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

Submission Title: [IG DEP Transmission Control of UWB-BAN to co-exist with 4G,5G Using the Integrated Terminal]

Date Submitted: [15 January 2021]

Source: [Minsoo Kim1, Ryuji Kohno1,2] [1;Yokohama National University, 2;Centre for Wireless Communications(CWC), University of Oulu,]
Address [1; 79-5 Tokiwadai, Hodogaya-ku, Yokohama, Japan 240-8501
2; Linnanmaa, P.O. Box 4500, FIN-90570 Oulu, Finland FI-90014]
Voice:[1; +81-45-339-4115, 2:+358-8-553-2849], FAX: [+81-45-338-1157]
Email:[1: minsoo@minsookim.com, kohno@ynu.ac.jp, 2: Ryuji.Kohno@oulu.fi]

Re: []

Abstract: [A cognitive transmission parameters control method using proposed integrated terminal for both wireless body area network(WBAN) and 4G/5G network is introduced. The integrated terminal performs a common base station and controls transmission parameters of a WBAN so that its interference to the 4G/5G network can be kept below the permissible level.]

Purpose: [information]

Transmission Control of UWB-BAN to co-exist with 4G/5G Using the Integrated Terminal

Minsoo Kim*, Ryuji Kohno*†

＊Yokohama National University, Japan
† Centre for Wireless Communications(CWC), University of Oulu, Finland

CHAPTER 1 INTRODUCTION

1.1 Issues on BAN & 4G/5G coexistence

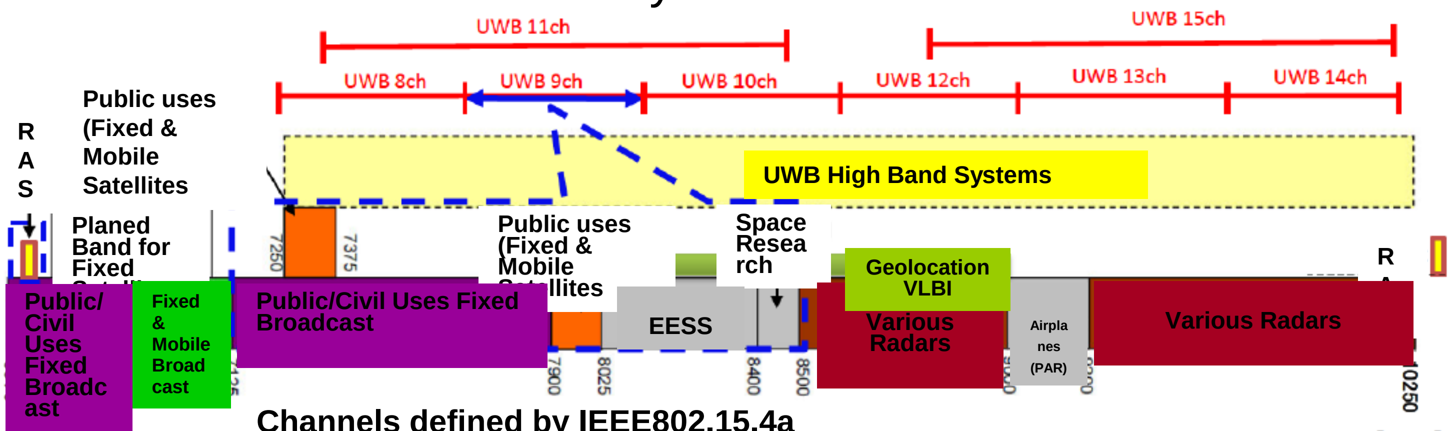
1.2 Limitations of conventional methods

1.3 Limitations of conventional DAA

1.3 Purpose and Suggestion

1.1 Issues on BAN & 4G/5G coexistence

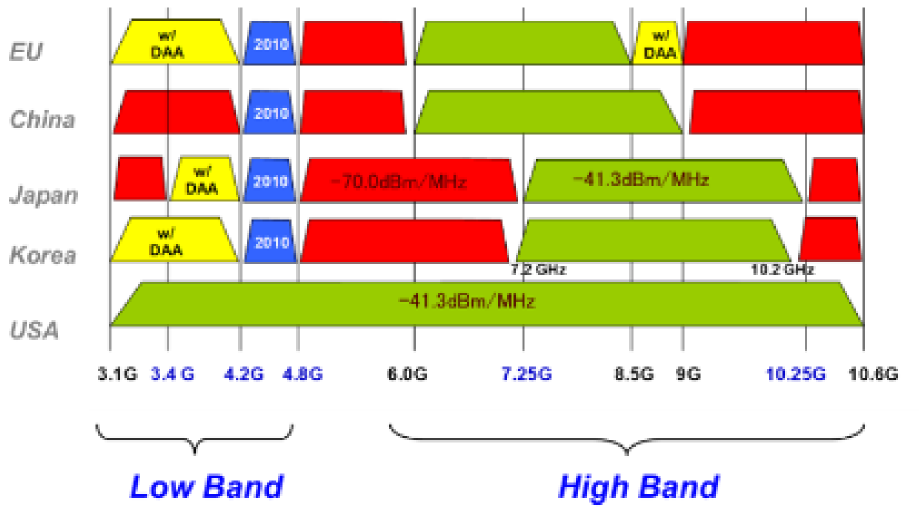
- WBAN systems operating in the ultra-wideband (UWB) overlap with the frequency bands used by other systems.
- Therefore, several methods for the WBAN to coexist with other systems have been examined so far.
    - Transmit power limitation according to spectrum mask
    - Detect And Avoid (DAA)
    - Low Duty Cycle (LDC)
- Especially, it is necessary not to interfere with systems using licensed bands such as 4G/5G cellular systems.



