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

Submission Title: IG DEP Feasible Technologies for Enhanced Dependability of WBAN

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Re: IG DEP Reabilble Technologies and Theories for Enhanced Dependability of Wireless Networks and Infrastracture

Abstract: IG-DEP focused on amendment of existing IEEE802.15.6 for WBAN with enhanced dependability such as enhanced dependability in cases of overlaid multiple BANs and co-exiting other radios, feedback loop for remote sensing and controlling. Corresponding to the discussion, technical requirement has been updated. To carry out the enhanced dependability there are many feasible technologies and theories. Some of them fare introduced.

IG DEP Feasible Technologies for Enhanced Dependability of WBAN

November 11th, 2020

Ryuji Kohno; Yokohama National University(YNU), Japan & CWC, University of Oulu, Finland

1. 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. 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.

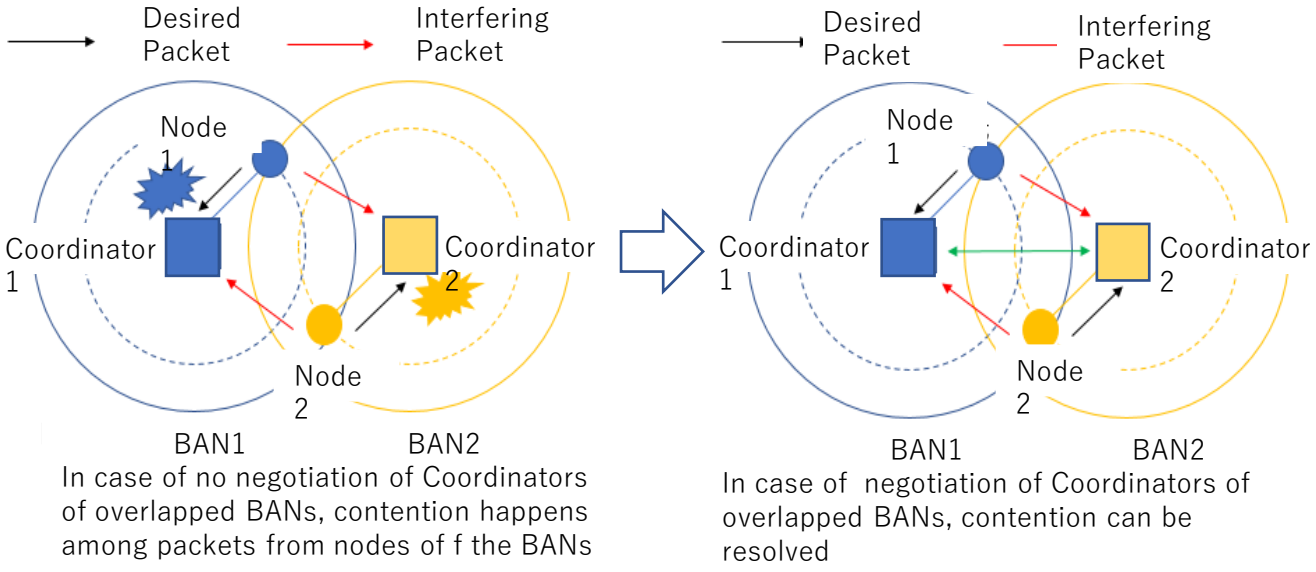
2.1 Contention among Overlaid BANs

Issue

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

Solution

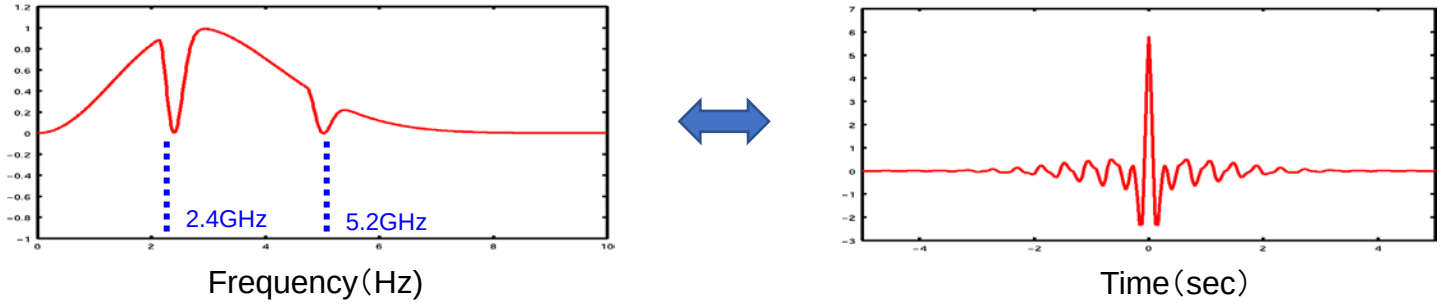
- Negotiation between coordinators scheduling between different BANs, to prevent deterioration due to inter-BAN interference



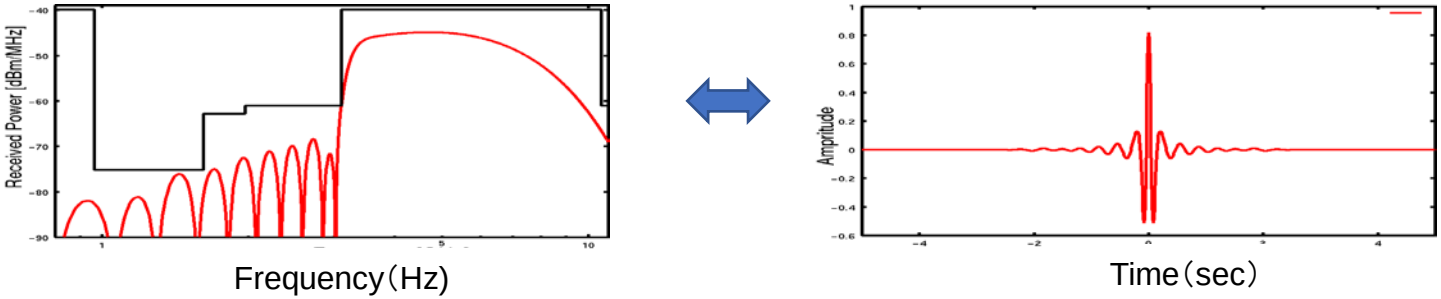
- What is interference at the MAC layer
  - Sensor nodes within the communication range try to transmit packets at the same timing, causing collisions, making it impossible to communicate correctly

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

2.2 Interference Mitigation among Other Radios(1/2)



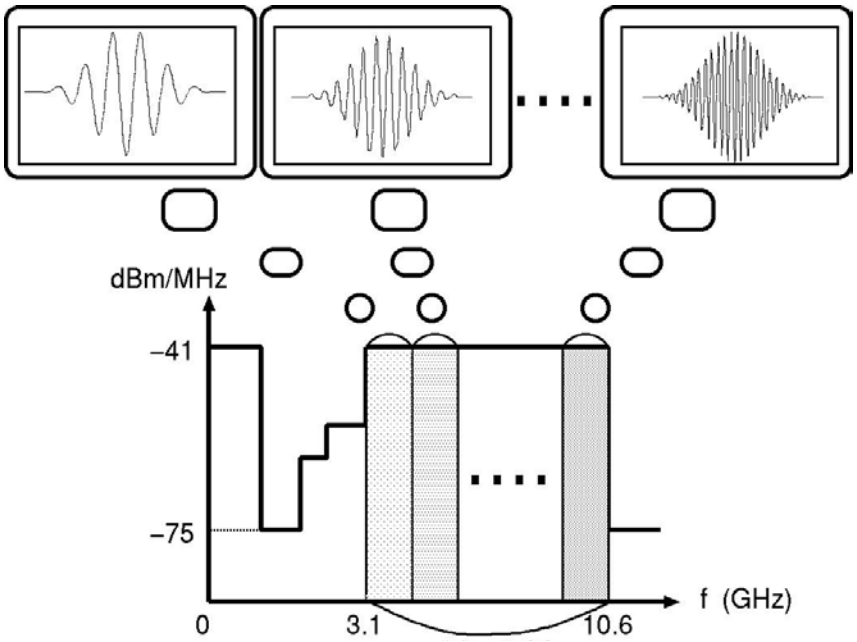
(a) Time Waveform of Pulse (right figure) and its Frequency Spectrum with notches in 2.4 and 5.2GHz for WLAN (left figure)



(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.

