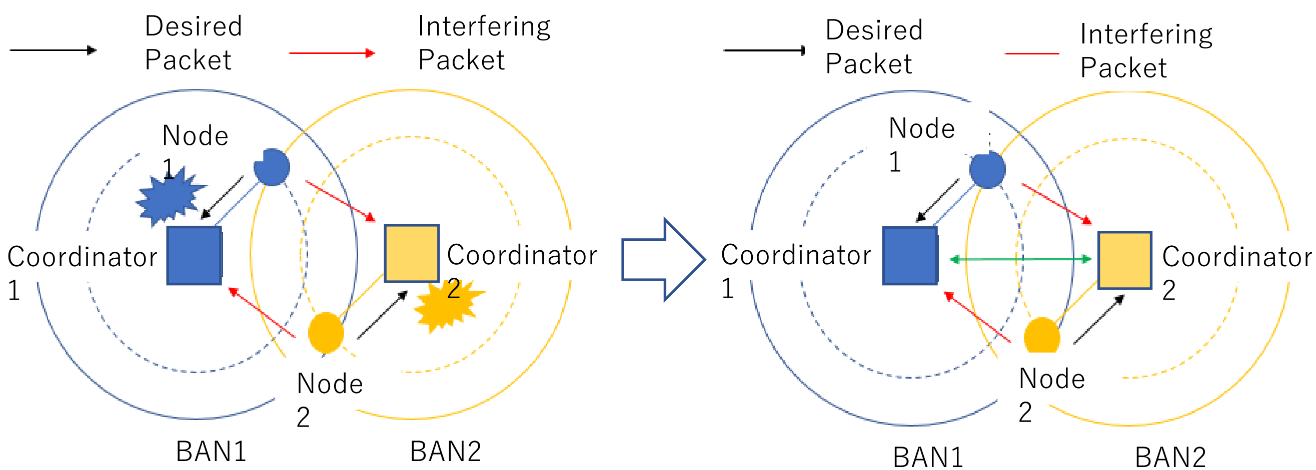
2.8 Contention among Overlaid BANs

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



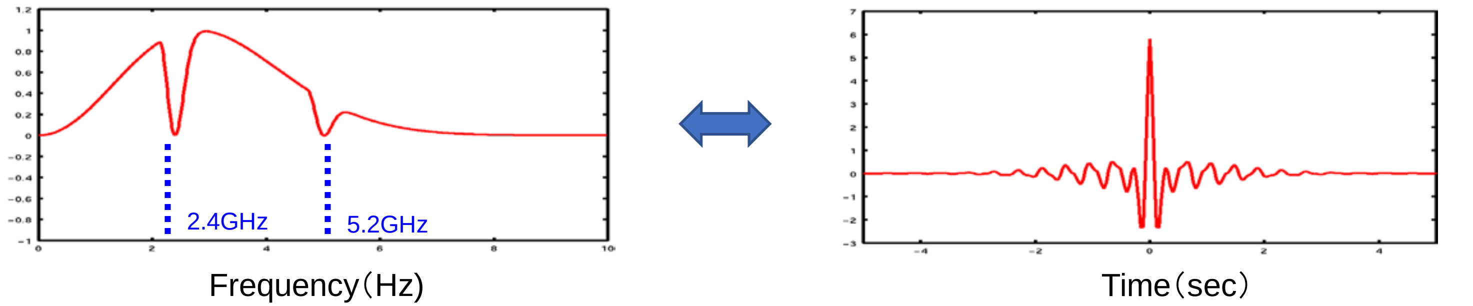
In case of no negotiation of Coordinators of overlapped BANs, contention happens among packets from nodes of f the BANs

In case of negotiation of Coordinators of overlapped BANs, contention can be resolved

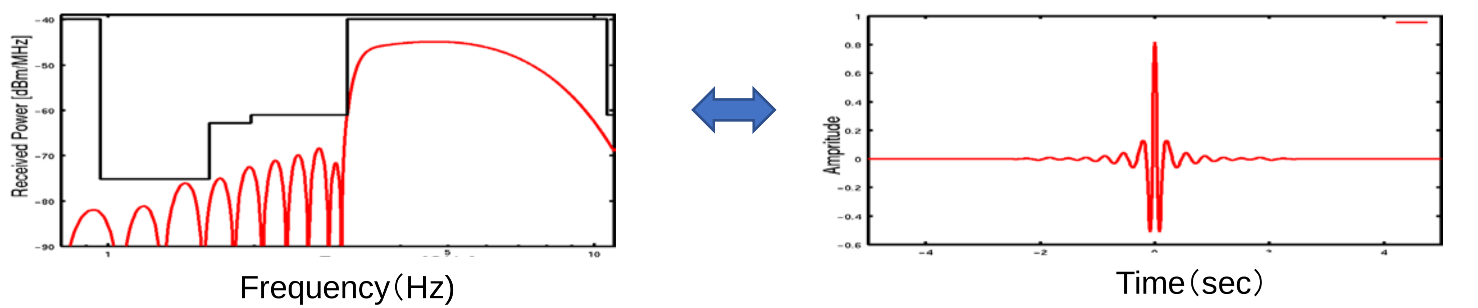
- What is interference at the MAC layer
  - Sensor nodes within the communication range try to transmit packets at the same timing, causing collisions, making it impossible to communicate correctly

