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

Submission Title: [IG DEP Wireless Technologies to Assist Search and Localization of Victims of Wide-scale Natural Disasters by Unmanned Aerial Vehicles(UAVs)]

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Source: [Takumi Kobayashi1, Satoshi Seimiya1, Kouhei Harada1 , Masaki Noi1, Zane Barker4, Josh McCulloch4, Andreas Willig4, Graeme K Woodward4, Ryuji Kohno1,2,3] [1;Yokohama National University, 2;Centre for Wireless Communications(CWC), University of Oulu, 3;University of Oulu Research Institute Japan CWC-Nippon, 4;University of Canterbury, New Zealand]

Address [1; 79-5 Tokiwadai, Hodogaya-ku, Yokohama, Japan 240-8501
2; Linnanmaa, P.O. Box 4500, FIN-90570 Oulu, Finland FI-90014
3; Yokohama Mitsui Bldg. 15F, 1-1-2 Takashima, Nishi-ku,Yokohama, Japan 220-0011]

Voice:[1; +81-45-339-4115, 2:+358-8-553-2849], FAX: [+81-45-338-1157],

Email:[1: kohno@ynu.ac.jp, 2: Ryuji.Kohno@oulu.fi, 3: ryuji.kohno@cwc-nippon.co.jp] Re: []

Abstract: [This a part of the authort's plenary keynote in 20th International Symposium On Wireless Personal Multimedia Communications (WPMC2017), Royal Ambarrukmo Yogyakarta, Indonesia, December 19, 2017. As a typical use case of dependable wireless networks, reliable sensing and controlling multiple UAVs is introduced]

Purpose: [information]

Wireless Technologies to Assist Search and Localization of Victims of Wide-scale Natural Disasters by Unmanned Aerial Vehicles(UAVs)

Takumi Kobayashi*, Satoshi Seimiya*, Kouhei Harada* , Masaki Noi*, Zane Barker, Josh McCulloch**, Andreas Willig**, Graeme K Woodward** , and Ryuji Kohno*†**

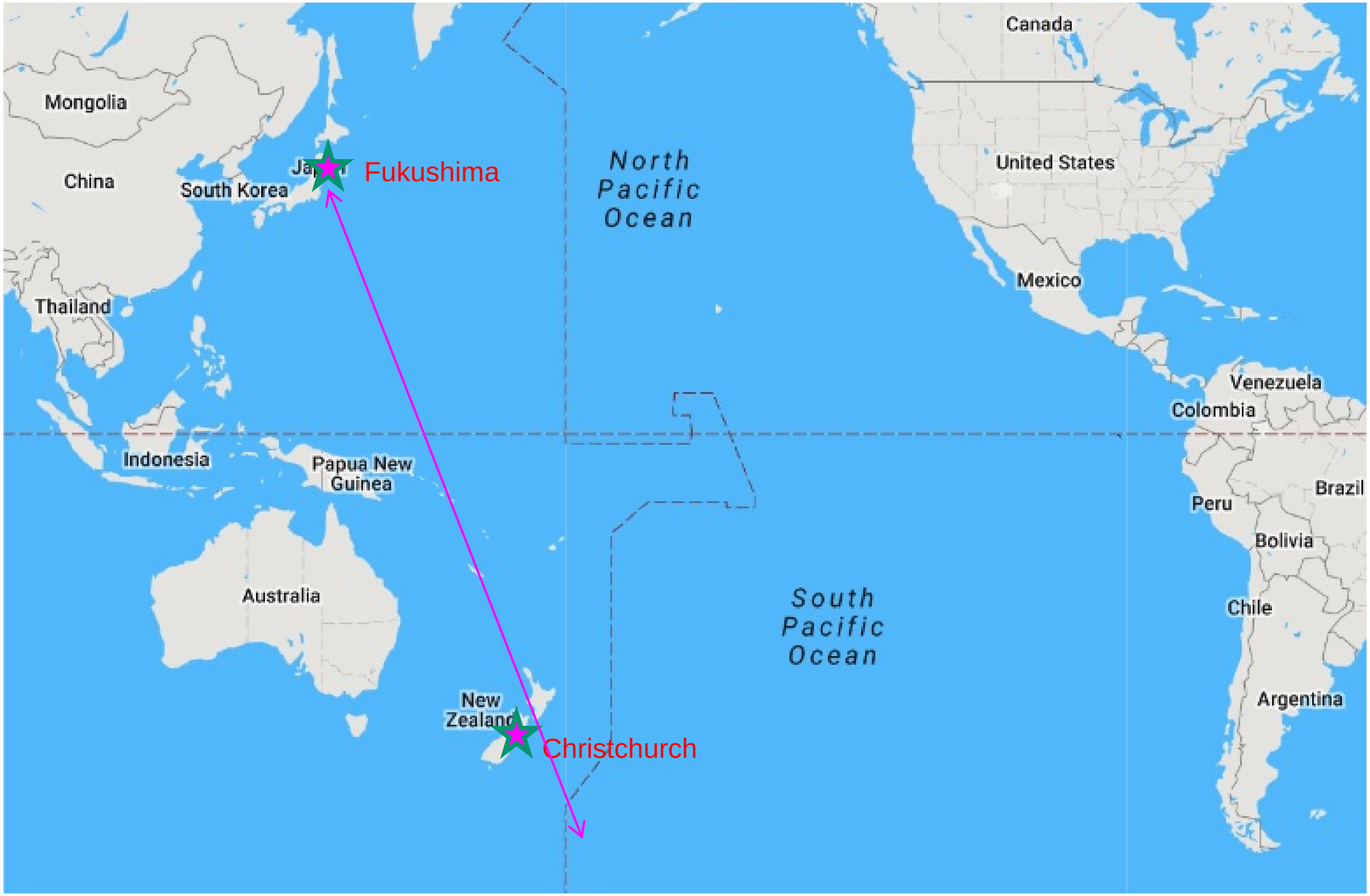
*Graduate School of Engineering, **Yokohama National University, Japan**