2.2 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

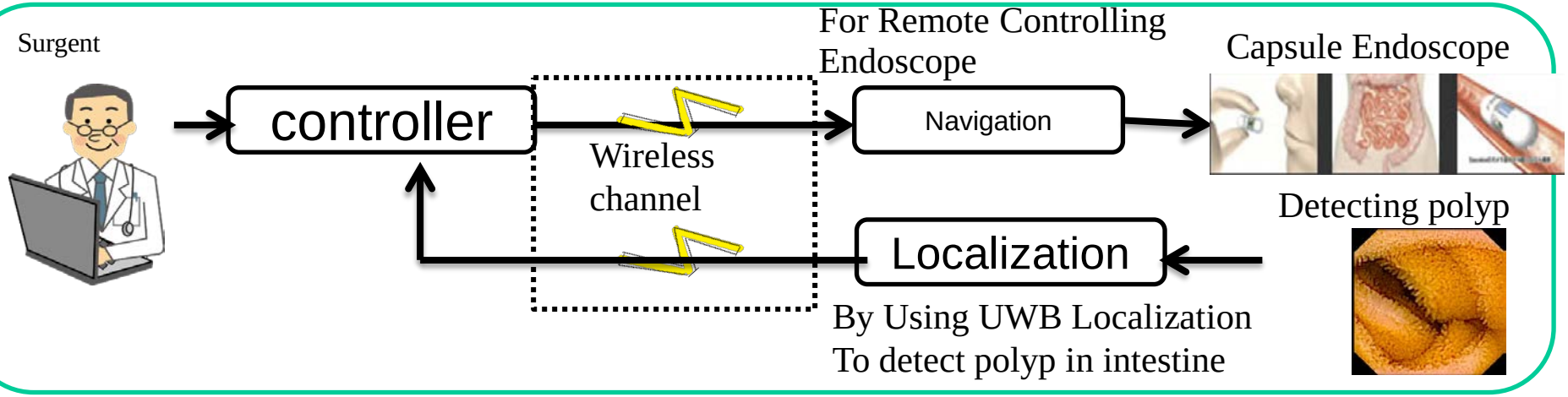
$$f_k(t) = \cos[2\pi(f_L + \frac{(1+2k)B}{2N})t] \times \frac{\sin(B\pi t)}{N\pi t}$$

B:bandwidth [$f_H \sim f_L$]

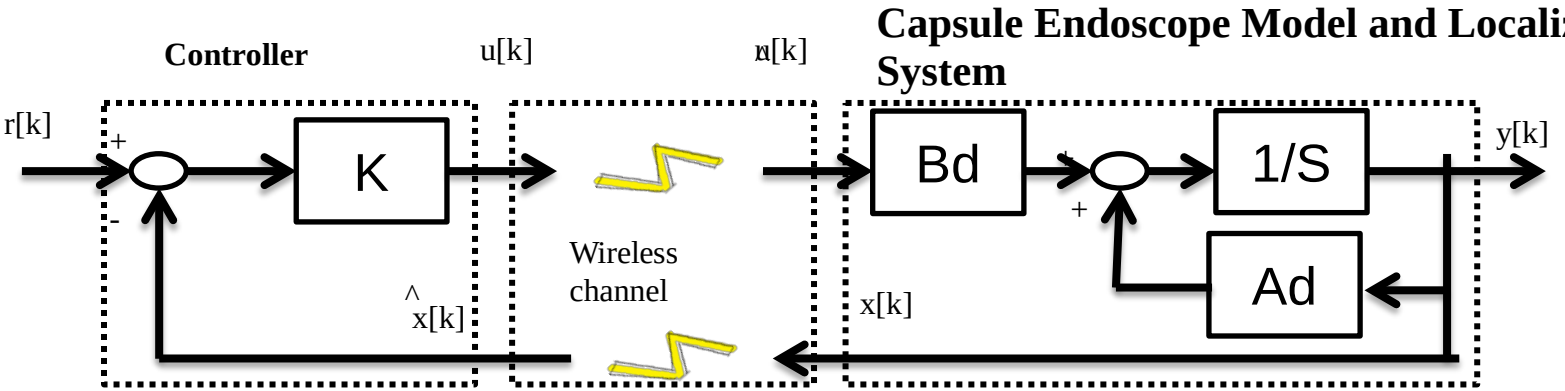
(c) Principle of Soft Spectrum Adaptation which can design any pulse waveform corresponding a desired spectral shape

3.2 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

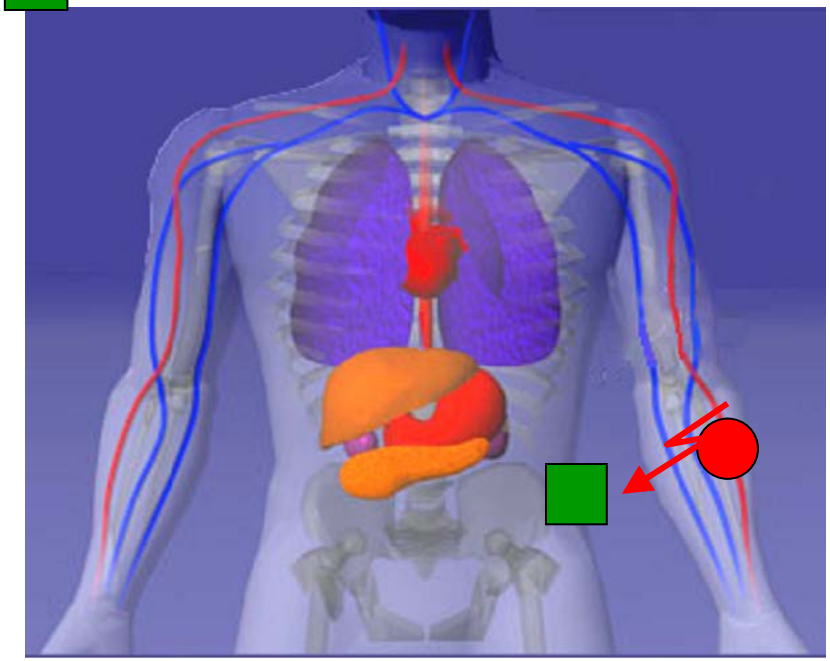


Feedback Delay Loop Model with Motion Equation

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



Injection unit of Insulin

Insulin Pomp installed Glucose sensor

RF Transmitter

Glucose sensor

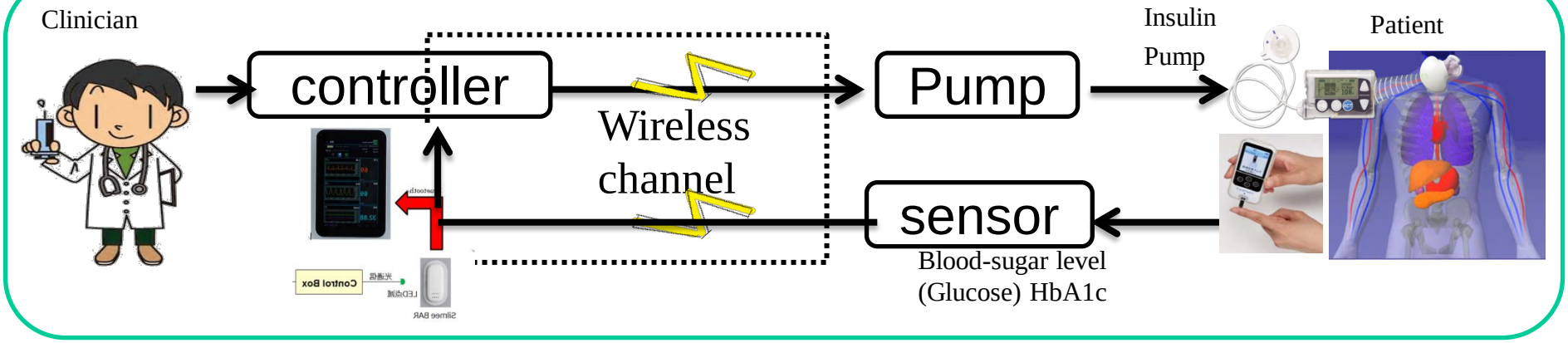
Sensor and data transmission unit

CGM System for data receiver

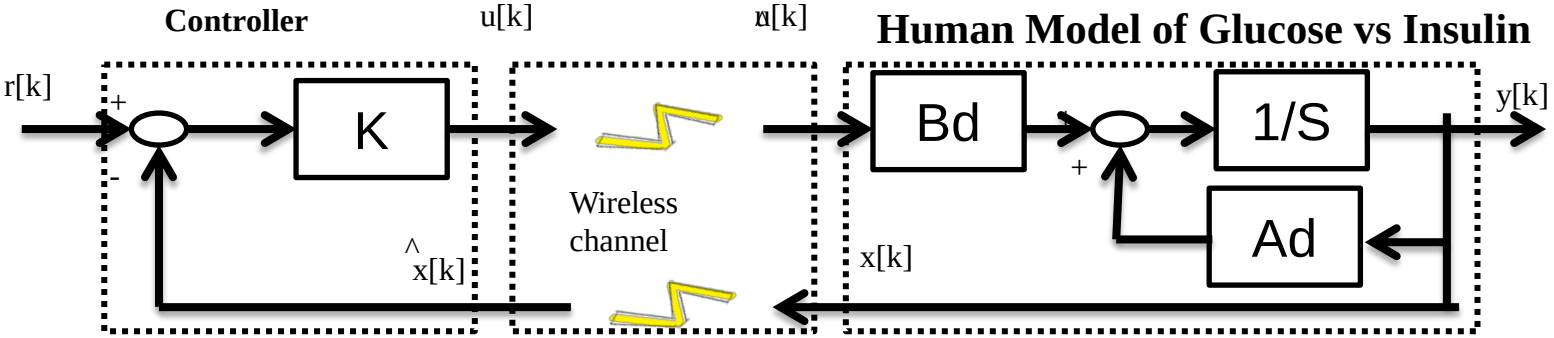
Injector controller adjusts the amount of insulin to be injected according to the blood sugar level provided by sensors.