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

2.9 Interference Mitigation among Other Radios(1/2)



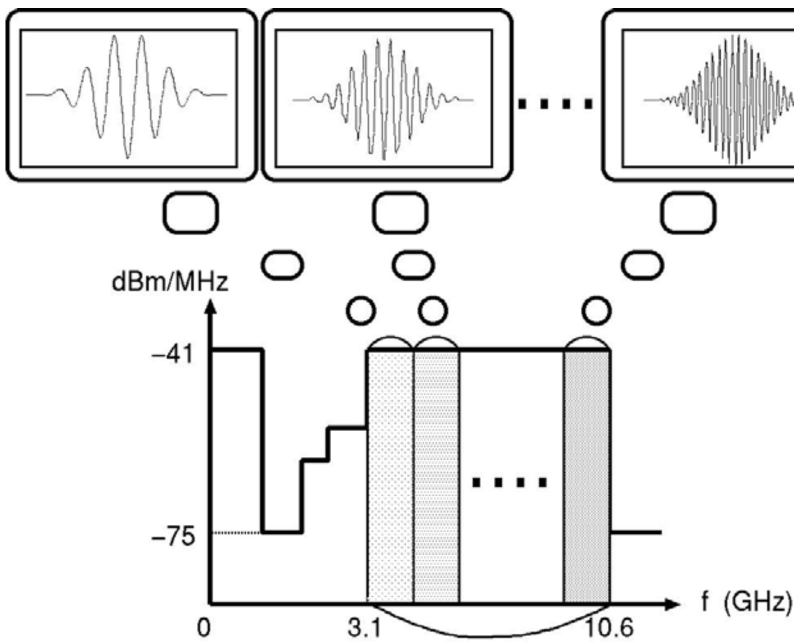
(a) Time Waveform of Pulse (right figure) and its Frequency Spectrum with notches in 2.4 and 5.2GHz for WLAN (left figure)



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

Ref. R.Kohno, H.Zhang, H.Nagasaka, "Ultra Wideband impulse radio using free-verse pulse waveform shaping , Soft-Spectrum adaptation, and local sine template receiving," doc.: IEEE 802.15-03/097r1, March 3, 2003.

2.9 Interference Mitigation among Other Radios(2/2)



Division to N portion

Synthesized Pulse Waveform

$$f(t) = \sum_{k=1}^{N} f_k(t)$$

Component Pulse Waveform Corresponding to Each Frequency Sub Band

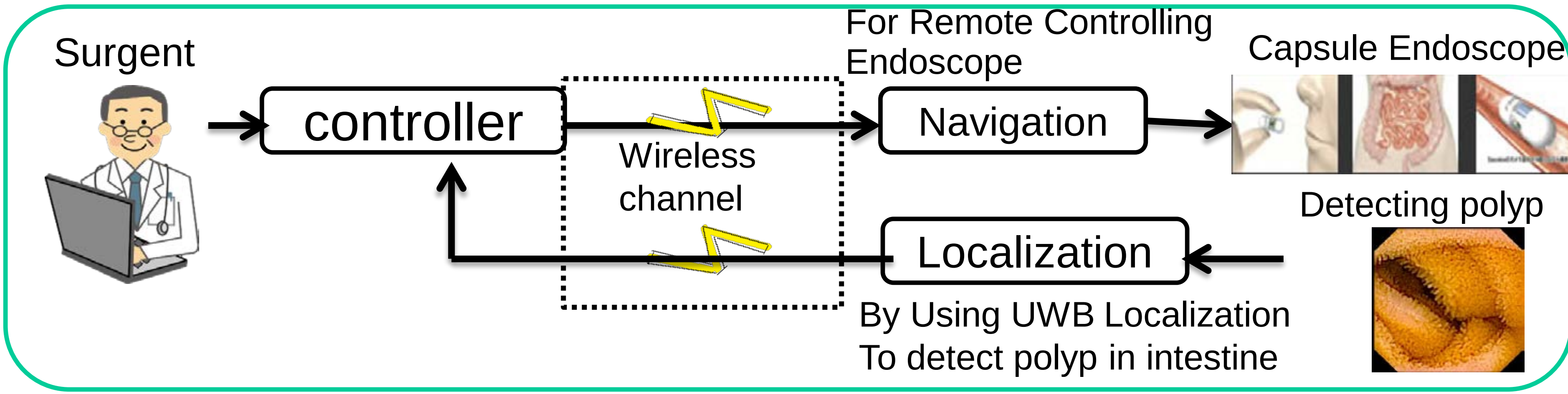
$$f_k(t) = \cos[2\pi(f_L + \frac{(1+2k)B}{2N})t] \times \frac{\sin(B\pi t)}{N\pi t}$$

B:bandwidth [$f_H \sim f_L$]

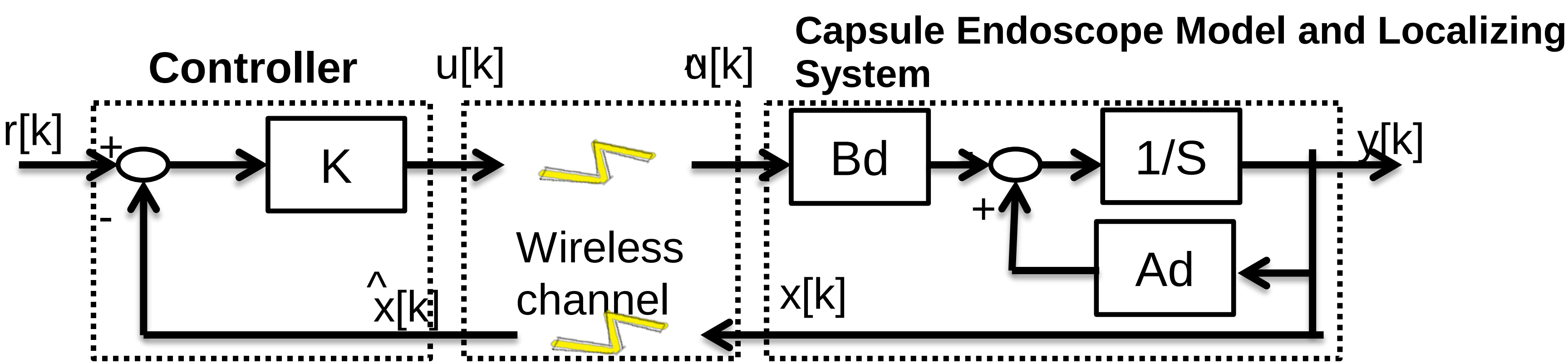
(c) Principle of Soft Spectrum Adaptation which can design any pulse waveform corresponding a desired spectral shape