, **University of Canterbury, New Zealand

† University of Oulu Research Institute Japan–**CWC-Nippon**, Co. Ltd.

Ref. 1. A part of plenary keynote speech in the 20th International Symposium On Wireless Personal Multimedia Communications (WPMC2017), Royal Ambarrukmo Yogyakarta, Indonesia, December 19, 2017
2. 2016-2017 NZ(UC)-Japan(YNU) Joint Project: Dependable Wireless Body Area Networks to Support Search and Rescue and Medical Treatment in Disaster Scenarios Using Multiple UAVs

Earthquakes in Christchurch, NZ on Feb.22, and in Fukushima, Japan on March 11, 2011



Emergency in Disasters e.g. Earthquake, Tsunami

- In case of **emergent disaster environment** such as earthquake and Tsunami, **Dependable networks** must be important to rescue victims and recovering infrastructure.

- Most of existing infrastructure networks are not available to find and rescue victims.
- **Dependable and cost effective emergency networks** are necessary to guarantee life and life line for human living.

Search and Rescue for Victims in Disaster

- Due to damage of buildings, it is very difficult that to find victims remained in broken buildings.
- To deliver rescue team and robot, victim location should be found.

- **UAVs** (Unmanned Aerial Vehicles) or **Drones** can be applied by cost effective manner.

Joint Japan and New Zealand Project forSearch and Rescue in Disaster by Using Multipole UAVs(Drones)

- UAVs or drones which can…
  - be used indoor and outdoor
  - be operated by anyone
  - hover in mid air stably
  - be easy remote controllable

is suitable for search and rescue victims.