Channels defined by IEEE802.15.4a
and Radio Uses in the Frequency Band 6.57-10.25GHz in Japan

1.2 Limitations of conventional methods

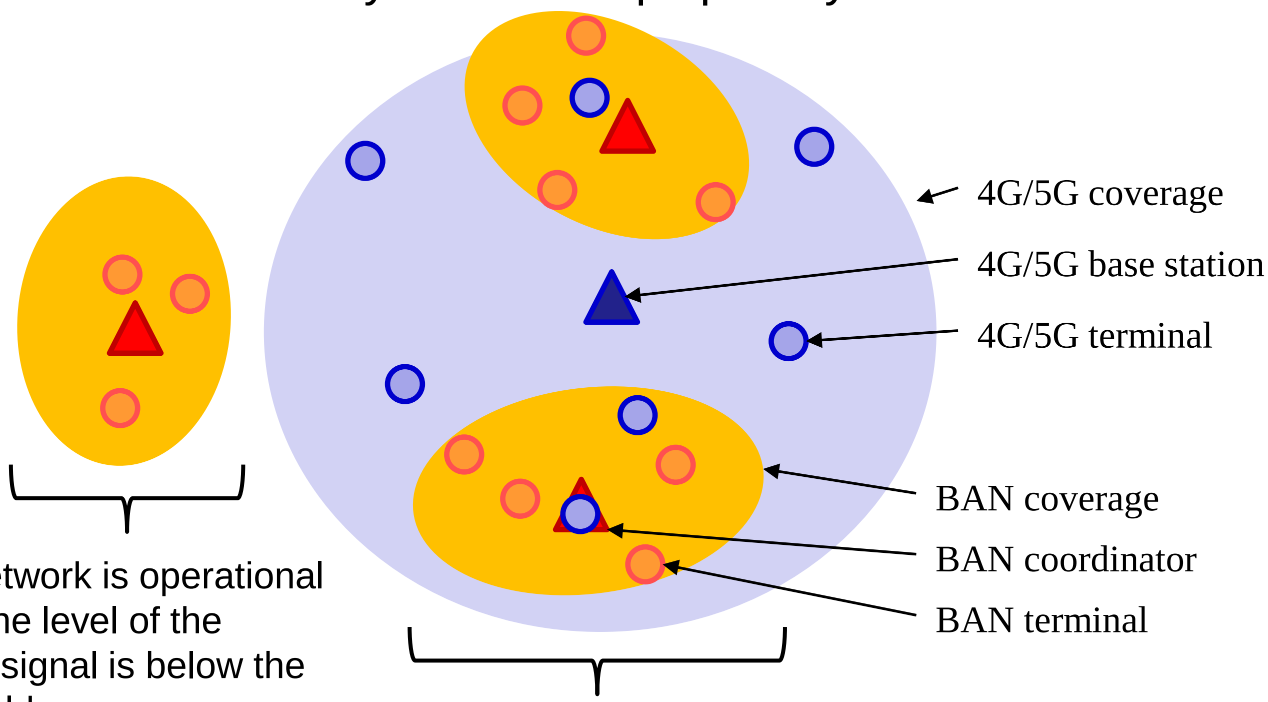
- Uniformly limiting the transmit power according to the spectrum mask regardless of whether the possible victim terminal is nearby or not is inefficient since it could deprive WBAN of its communication opportunities more than necessary.
- DAA methods increases the cost of WBAN because the WBAN device should have the ability to detect signals from other systems.
- LDC methods lower the WBAN throughput significantly.



Spectrum mask for UWB Radio

1.3 Limitations of conventional DAA

- Even though WBAN can detect signals from other systems in reliable way, As 4G/5G cellular systems are widely used, it is inevitable that a WBAN system and a cellular system overlap spatially in most situations.



This network is operational when the level of the 4G/5G signal is below the threshold.

To protect 4G/5G systems, these WBANs are deprived of communication opportunities when WBANs and 4G/5G systems are spatially overlapped.

1.4 Purpose and Suggestion

Purpose

- Even in an environment where WBAN and 4G/5G cellular systems coexist, provide communication opportunities for WBAN, while protecting cellular system communication.
  - Maximize WBAN throughput.
  - Keep the WBAN's interference on cellular systems within permissible level.
- By improving the effectiveness of WBAN, this could accelerate the spread and commercialization of WBAN.

Suggestion

- We propose an Integrated Terminal, which is a device equipped with the both modules of a WBAN coordinator and a 4G/5G cellular terminal.
- We also propose an algorithm that an integrated terminal controls the WBAN transmission parameters, according to the interference level retrieved through its 4G/5G cellular module.