2.10 Feedback Sensing and Controlling Loop for Remote Diagnosis and Therapy

Remote Sensing Polyp and Controlling Capsule Endoscopy in Intestine



Wireless Feedback Sensing and Controlling Loop for Endoscope

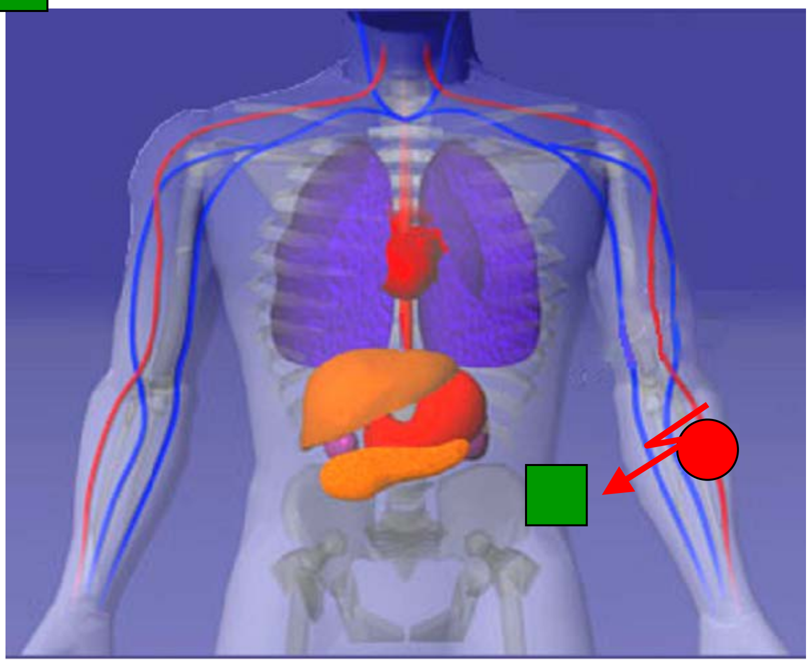


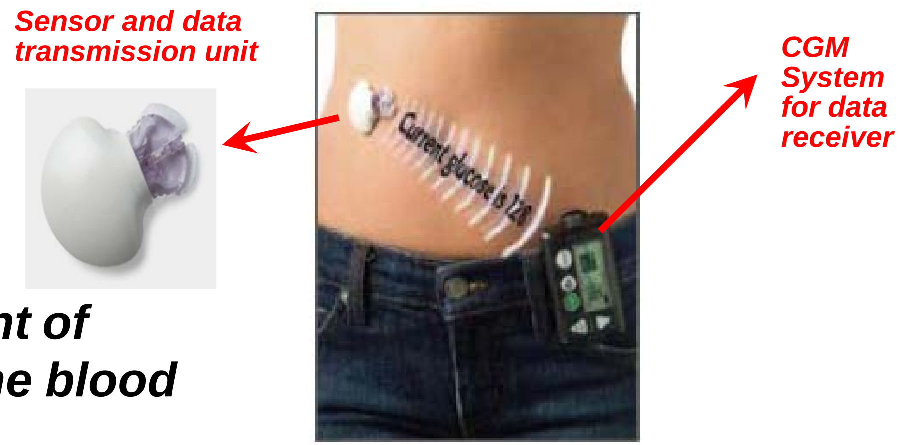
Feedback Delay Loop Model with Motion Equation

Remote Medicine of Types I & II of Diabetes Patients Using Wireless BAN with Glucose Sensor & Insulin Pump