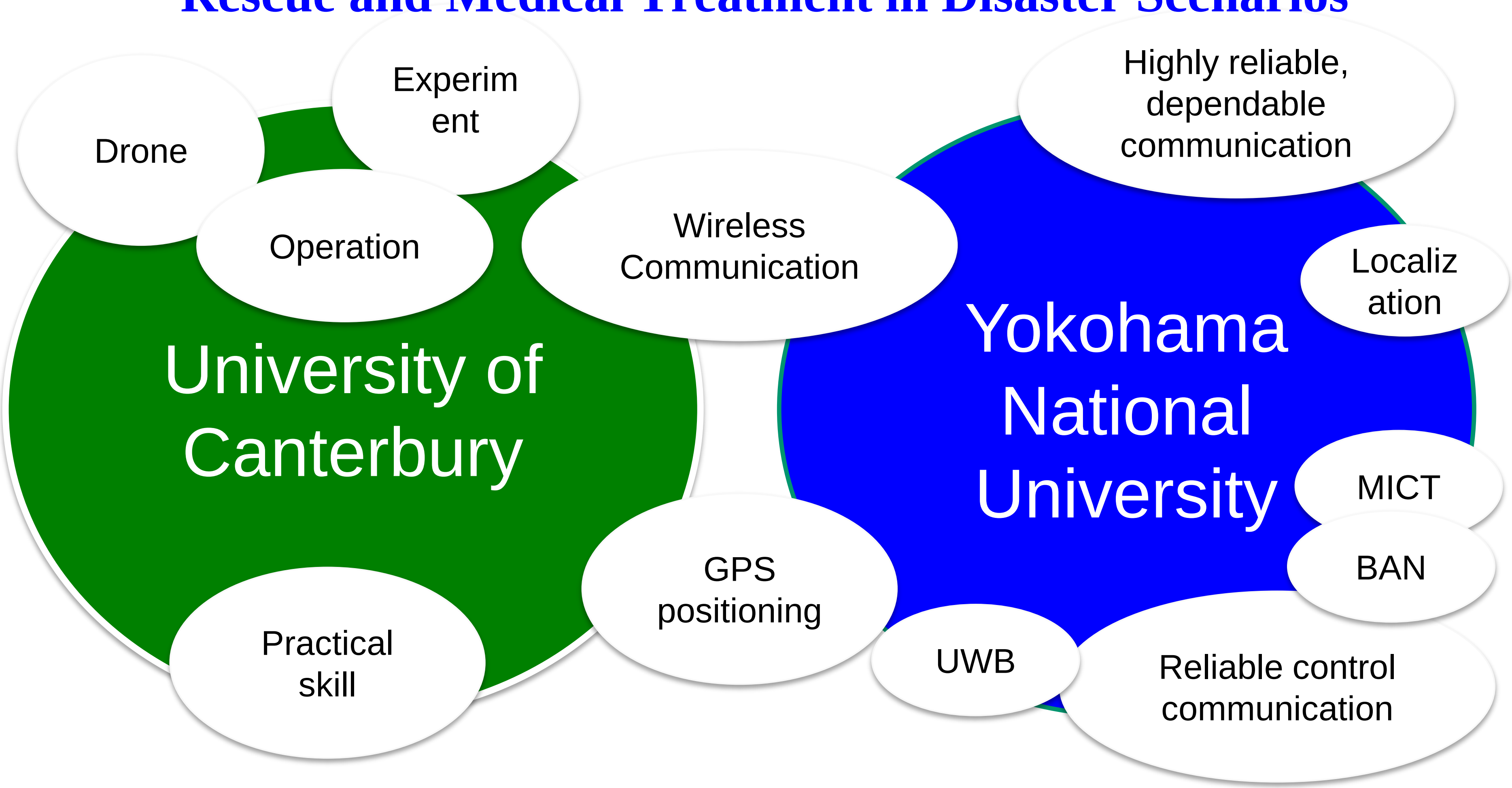
Subject: Dependable Sensing and Controlling Multiple Drones

2016-2017 NZ(UC)-Japan(YNU) Joint Project ;