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



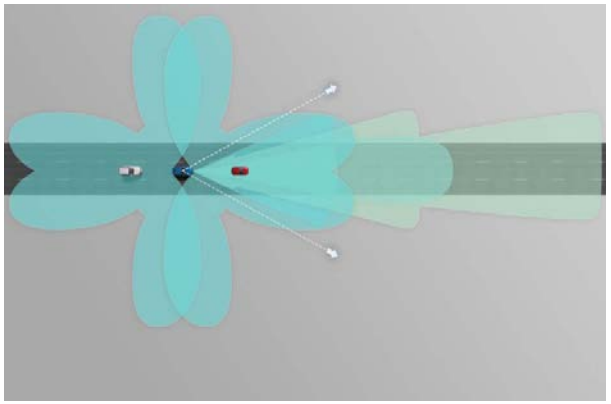
Feedback Delay Loop Model with Motion Equation

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.

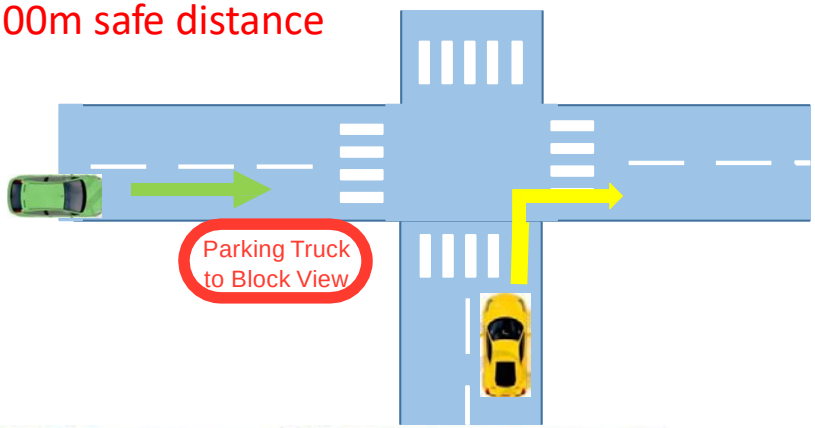


Surround vision with redundant sensors

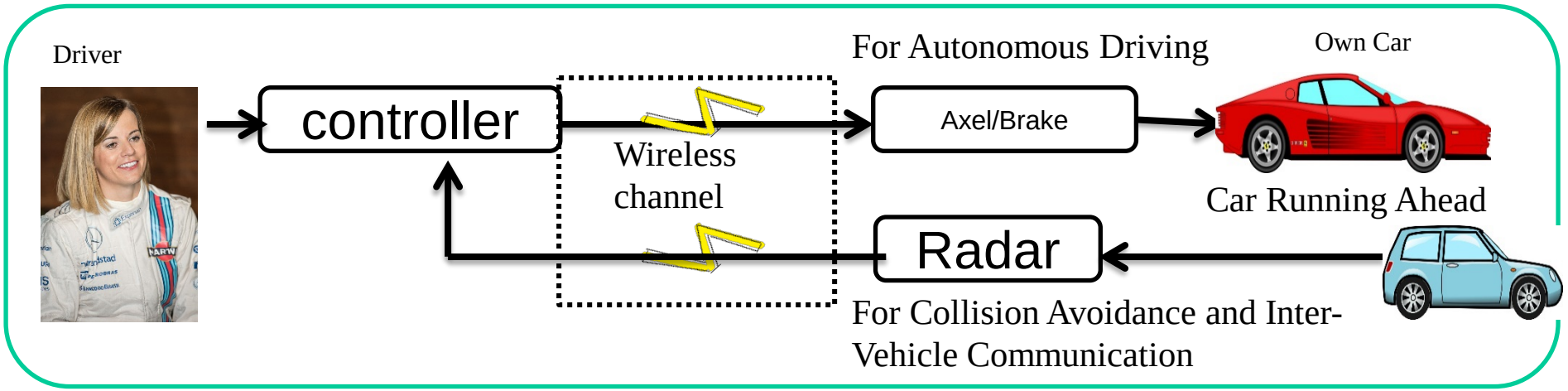
For automotive, Inter-vehicle communications(IVC) and Machine-to-Machine(M2M) inside a car like auto braking and autonomous driving must be core applications of Dependable M2M and IoT.

Step by Step from Auto Braking to Autonomous Driving

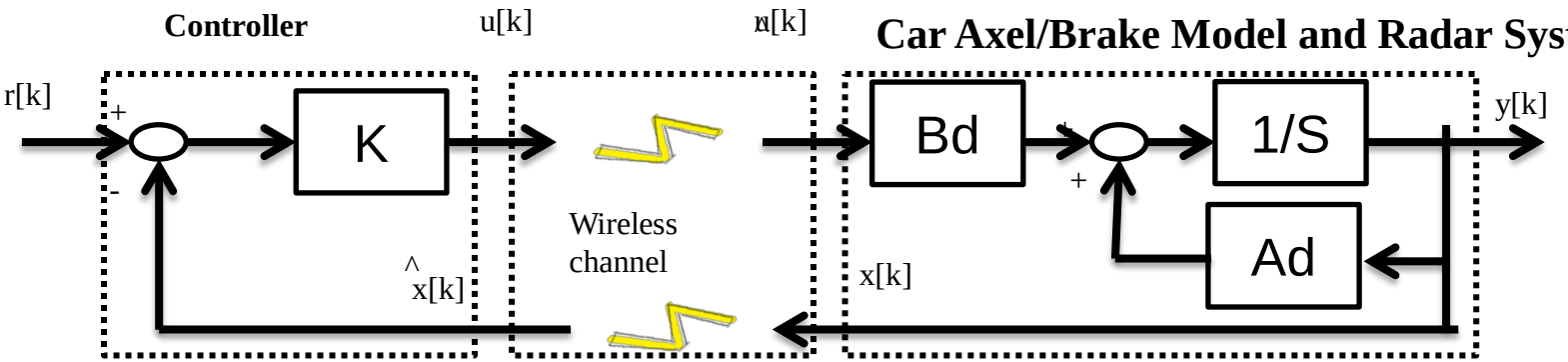
Green car at 50 km/h implies
100m safe distance