Sensor with wireless transceiver

Insulin injector and controller

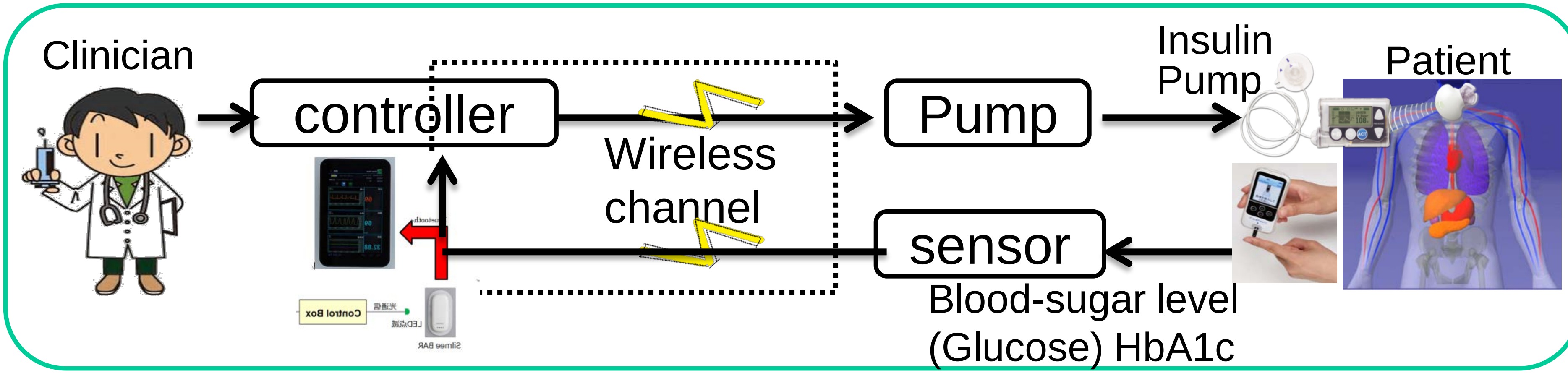




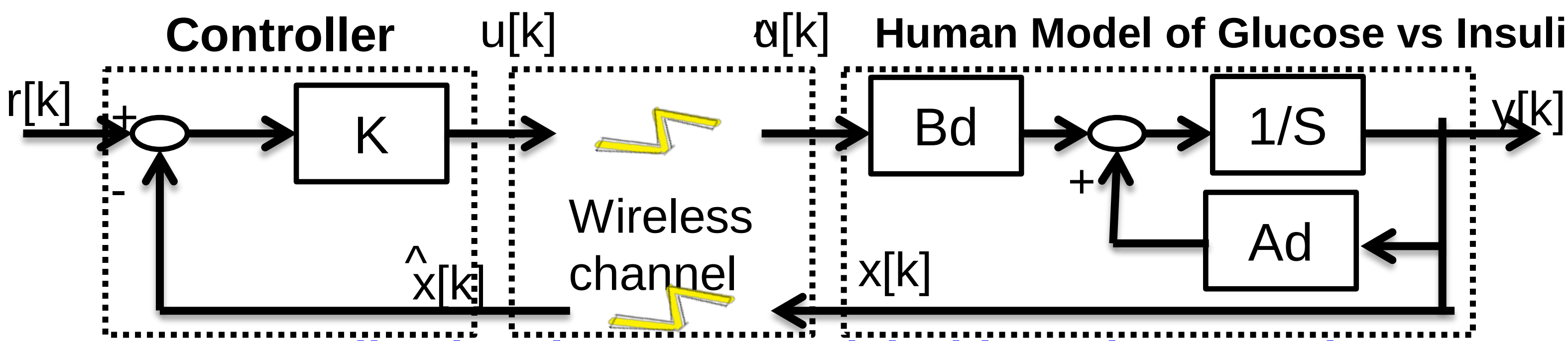
Injector controller adjusts the amount of insulin to be injected according to the blood sugar level provided by sensors.

Automatic management for diabetes

Automatic Remote Sensing Glucose and Controlling Insulin Pump for Diabetes Patients Using Wireless BAN



Wireless Feedback Sensing and Controlling Loop for Diabetes Patients



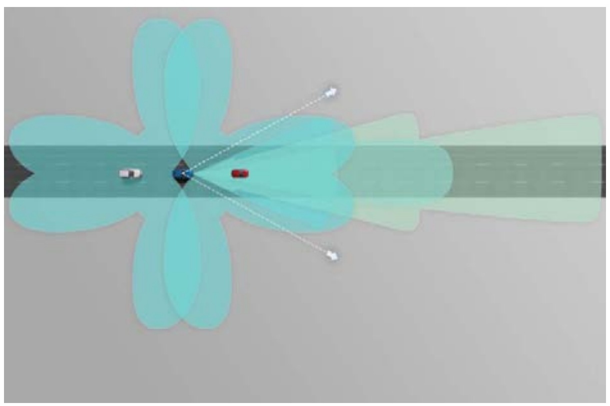
Feedback Delay Loop Model with Motion Equation

Wireless Feedback Controlling based on Cognitive Sensing with Dependable BAN must be necessary for life critical applications.

Dependable IoT/M2M for Advanced Driver Assistance Systems(1/2)

- 4-6 Mono Cameras
- 1-2 Stereo Cameras
- 2-4 Mid-Range Radar
- 2 Long Range Radar
- 8-16 Ultrasonic Sensors, 4 Wheel Speed Sensors
- Redundant Data Center
  - Number Crunchers for Data Fusion
  - ABS, ESP, …
  - Some ECUs we can’t tell you details today ☺
- Interaction with Powertrain, Body Domain, Navigation, Airbag, CAR2CAR, CAR2Infrastructure

Automated Driving is leaving the Research Labs. Soon it will be in mass production.