CHAPTER 2
AN INTEGRATED TERMINAL

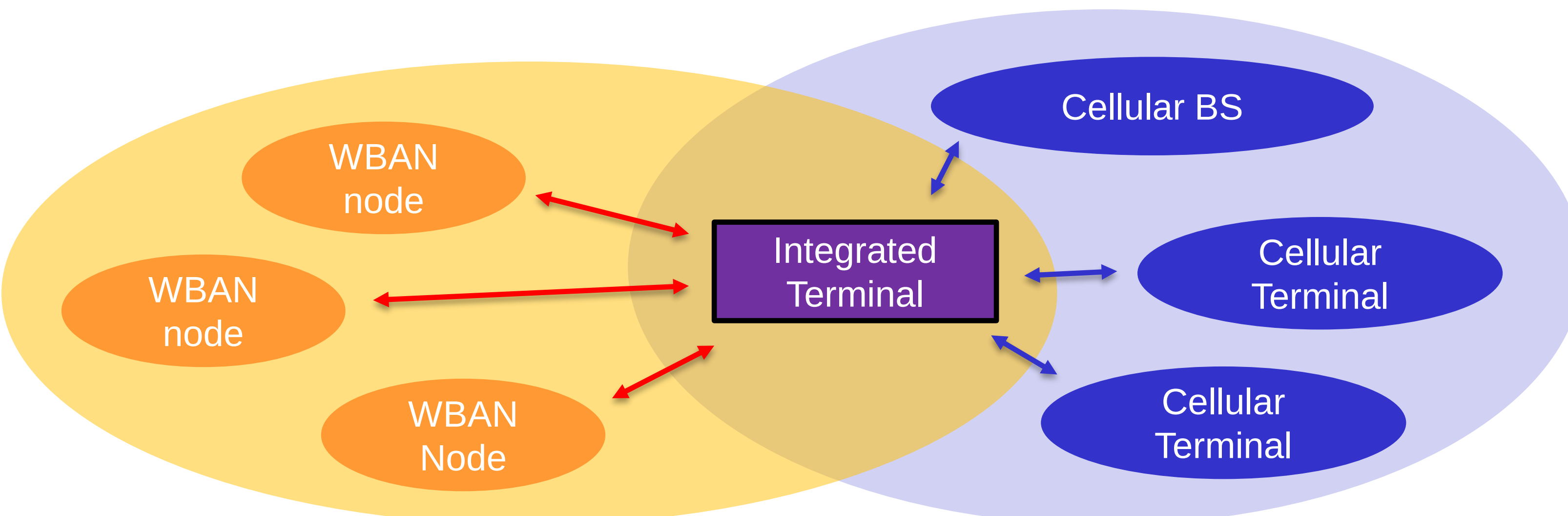
2.1 An Integrated Terminal

2.2 Classification of Integrated Terminals

2.3 System Model

2.1 An Integrated Terminal

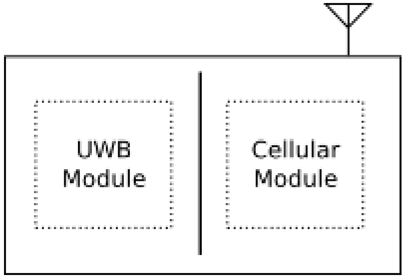
- An Integrated Terminal is a terminal which is equipped with the modules of a WBAN coordinator and a 4G/5G cellular terminal on a same device.
- Introducing Integrated Terminal can realize **cooperative sensing** which recognize the environment more accurately by using multiple terminals and **cognitive radio** which controls its own parameters according to its environment.



2.2 Classification of Integrated Terminals

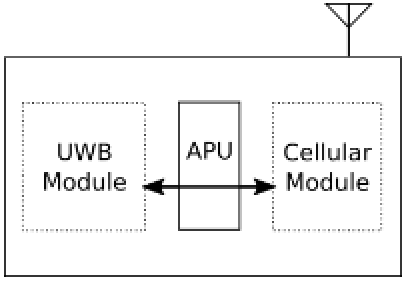
Integration Level 0

- Both WBAN and cellular modules are installed in the same device, but information is not exchanged between the modules.
- Example: current commercial smartphones



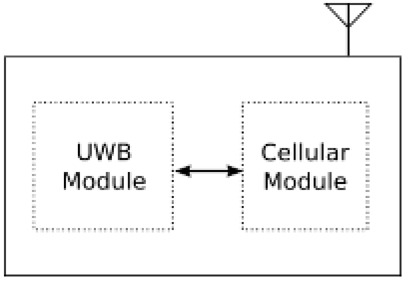
Integration Level 1

- The WBAN module in level 1 **integrated terminal can acquire cellular parameters** such as the desired SINR, desired signal power, interference signal power, and noise power through the cellular base station.
- Since both modules exchange information through APU, there are certain restrictions on the amount of information and the frequency of exchange.

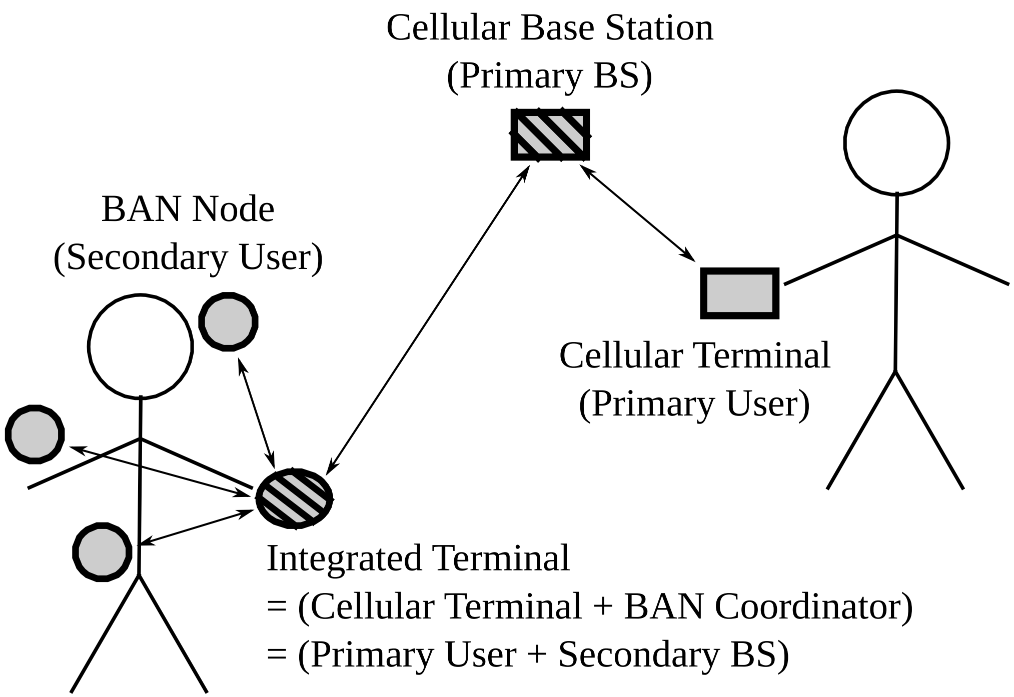


Integration Level 2

- Since both modules exchange information directly, the restrictions on the amount of information and the frequency of exchange can be lowered.
- The WBAN module in level 2 integrated terminal can **instantly** acquire cellular parameters.