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

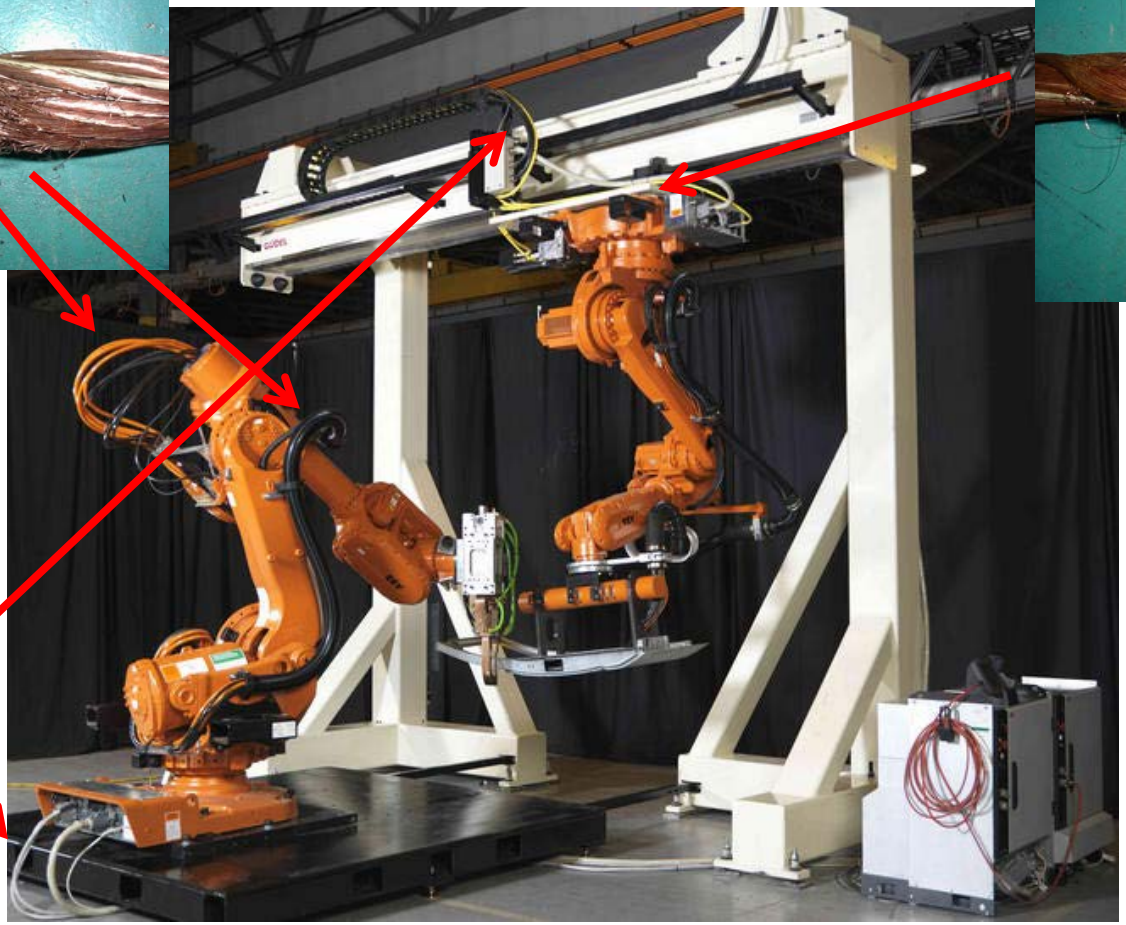


Wireless Feedback Sensing and Controlling Loop for Autonomous Driving



Feedback Delay Loop Model with Motion Equation

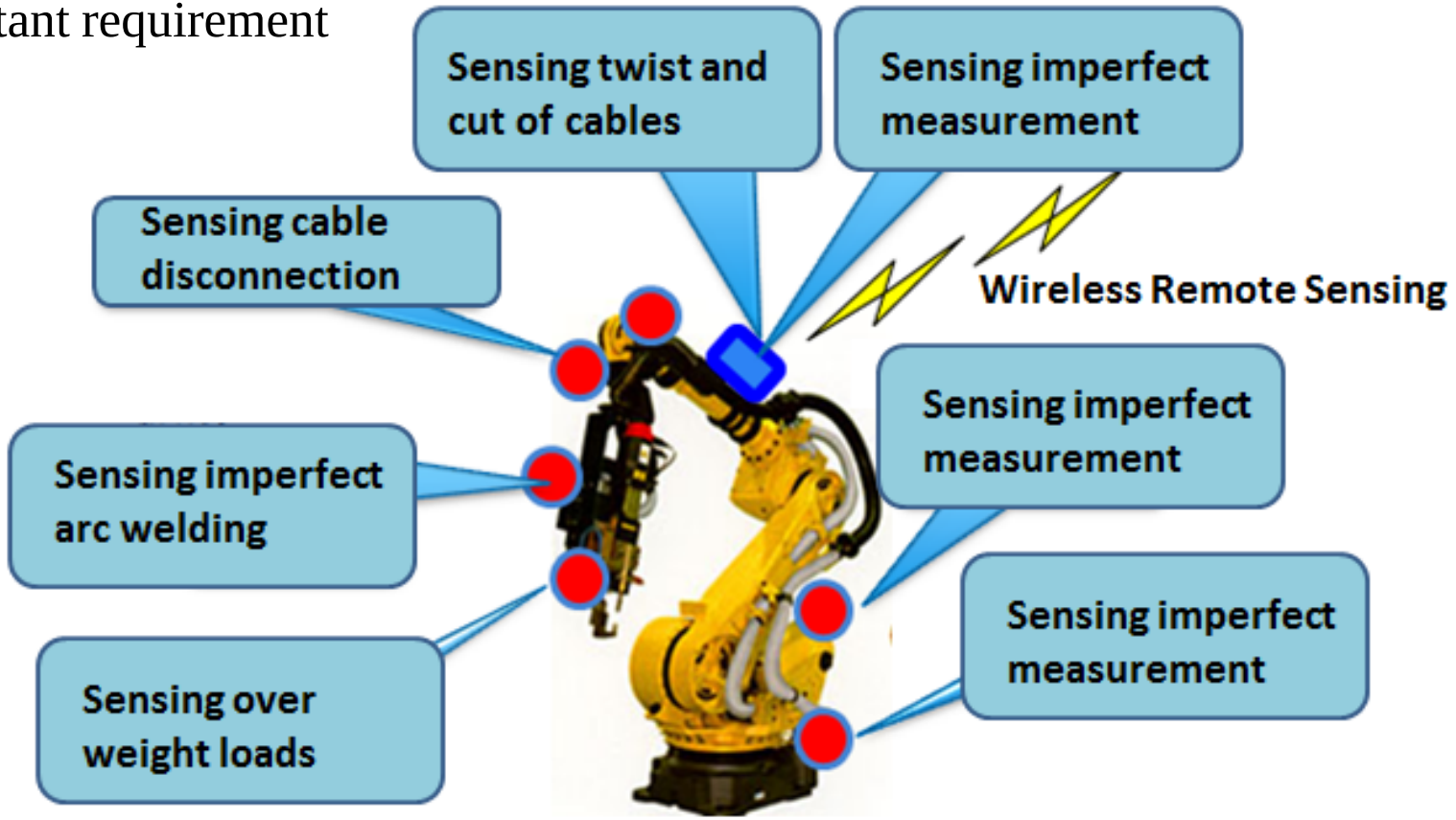
Use case in Factory Manufacturing Line; Detection of Twist and Cut of Cables



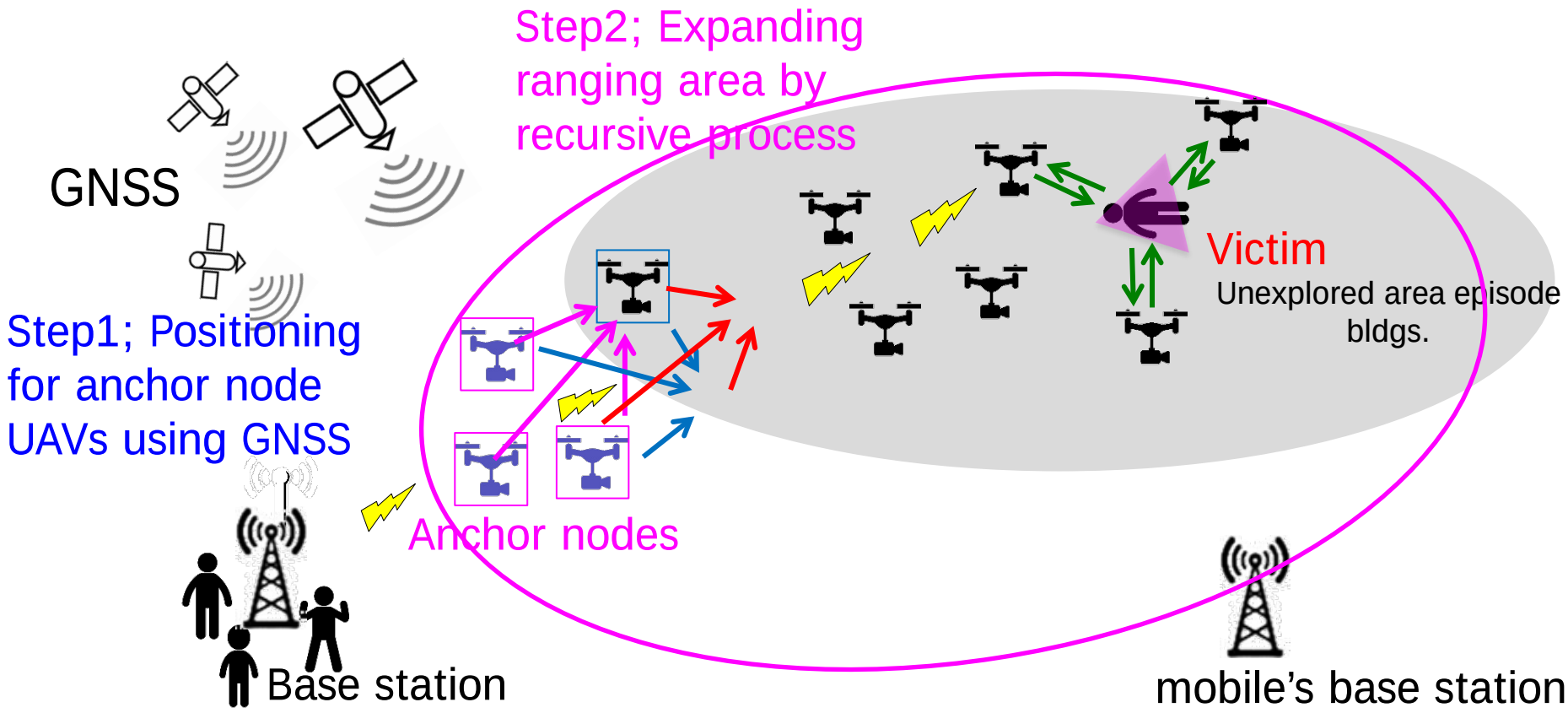
Prediction and Real-time Detection of twist and cut in signal and power cables