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

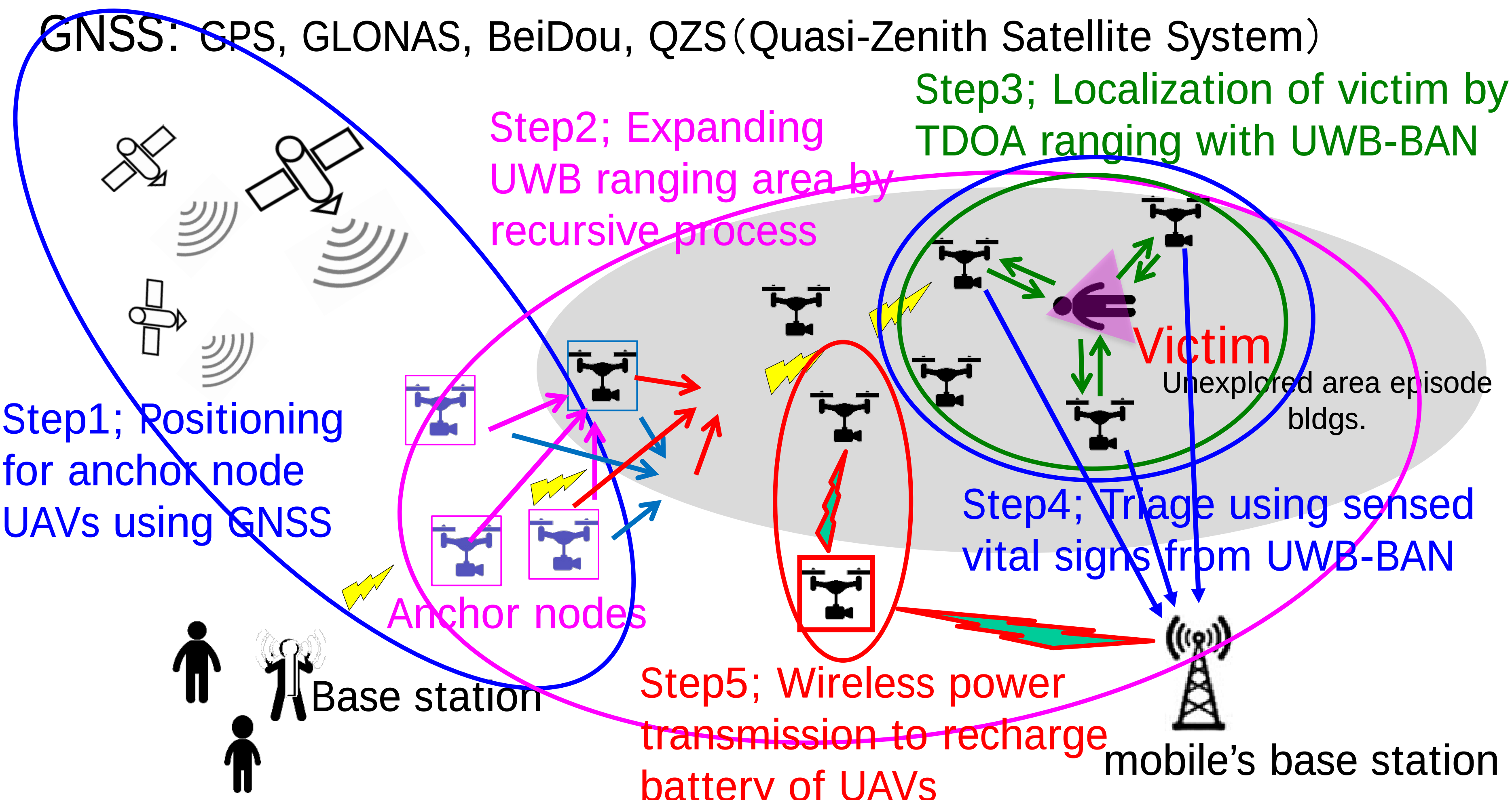
2016-2017 NZ(UC)-Japan(YNU) Joint Project ;