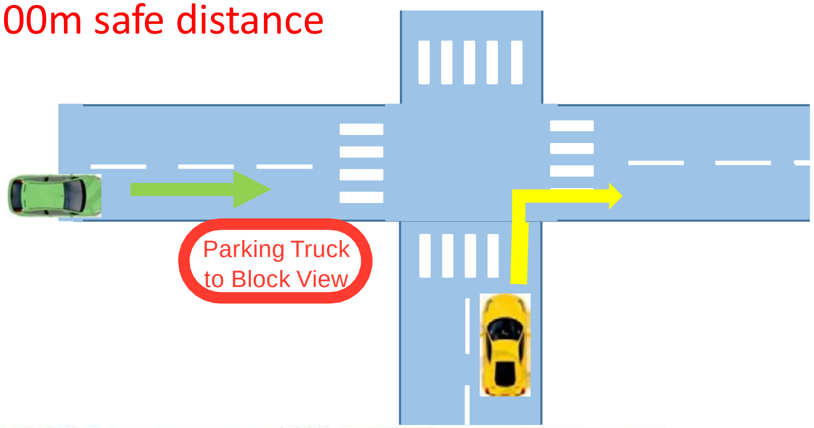


Surround vision with redundant sensors

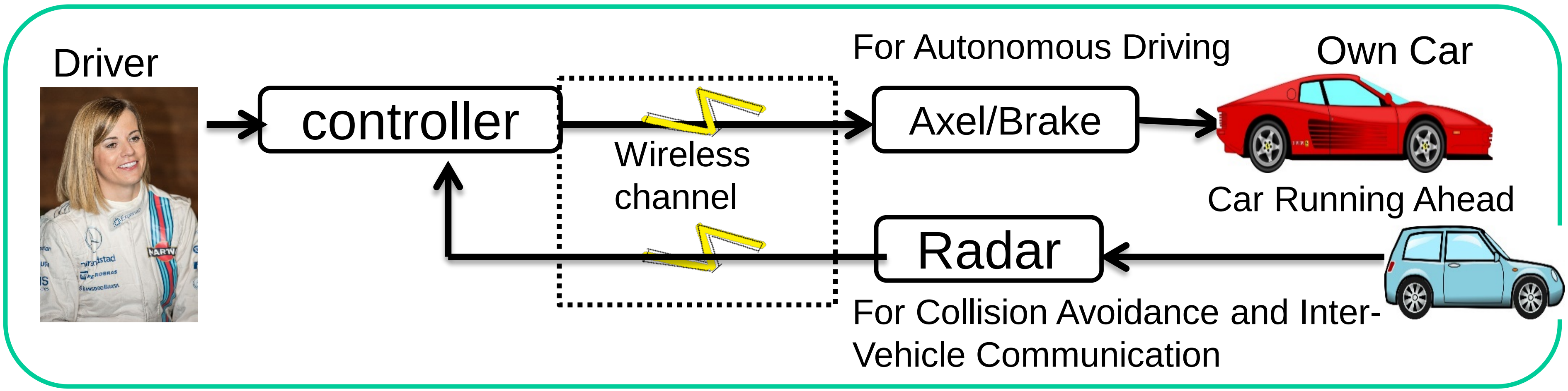
For automotive, Inter-vehicle communications(IVC) and Machine-to-Machine(M2M) inside a car like auto braking and autonomous driving must be core applications of Dependable M2M and IoT.

Step by Step from Auto Braking to Autonomous Driving

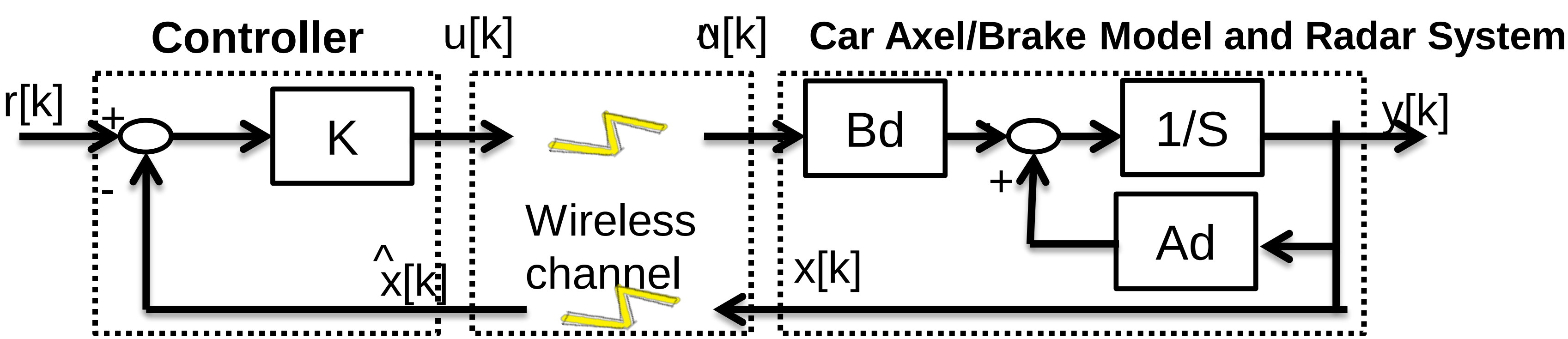
Green car at 50 km/h implies
100m safe distance



Collision Avoidance Radar and Automatic Brake Using Wireless Dependable BAN of Things/M2M