2.3 System Model



- We consider an environment in which the cellular system and WBAN using UWB-PHY spatially overlap.
- The data collected from the WBAN node is sent to the outside by the cellular system via the integrated terminal that is the WBAN coordinator.

CHAPTER 3
TRANSMISSION POWER CONTROL

3.1 System Formulation

3.2 Transmission Power Control Algorithm

3.3 Sequence Diagram

3.4 Numerical Evaluation

Interference to the cellular terminal

Performance of WBAN system

3.5 Summary

3.1 System Formulation

Protection of the primary system

- To protect the primary use of cellular system, the SINR of the cellular terminal should be above the desired SINR.

$$\gamma_i^{\mathrm{pri}} \geq \gamma_{\mathrm{th}}^{\mathrm{pri}}$$

$$\gamma_i^{\mathrm{pri}} = \frac{P_i^{\mathrm{pri}} \alpha_i^{\mathrm{pri}}}{P_j^{\mathrm{sec}} \alpha_{i,j}^{\mathrm{cross}} + \nu_i^{\mathrm{pri}}},$$

Desired signal power of cellular terminal

Interference signal power from WBAN node

Maximize WBAN performance

- In order to maximize the performance of the WBAN system for secondary use, maximize the transmission power of the WBAN node under the condition that the SINR of the cellular terminal is maintained above the desired SINR.

$$P_j^{\mathrm{sec}} \leq \frac{1}{\alpha_{i,j}^{\mathrm{cross}}} \left(\frac{P_i^{\mathrm{pri}} \alpha_i^{\mathrm{pri}}}{\gamma_{\mathrm{th}}^{\mathrm{pri}}} - \nu_i^{\mathrm{pri}} \right)$$

3.2 Transmission Power Control Algorithm

(1) Initialization

- The integrated terminal acts as a WBAN coordinator and transmits the initial value of the transmission power of WBAN nodes on a beacon.
- Each WBAN node sets its own transmission power according to the initial value.

(2) Transmission of WBAN signal

- The WBAN node transmits its own packet with the transmission power allowed by the integrated terminal.
- Cellular terminals receive this signal as interference.

3.2 Transmission Power Control Algorithm

(3) Interference monitoring of cellular terminals

- The cellular terminal monitors the received power when the cellular link is idle and transmits the power value to the integrated terminal.

$$y_i^{\mathrm{I}}(t) = \sum_{j=1}^{M} \sqrt{P_j^{\mathrm{sec}}\, \alpha_{i,j}^{\mathrm{cross}}}\, \delta_j^{\mathrm{sec}}(t)\, u_j^{\mathrm{sec}}(t) + n_i^{\mathrm{pri}}(t)$$

$$\begin{aligned} E_i^{\mathrm{I}} &= \int_{\Delta t} \left\{ y_i^{\mathrm{I}}(t) \right\}^2 dt \\ &= P_j^{\mathrm{sec}}\, \alpha_{i,j}^{\mathrm{cross}} \int_{\Delta t} \left\{ u_j^{\mathrm{sec}}(t) \right\}^2 dt \\ &\quad + 2\sqrt{P_j^{\mathrm{sec}}\, \alpha_{i,j}^{\mathrm{cross}}} \int_{\Delta t} u_j^{\mathrm{sec}}(t)\, n_i^{\mathrm{pri}}(t)\, dt + \int_{\Delta t} \left\{ n_i^{\mathrm{pri}}(t) \right\}^2 dt \\ P_i^{\mathrm{I}} &= E_i^{\mathrm{I}} / \Delta t \\ &= P_j^{\mathrm{sec}}\, \alpha_{i,j}^{\mathrm{cross}} + \nu_i^{\mathrm{pri}}, \end{aligned}$$