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

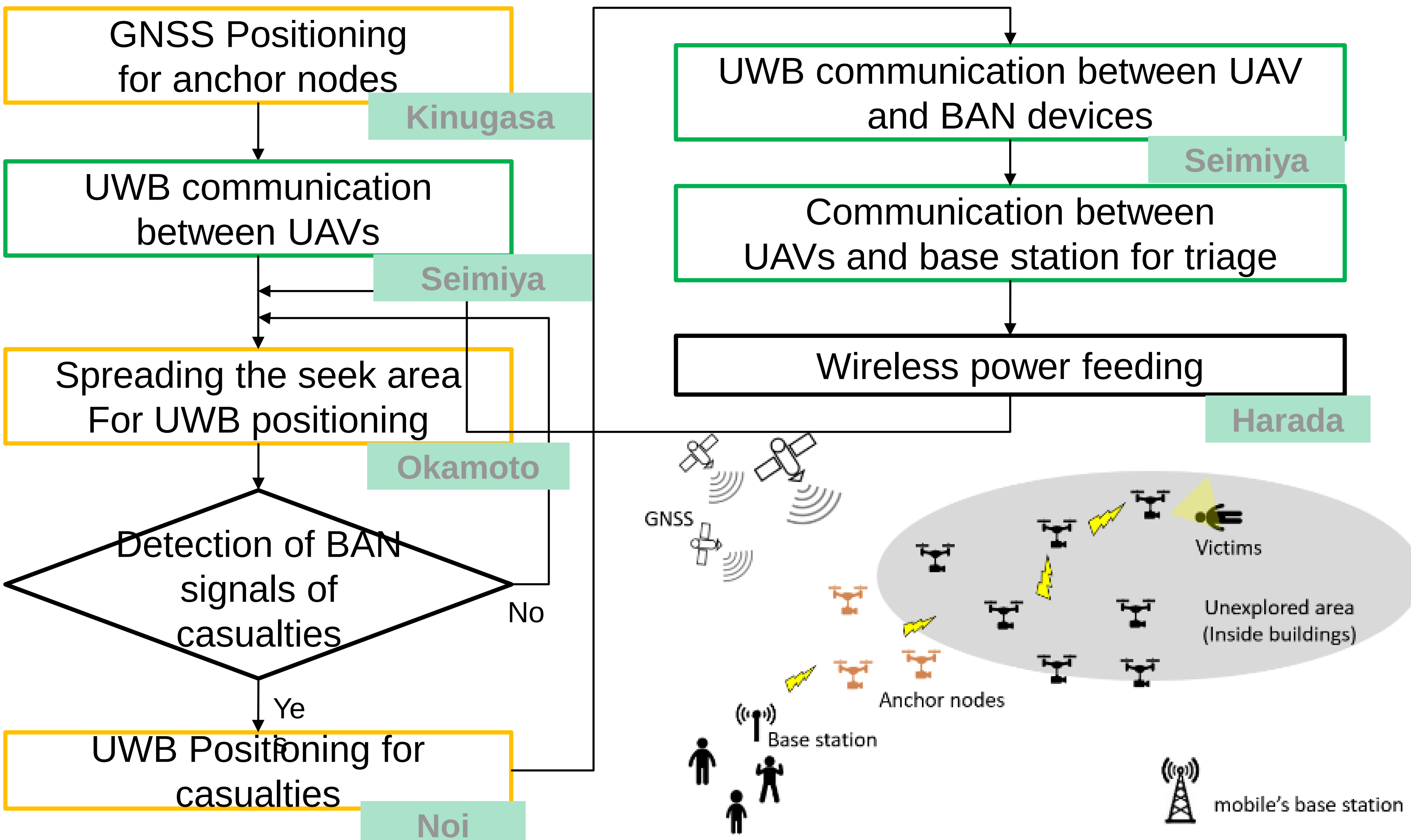


2016-2017 NZ(UC)-Japan(YNU) Joint Project ;

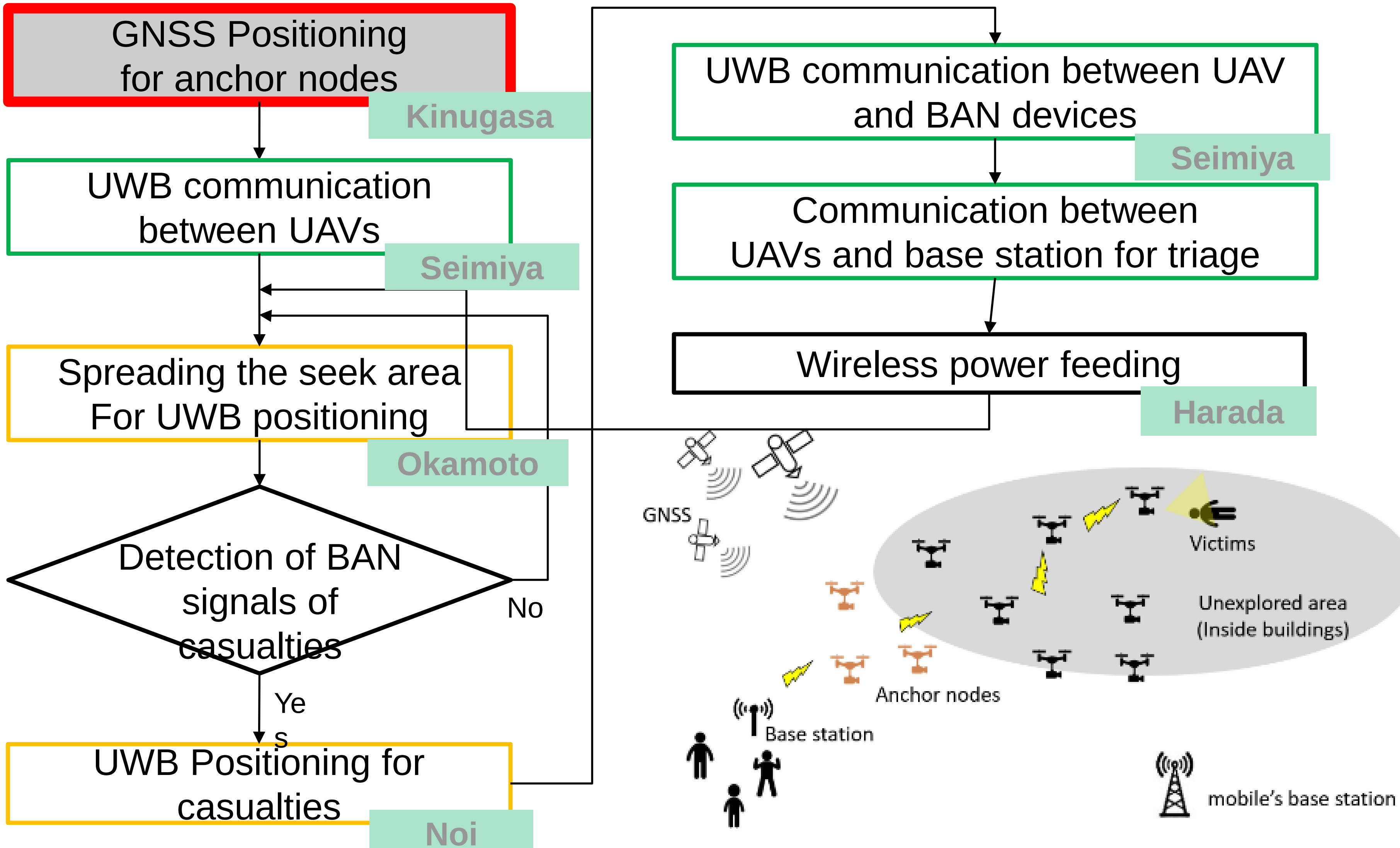
Dependable Wireless Body Area Networks to Support Search and Rescue and Medical Treatment in Disaster Scenarios Using Multiple UAVs