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

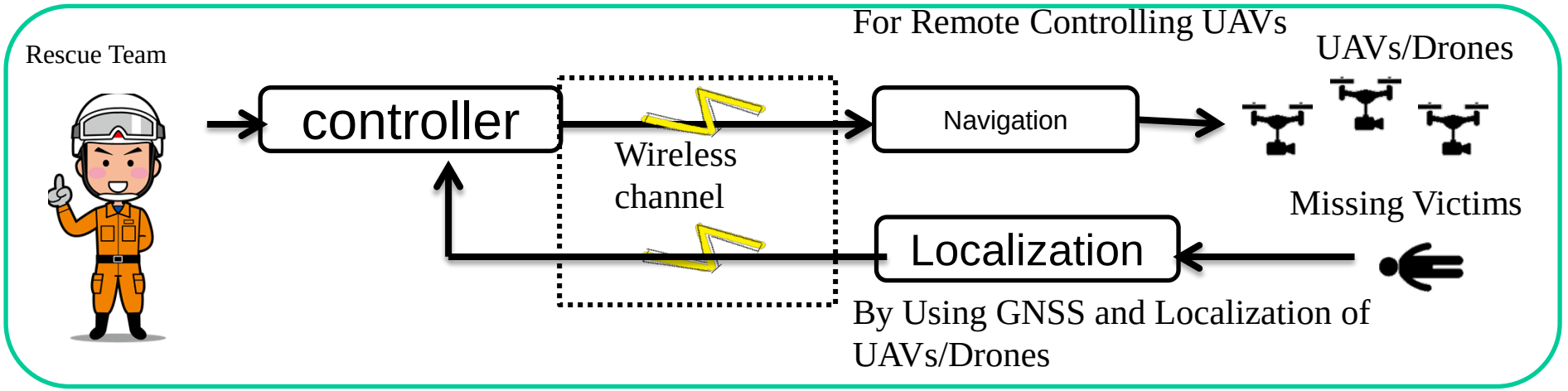
In order to improve QoS of controlling robots in factory lines, real-time sensing and controlling with permissible feedback control loop must be important requirement



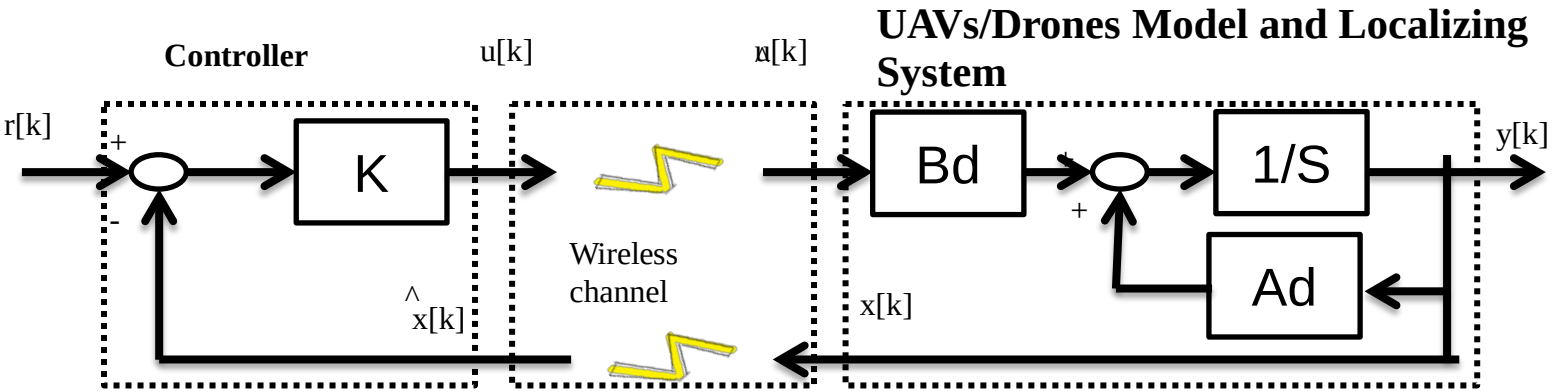
2016-2017 New Zealand(UC)-Japan(YNU) Joint Project; Dependable Wireless Body Area Networks to Support Search and Rescue and Medical Treatment in Disaster Scenarios Using Multiple UAVs



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

3.3 Theory and Technology for Dependable Network: Interdisciplinary Works between Controlling Theory and Communication Theory

1. A transceiver has to know the aim of controlling.
2. Controlling theory describe the action by mathematical form for the aim.
3. Conventional controlling theory does not care of transmission errors in a wireless channel but focus on stability of controlling.
4. Conventional communication theory or information theory does focus on transmission errors but does not care of different importance or priority of each information segment.

We need to combine Controlling Theory and Communication Theory for Dependable Wireless Controlling or M2M.

3.4 Research Subjects of Dependable Wireless

（1）Although conventional controlling theory does not care of errors in a link or a channel, a new controlling theory will be established in a case of assuming channel errors in a controlling link or network. A new communication theory for M2M controlling should be established to achieve much more reliable, secure, robust against errors, or dependable connection.

（2）Common theories and algorithms between controlling and communication theories will be established. For instance, Levinson-Darvin algorithm in linear prediction has commonality with Barlecamp-Massy algorithm of coding theory.

（3）Dependable wireless M2M may promote a new global trend of R&D and business in wide variety of industries, car, energy, communications, finance, construction, medicine in a world.

3.5 Bi-directional transmission model

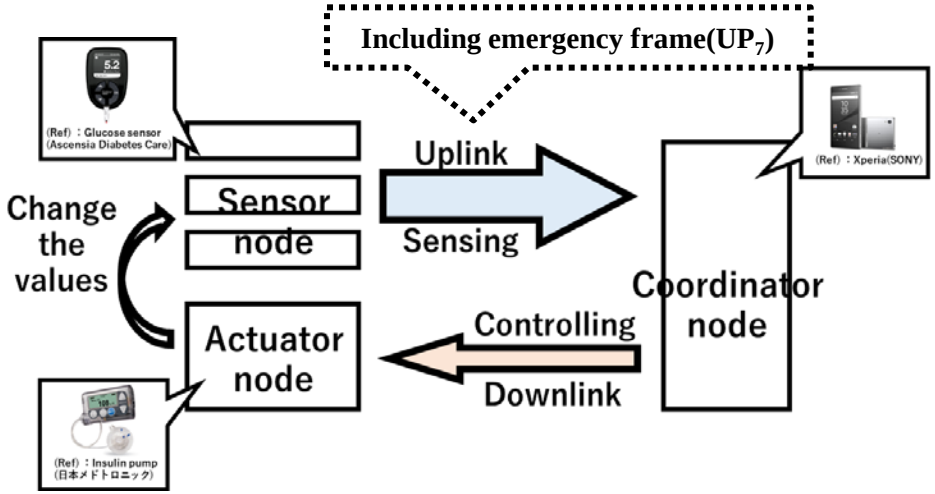


Fig. A example of feedback model

Table. Benchmark of bi-directional model

Parameters	Uplink	Downlink
Payload length	Short~Long*	Short
Interval of frame generation	Low~High*	Low
Priority	Low~High*	Highest

* : Depends on the types of node

Table. Relation between UP(User Priority) mapping and control frame(Downlink)