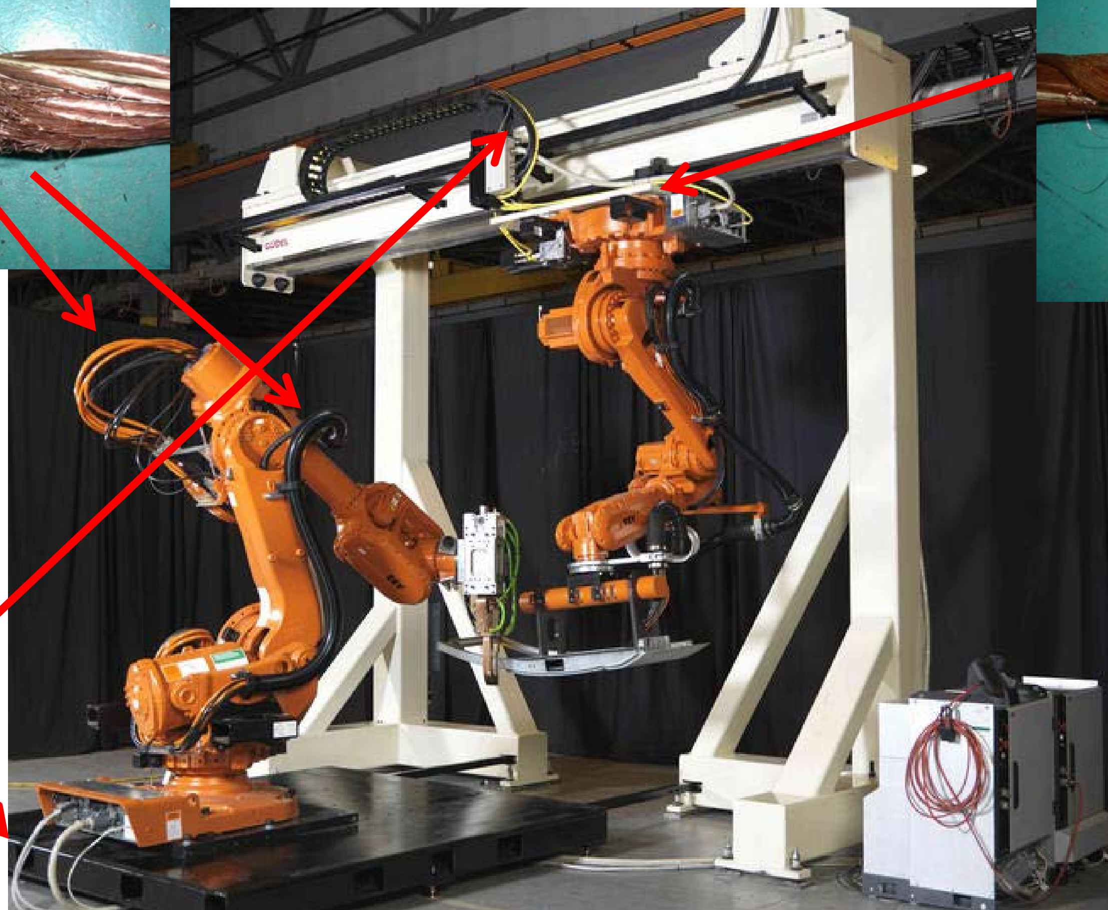


Wireless Feedback Sensing and Controlling Loop for Autonomous Driving



Feedback Delay Loop Model with Motion Equation

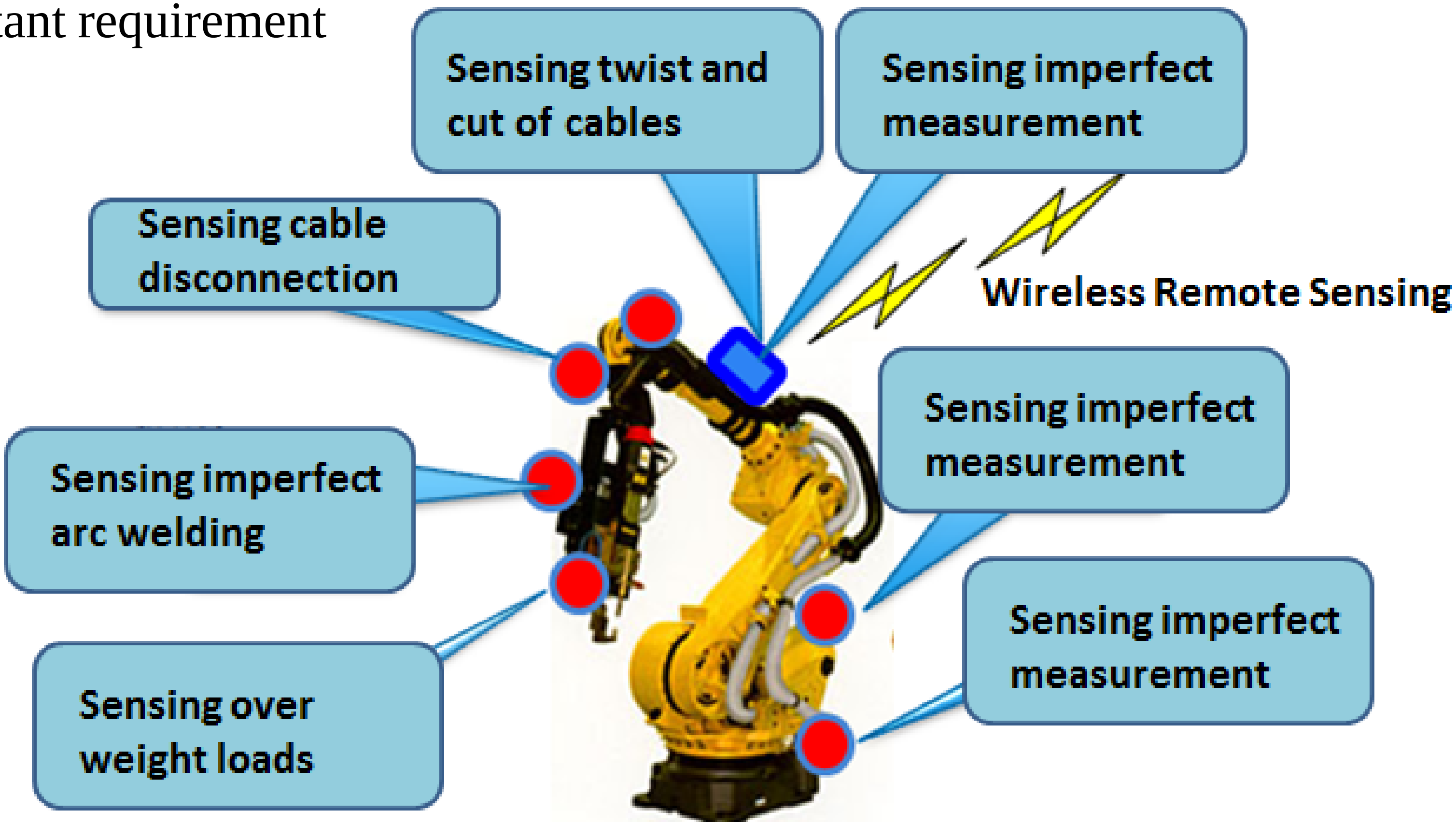
Use case in Factory Manufacturing Line; Detection of Twist and Cut of Cables