Flowchart to Search Casualties



Flowchart to Search Casualties



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GNSS positioning for anchor nodes

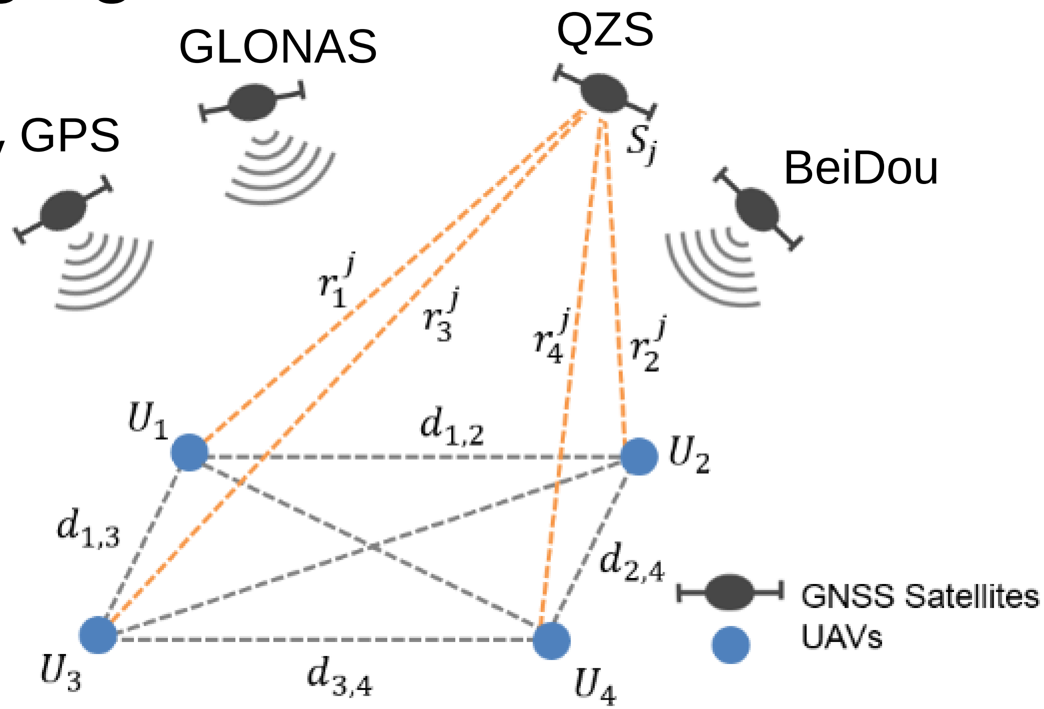
Cooperative Satellite Positioning for UAVs with UWB Ranging Measurements

Key Issues

Can we cancel the main errors included in GNSS measurement by using several drones where are located in short distance?

Key Ideas

- Cooperative satellite positioning can cancel main errors e.g. ionosphere delay, troposphere delay, satellite clock offset etc.
- Use of UWB ranging measurement may reduce positioning error
- Combining GNSS positioning and UWB ranging is new.