3.2 Transmission Power Control Algorithm

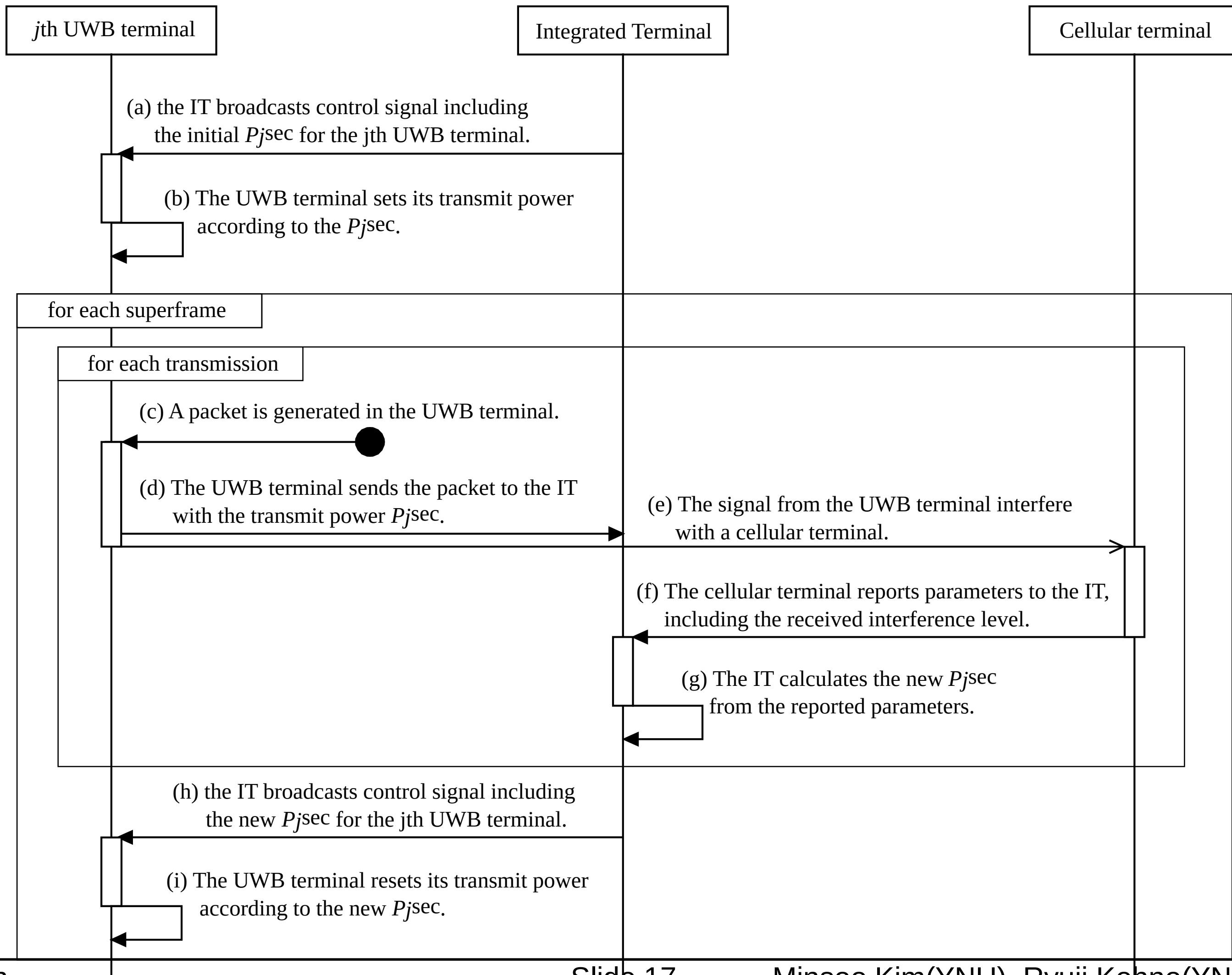
(4) Transmission power update on integrated terminal

- The integrated terminal calculates the next transmission power of WBAN nodes from the undesired signal power received by the cellular terminal, puts it on a beacon, and transmits it to each WBAN node

$$\alpha_{i,j}^{\mathrm{cross}} = \frac{P_j^{\mathrm{sec}}}{P_i^{\mathrm{I}} - \nu_i^{\mathrm{pri}}}$$

$$\hat{P}_j^{\mathrm{sec}} \leq \frac{P_j^{\mathrm{sec}}}{P_i^{\mathrm{recv}} - \nu_i^{\mathrm{pri}}} \left(\frac{P_i^{\mathrm{pri}}\, \alpha_i^{\mathrm{pri}}}{\gamma_{\mathrm{th}}^{\mathrm{pri}}} - \nu_i^{\mathrm{pri}} \right)$$

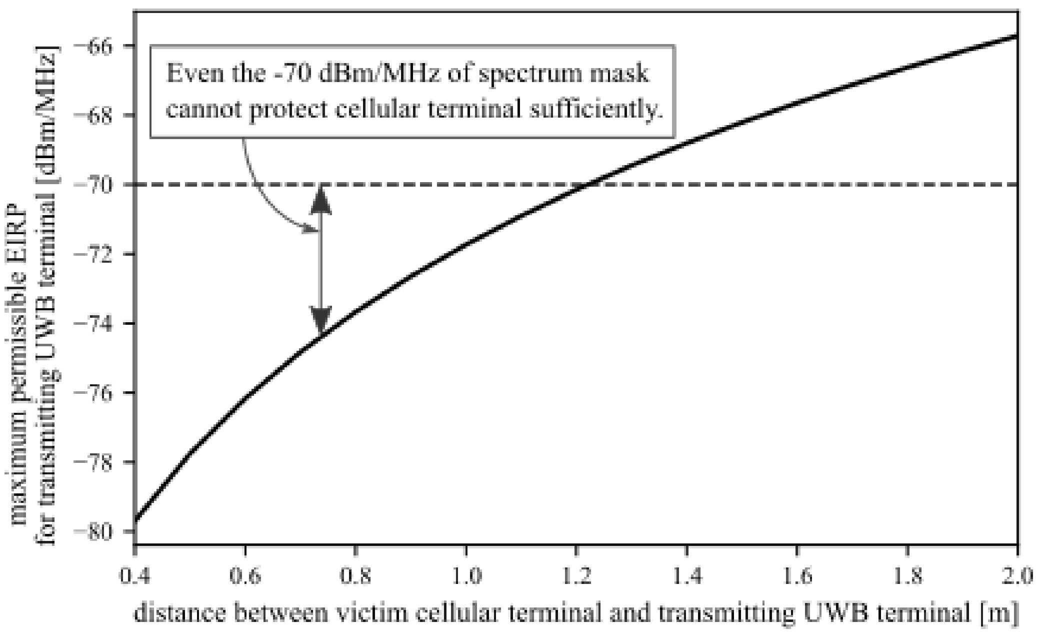
3.3 Sequence Diagram



3.4 Numerical Evaluation

- Center frequency: 3.4 GHz
  - Frequency band with the highest EIRP in FCC spectrum mask
  - Frequency band used in LTE and 5G
- Permissible interference PSD at cellular terminals: -114.8 dBm/MHz
  - The SINR of a cellular terminal changes depending on the channel gain, modulation method, positional relationship, etc. of the cellular system.
  - For evaluation that does not depend on the specifications of the cellular system, the interference with the cellular terminal is evaluated by the power spectrum density of the interference signal from the WBAN node
- Channel model: free propagation
  - In WBAN that communicates at short distance with low power, the most influential factor is the distance between terminals.
  - Therefore, a free propagation model is used to evaluate the change in performance depending on the distance of the terminal.