Prediction and Real-time Detection of twist and cut in signal and power cables

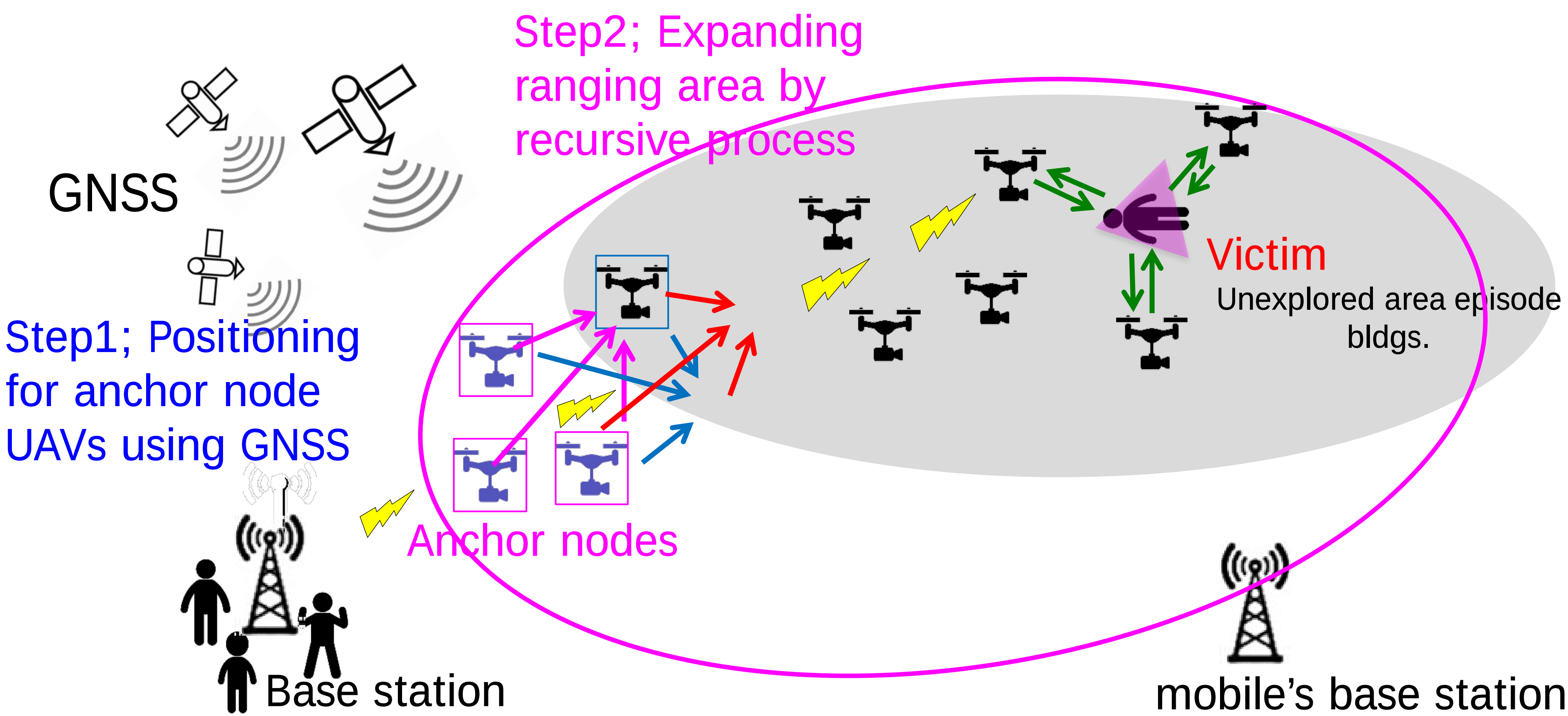
Use case ; Real-time Monitoring or/and Controlling Robots