Priority	User priority	Traffic designation	Frame type
Lowest	0	Background (BK)	Data
	1	Best effort (BE)	Data
	2	Excellent effort (EE)	
	3	Video (VI)	
	4	Voice (VO)	
	5	Medical data or network control	
	6	High-priority medical data or network control	
Highest	7	Emergency or medical implant event report	Data

Downlink frame based on all levels

- **Issues of bi-directional WBAN system in MAC layer**

・Priority order become like this sign of inequality, but standard is not considered

medical < emergency < control(downlink)

  - Change a part of conventional UP mapping and EAP

・In order to consider the quantitatively dependable performance

- **Focus on these features, we propose a MAC protocol for WBAN bi-directional transmission model**

Ref. Toshifumi Miyazaki, Ryuji Kohno: "A dependable MAC protocol matched to bi-directional transmission for dependable wireless body area network (WBAN), doc.# 15-18-0115-01-0dep

3.5 Modified MAC of IEEE 802.15.6 for Bi-Directional Packets of Sensing and Controlling Feedback Loop

Table. Modified UP mapping for bi-directional transmission

User priority	Traffic designation	Frame type
0	Best effort(BE)	Uplink
1	Video(VI)	Uplink
2	Voice(VO)	Uplink
3	Low-medical	Uplink
4	High-medical	Uplink
5	Emergency	Uplink, Downlink
6	Control data	Downlink

- Control frame is calculated and transmitted based on sensing frames which include medical and emergency traffic

−Change the UP class like table

- EAP is set in hybrid superframe structure in IEEE 802.15.6 based on UP mapping and allow to transmit only emergency frames(or implant event report)

−For this reason, in general, this phase becomes like a reserve field and performance in MAC layer(i.e. latency, throughput) decrease

- We proposed **M-EAP(Modified-EAP),** which is allowed to transmit both emergency and control frame of downlink.

−Become more busy phase than EAP, so the performance can be improved

−Adapt to priority control based on modified UP mapping

−In case, if frame collision occurred between uplink and downlink traffic, coordinator node can find the frame collision based on the feature of acknowledge

- This proposal scheme, M-EAP, is based on contention base, therefore it cannot guarantee the permissible values based on $P_{collision}$

3.6 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

3.6 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.

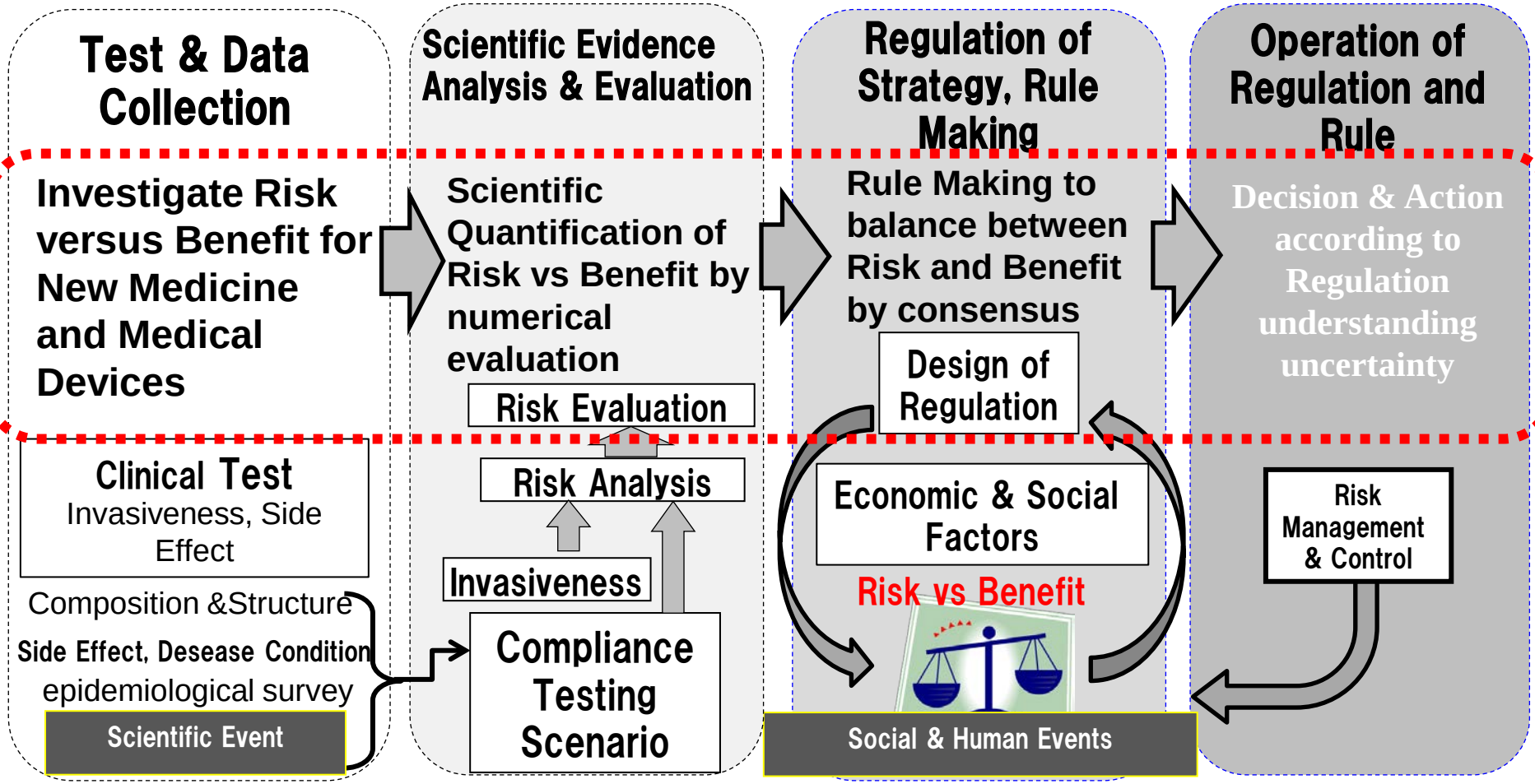
4. Technical Challenges for Enhanced Dependability

- 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.

4.1 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 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.**

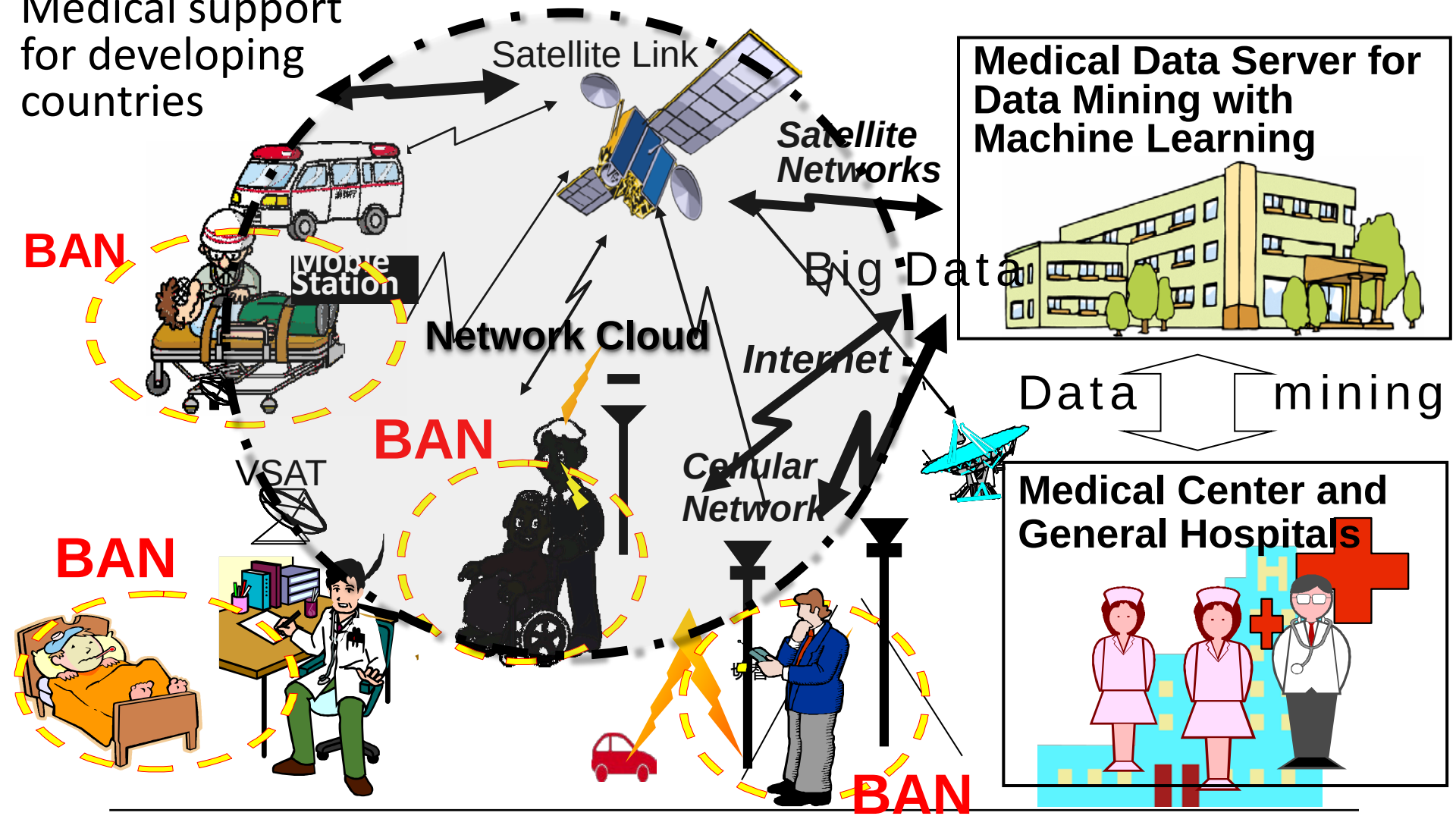
4.2 Regulatory Science to Guarantee Dependability and Compliance in case of Medicine and Medical Devices