Geolocaton Using Multiple GNSS such as GPS, GLONAS, BeiDou and QZS

Positioning for anchor nodes using GNSS

Cooperative Satellite Positioning for UAVs with UWB Ranging Measurements

Schedule
1) Mathematical model construction
2) Logging GNSS measurements ← Ongoing
3) Performance evaluation
4) Experiment using drone

Distance between rcv i and sat j

$r_i^j = \|\boldsymbol{x}_i - \boldsymbol{x}^j\|$

Distance between rcv a and rcv b

$d_{a,b} = \|\boldsymbol{x}_a - \boldsymbol{x}_b\|$

s_a	Receiver a clock offset (m)
ϵ	Noise (m)
n	Num. of receivers
m	Num. of satellites

1) Mathematical Model

Residual of pseudorange measurements between rcv a and rcv b

$$\tilde{\rho}_{a,b}^j = \rho_a^j - \rho_b^j = r_a^j - r_b^j + s_a - s_b + \epsilon$$

$$\Delta\tilde{\rho}_{a,b}^j = \frac{x_a - x^j}{r_a^j}\Delta x_a + \frac{y_a - y^j}{r_a^j}\Delta y_a + \frac{z_a - z^j}{z_a^j}\Delta z_a - \frac{x_b - x^j}{r_b^j}\Delta x_b - \frac{y_b - y^j}{r_b^j}\Delta y_b - \frac{z_b - z^j}{z_b^j}\Delta z_b + \Delta s_a - \Delta s_b$$

$$\Delta \mathrm{d}_{\mathrm{a,b}} = \frac{x_a - x_b}{d_{a,b}}\Delta x_a + \frac{y_a - y_b}{d_{a,b}}\Delta y_a + \frac{z_a - z_b}{d_{a,b}}\Delta z_a - \frac{x_a - x_b}{d_{a,b}}\Delta x_b - \frac{y_a - y_b}{d_{a,b}}\Delta y_b - \frac{z_a - z_b}{d_{a,b}}\Delta z_b$$

Estimation by the least square method

$$\boldsymbol{X} = \boldsymbol{A}^{-1}\boldsymbol{B}$$

Unknown state vector: $(4n \times 1)$

$$\boldsymbol{X} = [\Delta x_1, \Delta y_1, \Delta z_1, \cdots, \Delta x_n, \Delta y_n, \Delta z_n, \Delta s_1, \cdots, \Delta s_n]^T$$

Vector of measurements: $(n(n-1)(m+1)/2 \times 1)$

$$\boldsymbol{B} = \left[\rho_{1,1}, \cdots \rho_{n,m}, d_{1,2}, \cdots, d_{i,j}, \cdots, d_{n-1,n}\right]^T$$

Geometry matrix: $(n(n-1)(m+1)/2 \times 4n)$

$$\boldsymbol{A} = \begin{bmatrix} \boldsymbol{A_x} & \boldsymbol{A_s} \\ \boldsymbol{A_d} & \boldsymbol{O} \end{bmatrix}$$