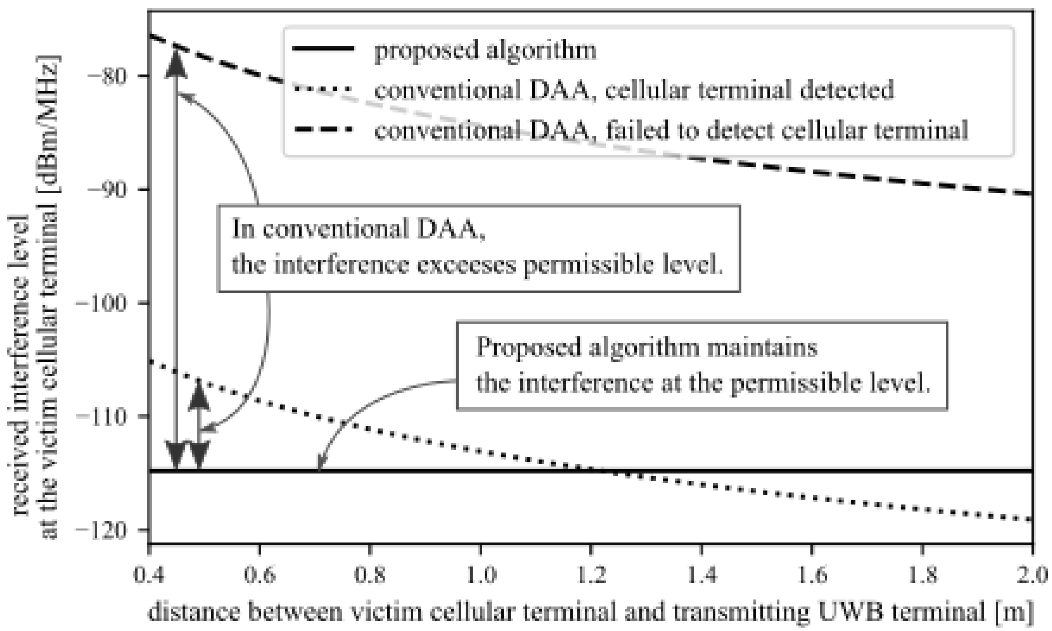
3.4 Interference to the cellular terminal



Maximum transmission level available for a WBAN node, which can protect a cellular terminal from interference signal from the WBAN node

- If the distance between the cellular terminal and the WBAN node is short, the maximum transmission level of the WBAN node which keeps the interference at the cellular terminal below the permissible value would be lower than -70 dBm / MHz.

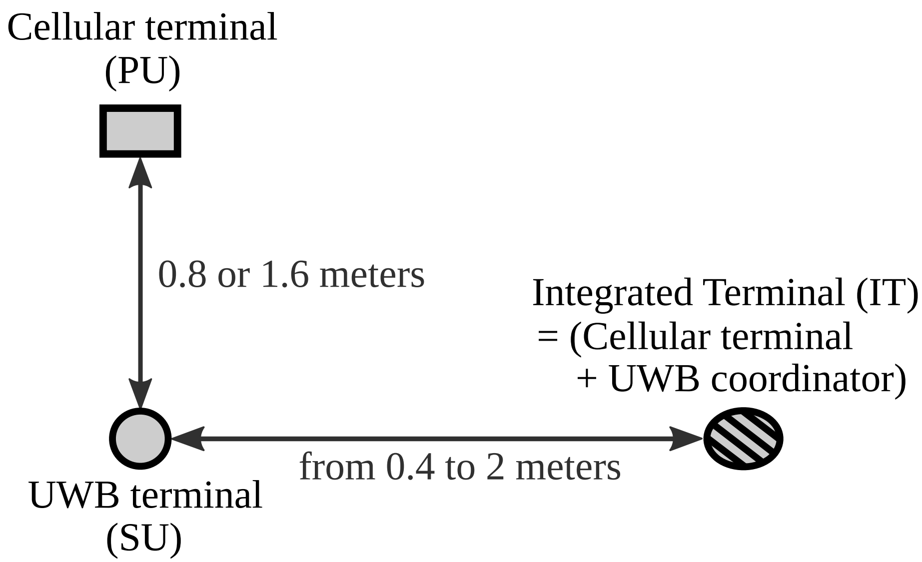
3.4 Interference to the cellular terminal