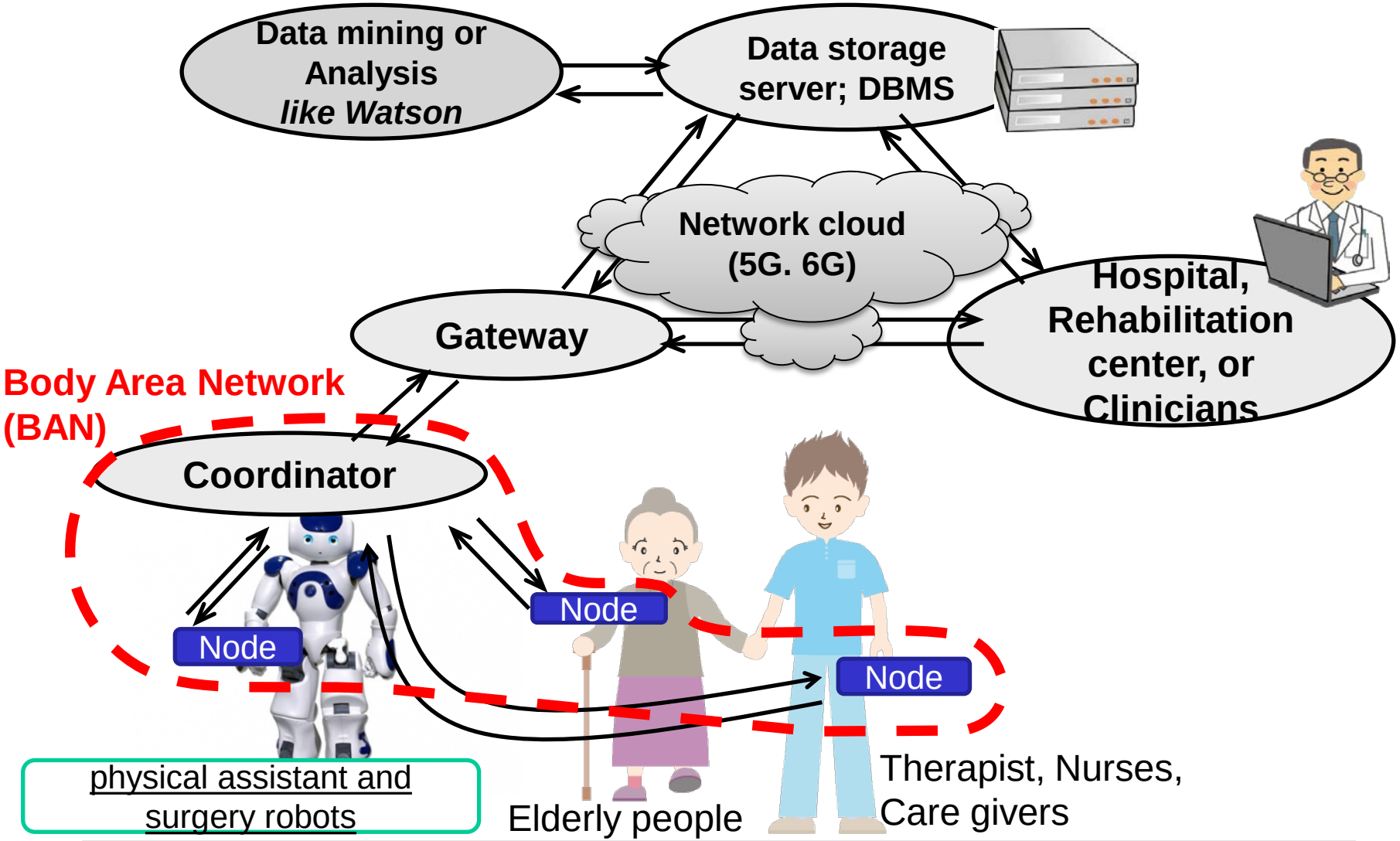
To enhance dependability of wireless systems, Regulatory Science is useful while showing risk vs benefit with cost and remained uncertainty because it can protect not only users but also manufactures

2.3 BAN- Use Cases for Remote Medical Services

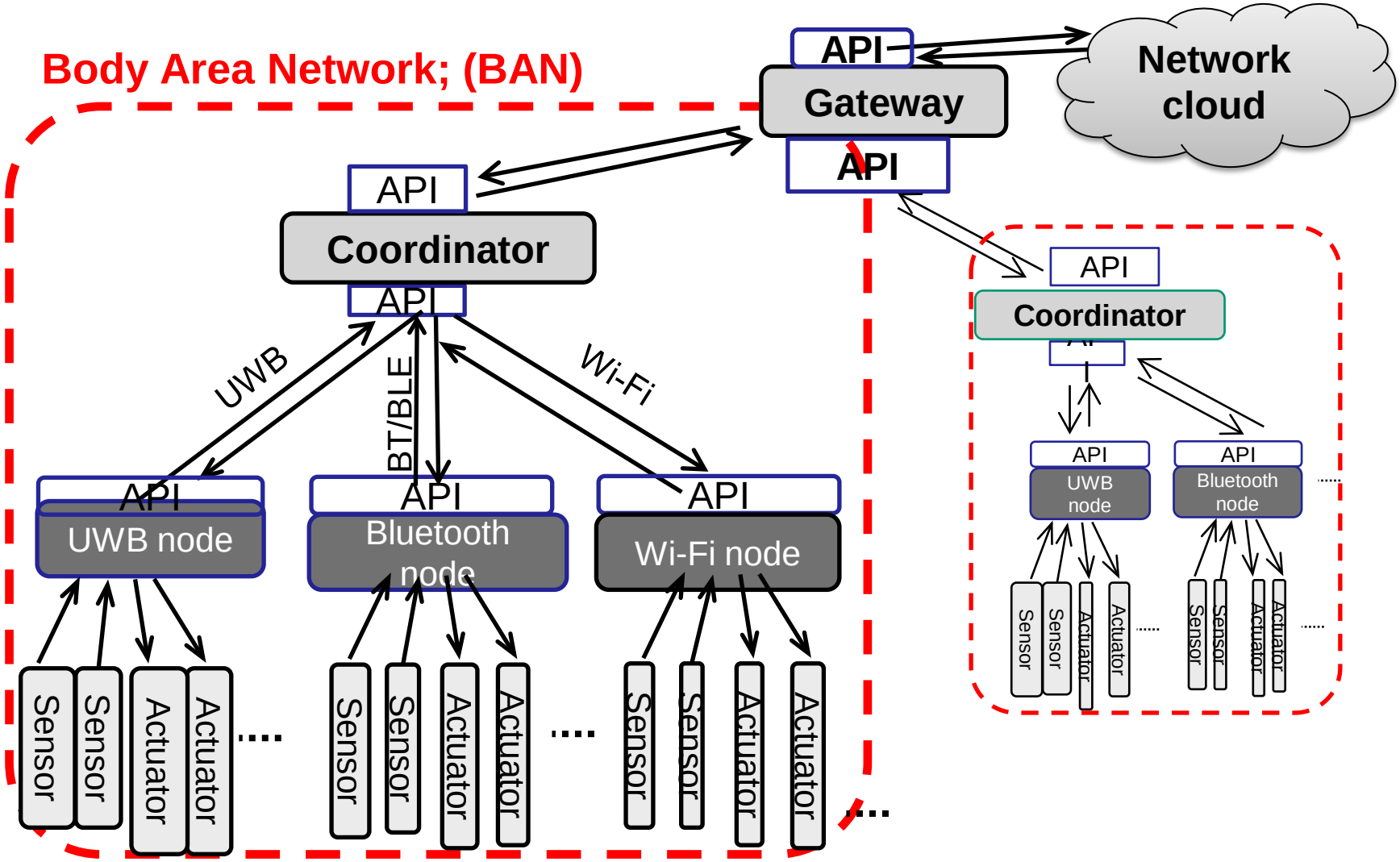
Medical support for developing countries