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

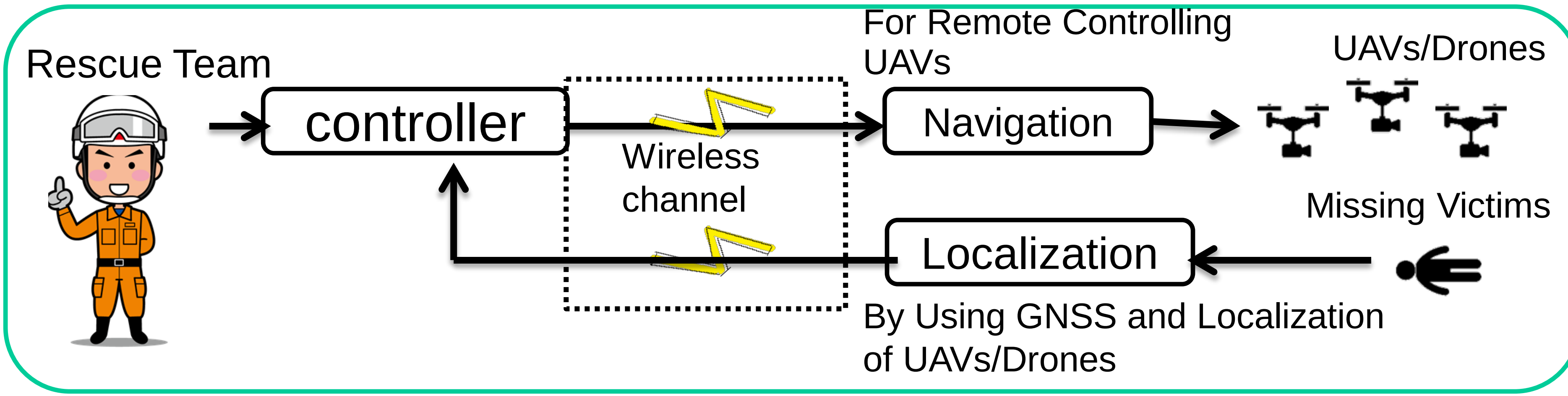


2016-2017 New Zealand(UC)-Japan(YNU) Joint Project；

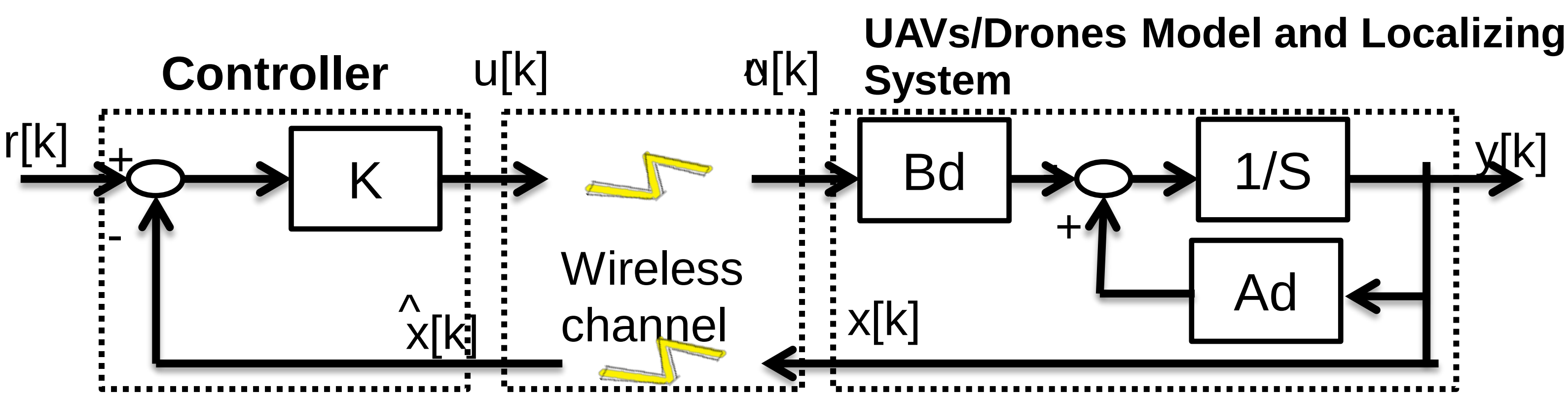
Dependable Wireless Body Area Networks to Support Search and Rescue and Medical Treatment in Disaster Scenarios Using Multiple UAVs



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

3.1 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.

3.2 Discussion on 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

3.2 Discussion on Uniqueness different from existing standards(2/2)

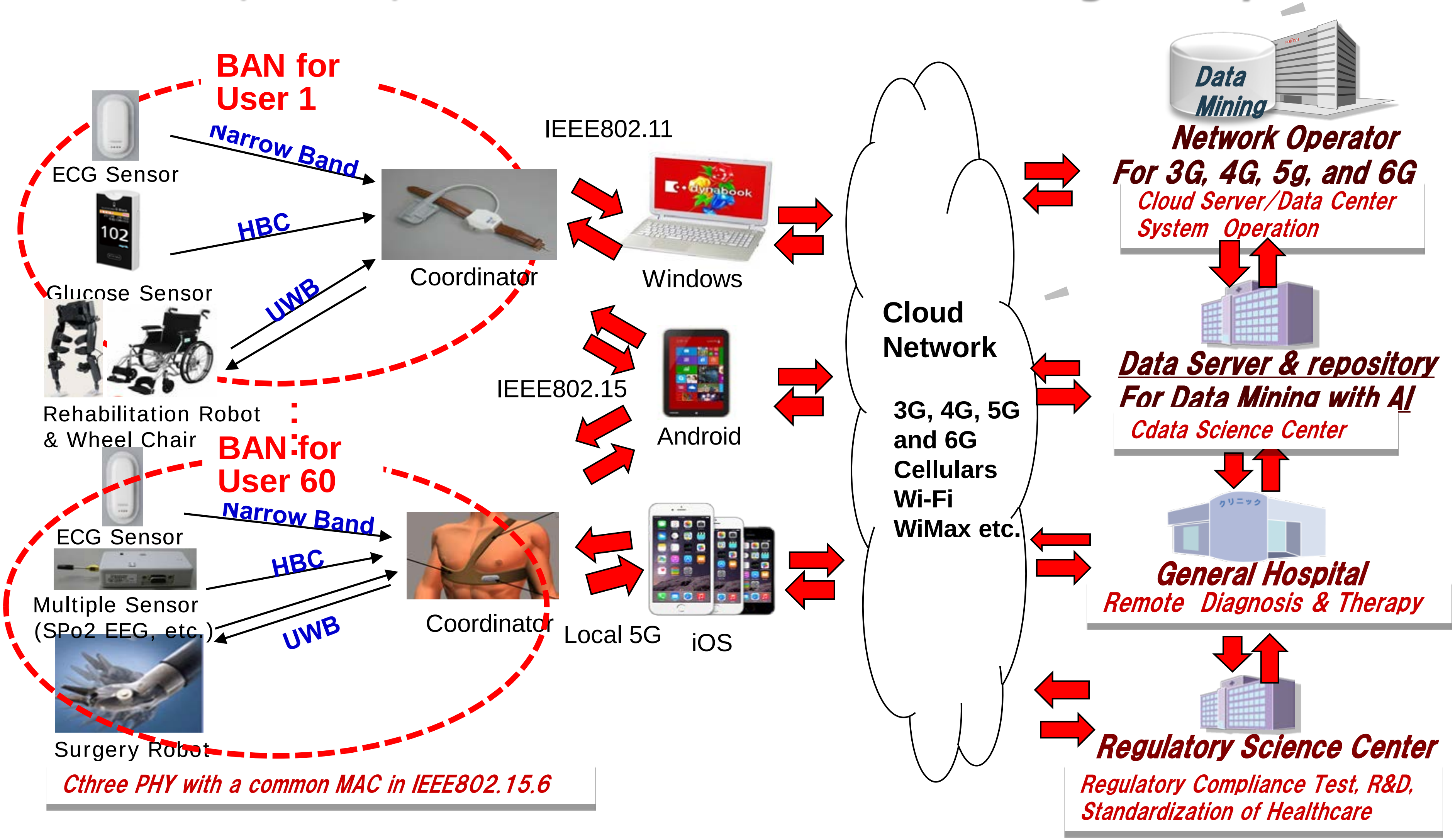
2. PHY technologies to satisfy technical requirement for enhanced dependability in the focused applications of in automotive industry.

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.

6G(Beyond 5G) ICT & Data Science Platform for Infrastructure with BAN , Cloud, and Data Servers Based on Regulatory Science



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

Contributions

- We focus on amendment of IEEE802.15.6 for enhanced dependability in PHY and MAC.
- We move on SG/TG/WG to complete the amendment.
- If you have any question and comment, you are welcome to discussion in IG-DEP or TG6a.
- Send content contributions to

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