Interference level received at victim cellular terminal

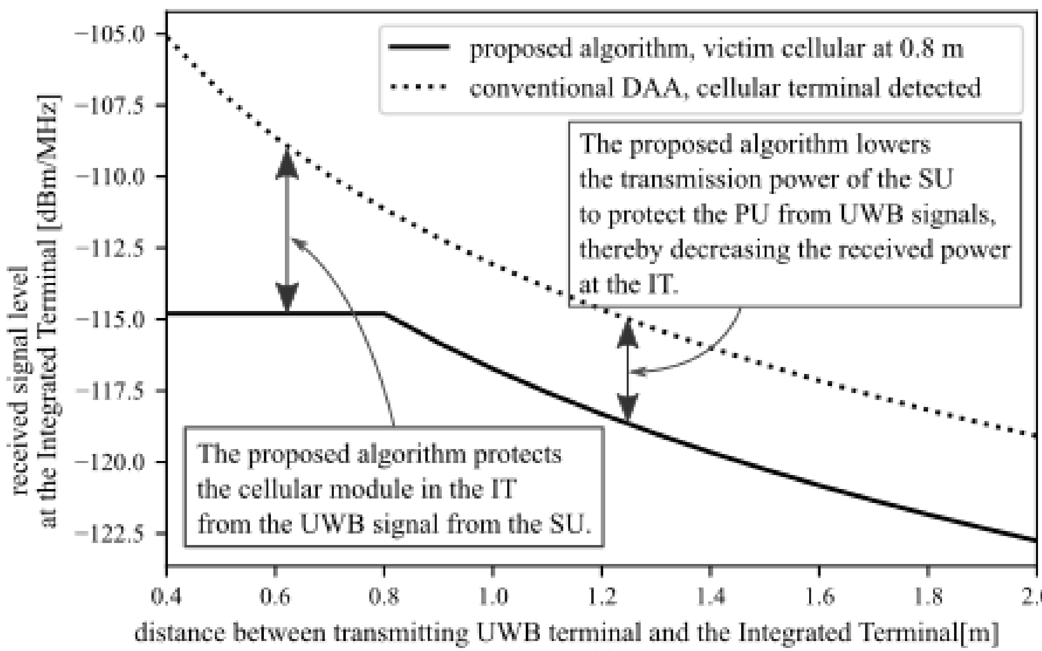
- By controlling the WBAN transmission power according to the real-time value of interference at the victim cellular terminal, interference at the cellular terminal can be maintained below the permissible value.

3.4 Performance of WBAN system



- Evaluated with a minimum set of a WBAN link and a cellular link, consist of an Integrated Terminal (IT), a Cellular Terminal (PU), and a WBAN node (SU),
- Distance between cellular terminal and WBAN node
  – 0.8 m: Considering a situation that a user uses a cellular terminal and a WBAN node simultaneously.
  – 1.6 m: Considering a situation that a WBAN node affects another person's cellular terminal

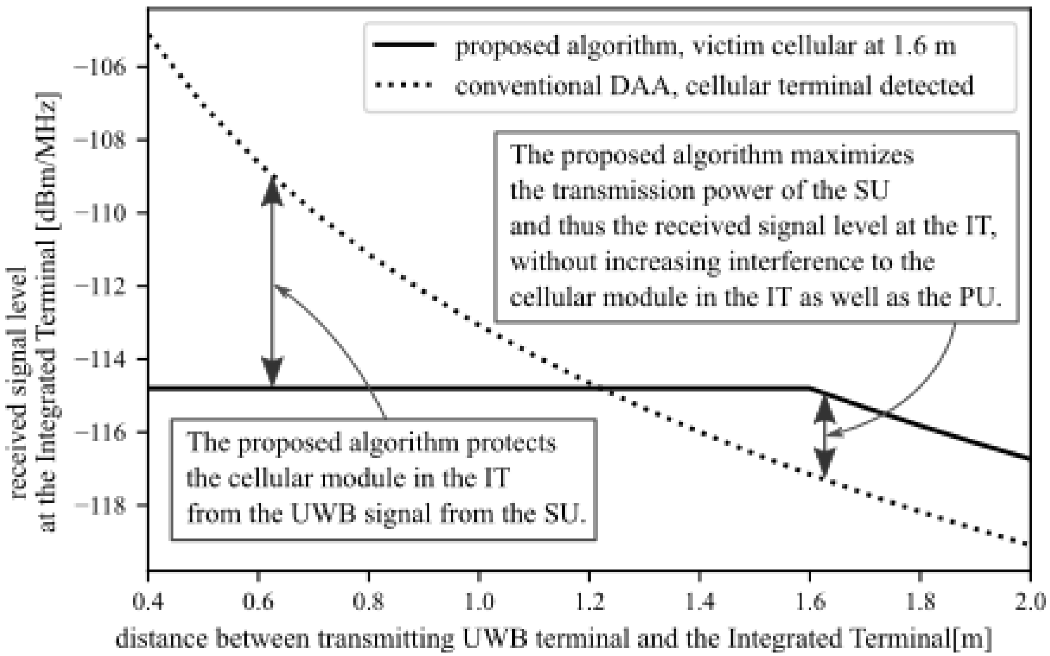
3.4 Performance of WBAN system



Desired signal power level from a WBAN node that the integrated terminal receives (Distance between cellular terminal and WBAN node = 0.8 m)

- Since protecting the cellular terminal from interference has higher priority, the signal power level of WBAN node is reduced.