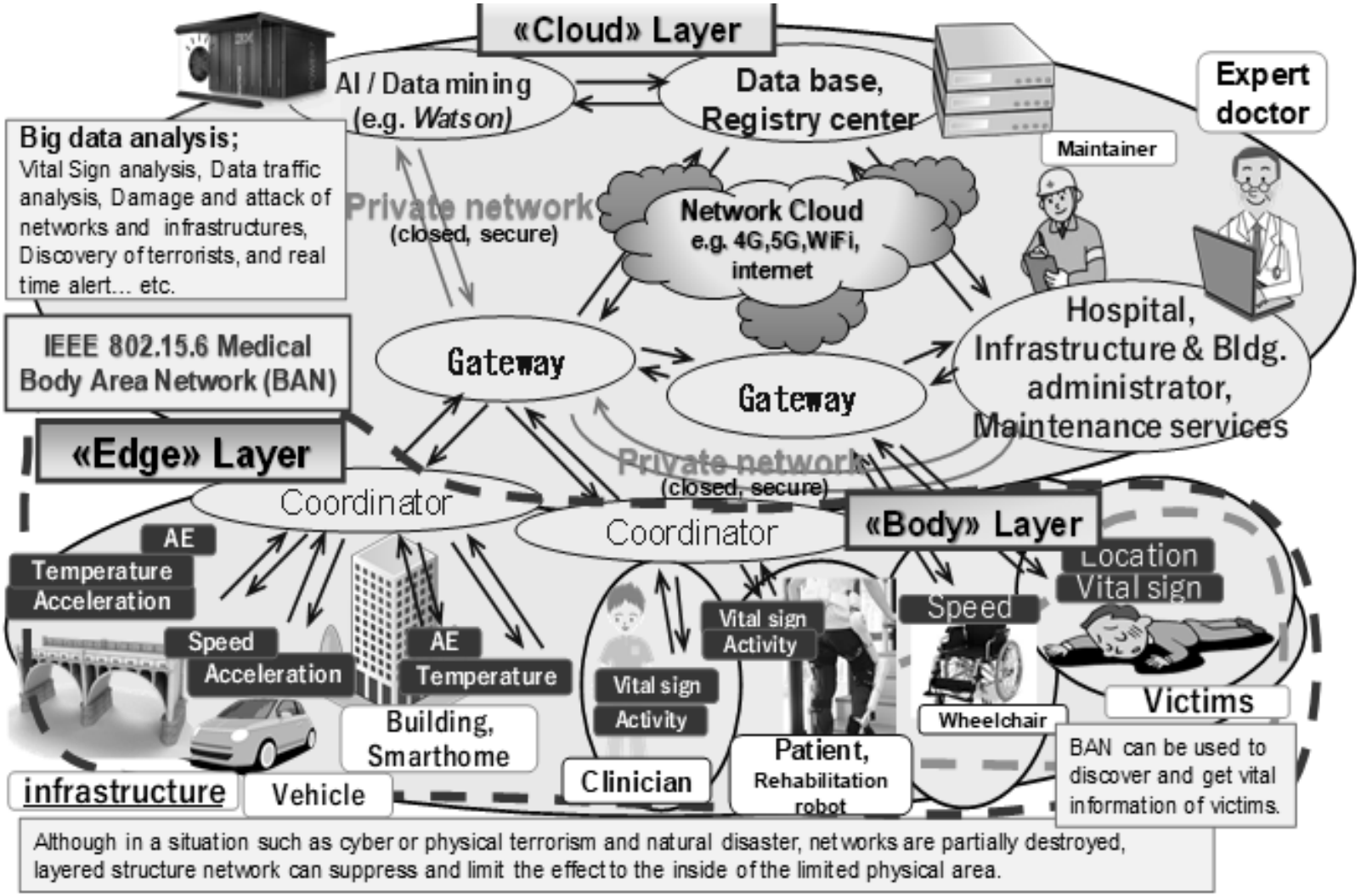
BAN-base Universal Platform with Network Cloud, Data Mining Server for Medical Healthcare



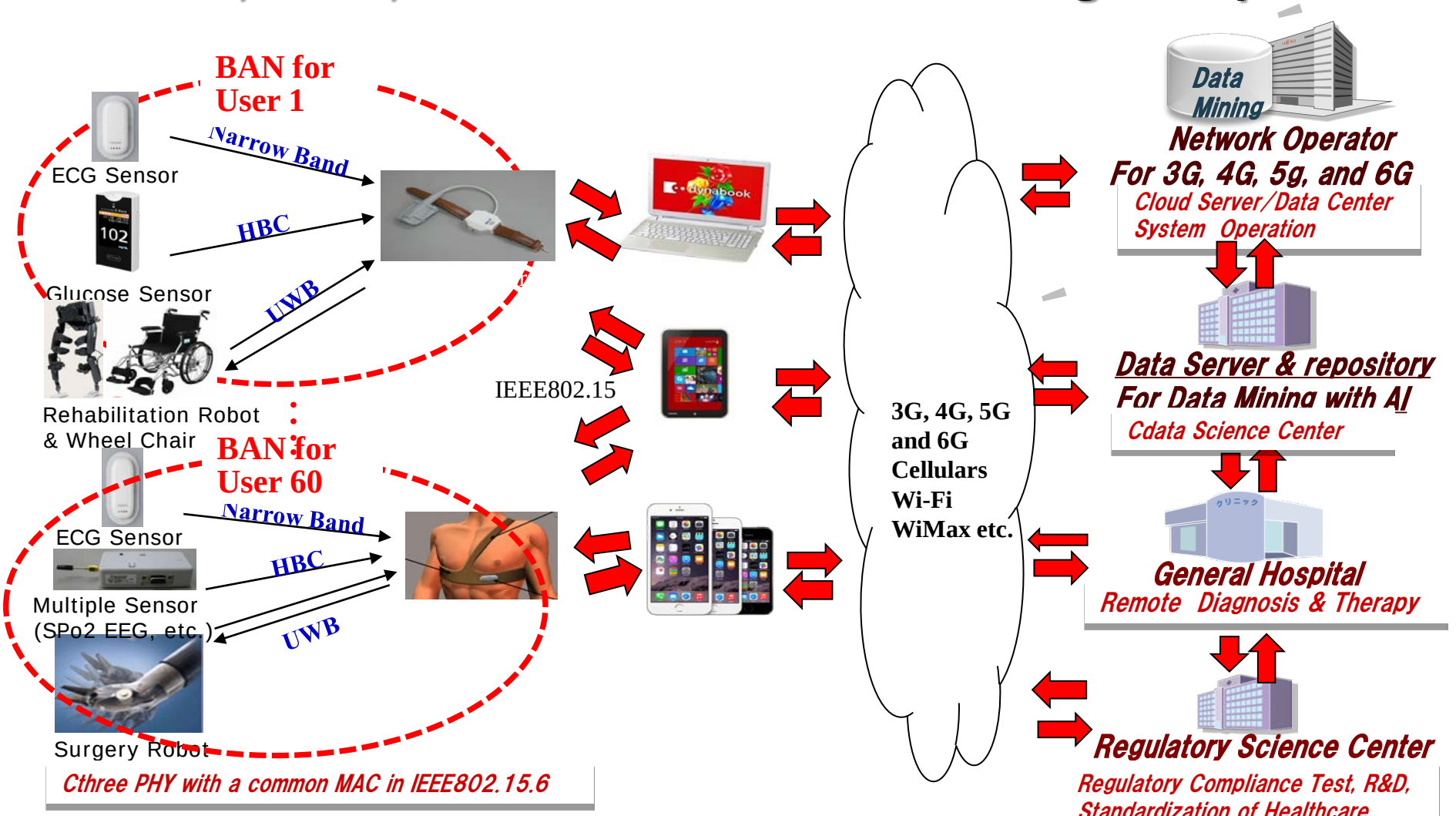
Medical Healthcare Data Mining and Networking Based on Universal Platform by Wireless BAN, Network Cloud, Data Server with AI Data Mining



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



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