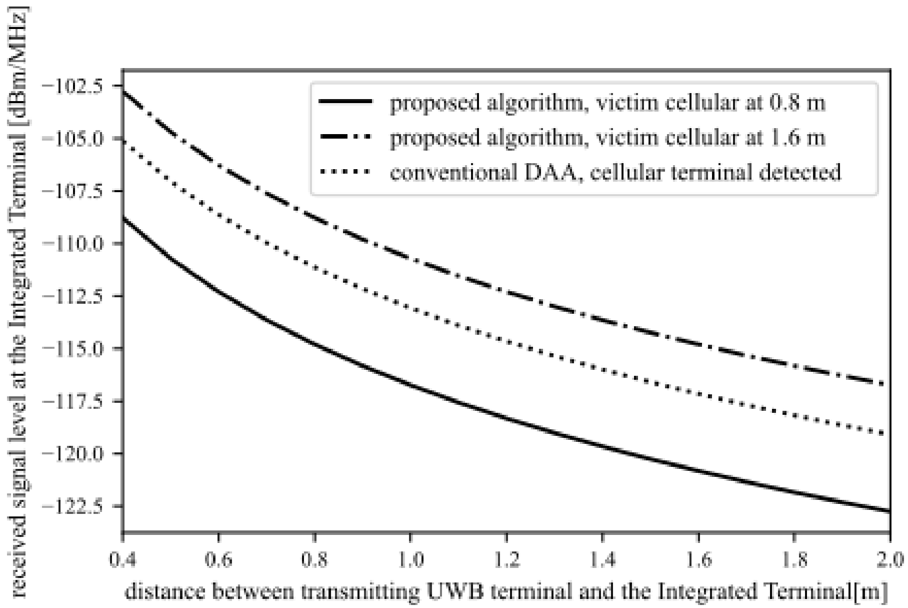
3.4 Performance of WBAN system



Desired signal power level from a WBAN node that the integrated terminal receives (Distance between cellular terminal and WBAN node = 1.6 m)

- If the cellular terminal is located farther from the integrated terminal, the WBAN node can send its signal with higher power level than the conventional method.

3.4 Performance of WBAN system



Desired signal power level from a WBAN node that the integrated terminal receives

- By raising the integration level, more accurate and appropriate transmission control can be available.
- For example, if the WBAN module on the integrated terminal can acquire more detailed real-time information such as transmitting/receiving/on standby of cellular module, the WBAN signal and cellular signal can also be separated in time domain, resulting higher WBAN signal level at the integrated terminal.

3.5 Summary

- By transmission power control algorithm using an integrated terminal,
  - It can be ensured that the interference from a WBAN node at a cellular terminal does not exceed the permissible level.
  - If a WBAN node and a cellular terminal are farther than about 1.2 m, the proposed algorithm can raise the WBAN signal level further, while protecting coexisting cellular system simultaneously.

CHAPTER 4
SEQUENCE LENGTH CONTROL

4.1 Need for Sequence Length Control

4.2 Result of Sequence Length Control

3.1 Need for Sequence Length Control

- When a cellular terminal is nearby, the power spectral density of the received BAN signal would be close to noise level, limiting to maintaining the reliability of WBAN communication.

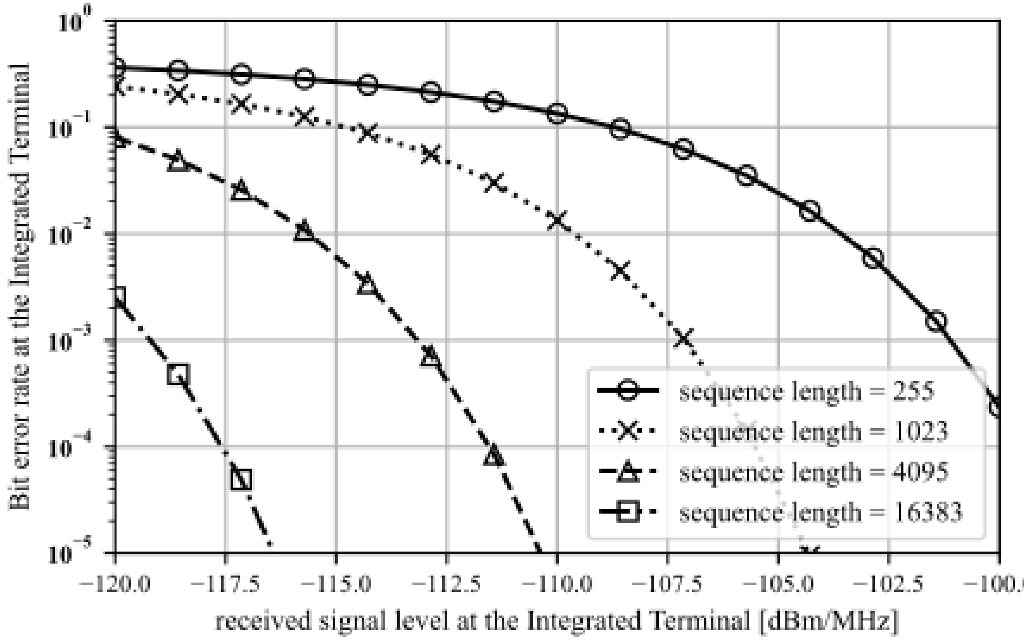
$$N_0 = 10\log_{10}(k_{\mathrm{B}} \cdot T \cdot 10^{6+3})$$

$$N_0|_{T=300} \approx -228.6 + 24.8 + 90 = -113.8 \ [\mathrm{dBm/MHz}]$$

Example: Power spectral density of noise at room temperature (26.85 ° C)

- In order to maintain the BER required for WBAN communication while suppressing the interference level of WBAN node to the cellular terminal below the permissible value, it is necessary to exploit processing gain by controlling the sequence length.

3.1 Result of Sequence Length Control



Bit error rate at the integrated terminal
depending on the received power level at the integrated terminal (BW = 1GHz)

- The bit error rate can be reduced by increasing the sequence length.

4. Conclusion

- An algorithm that controls the transmission power of WBAN nodes by sharing cellular system parameters with the WBAN via an integrated terminal is proposed.
- By dynamically controlling the transmission power and sequence length of the WBAN node according to the parameters of the cellular system instead of using the preset transmission power value,
  - Coexisting cellular systems can be protected, because the signal from the WBAN node does not exceed the permissible value of interference power in the cellular terminal.
  - The performance of WBAN can be improved at the same time, because the transmission power of the WBAN node can be maximized.

Thank you for your attention!