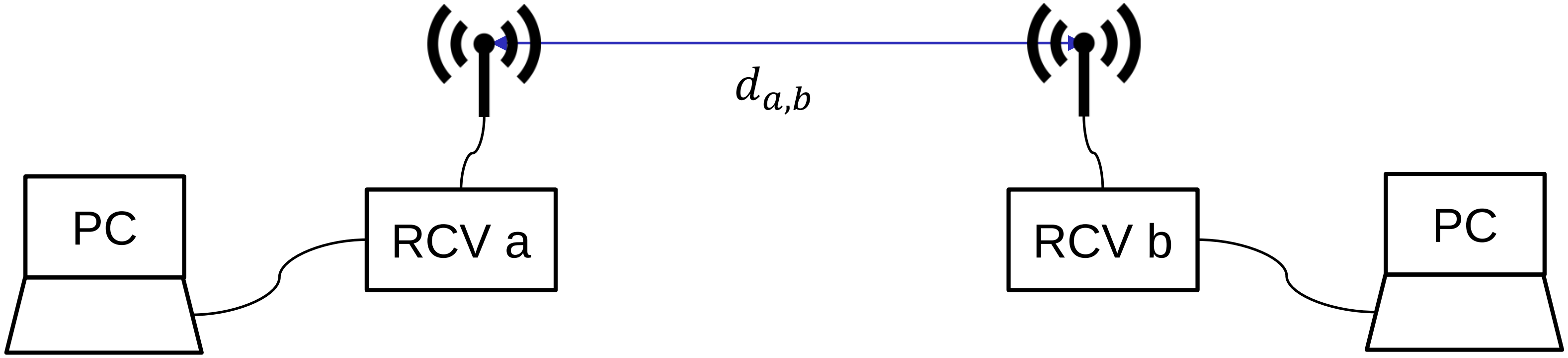
Positioning for anchor nodes using GNSS

Cooperative Satellite Positioning for UAVs with UWB Ranging Measurements

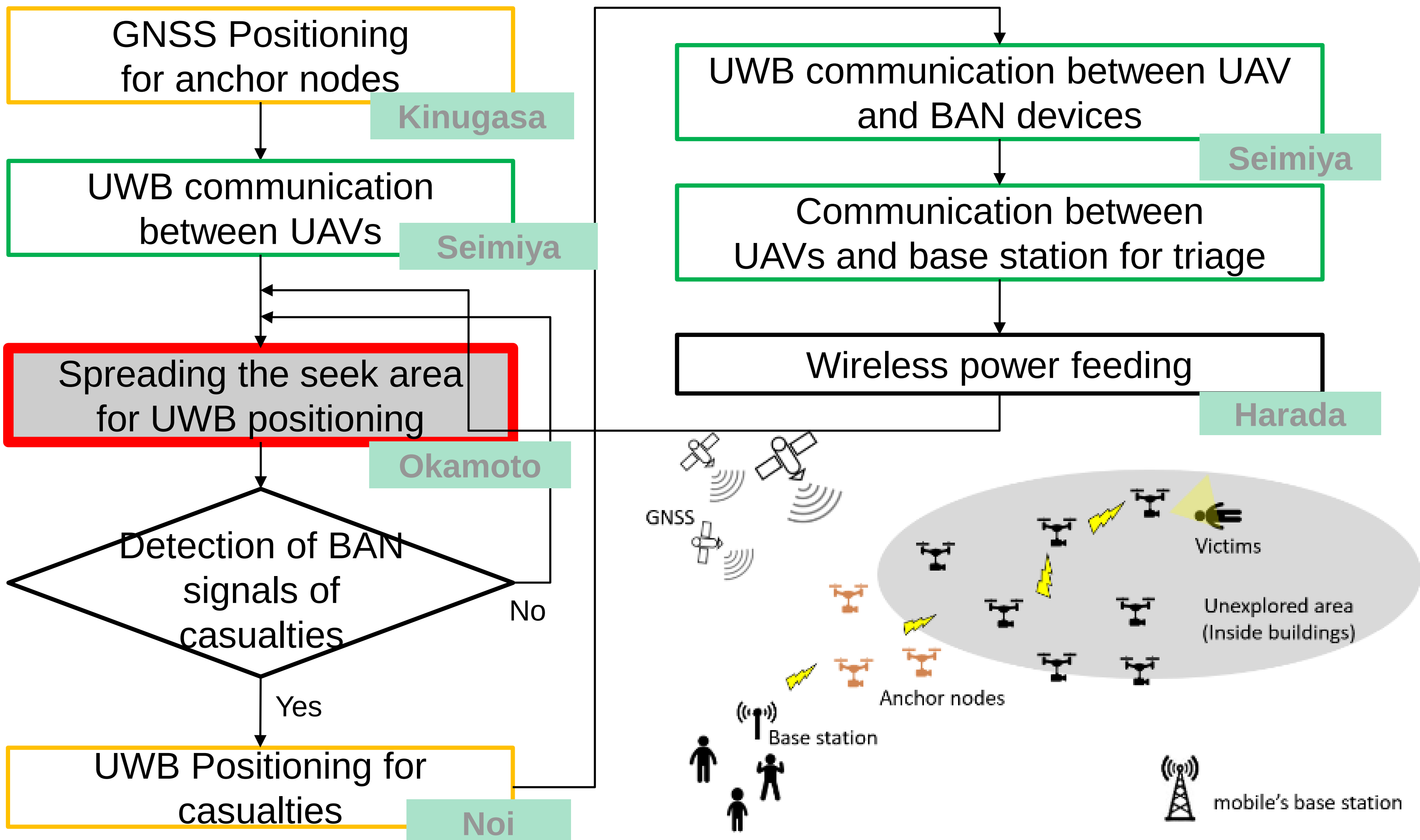
Schedule
1) Mathematical model construction
2) Logging GNSS measurements ← Ongoing
3) Performance evaluation
4) Experiment using drone

2) Logging GNSS measurements in NZ (Plan)

Logging using two GNSS receivers



Flowchart to Search Casualties

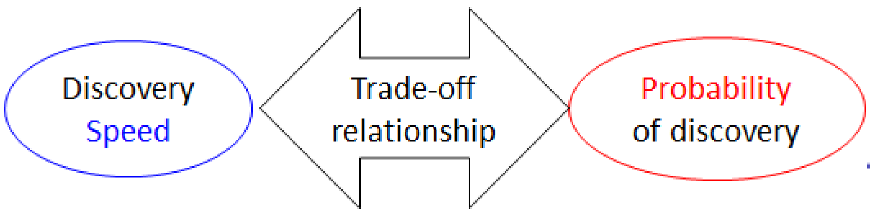


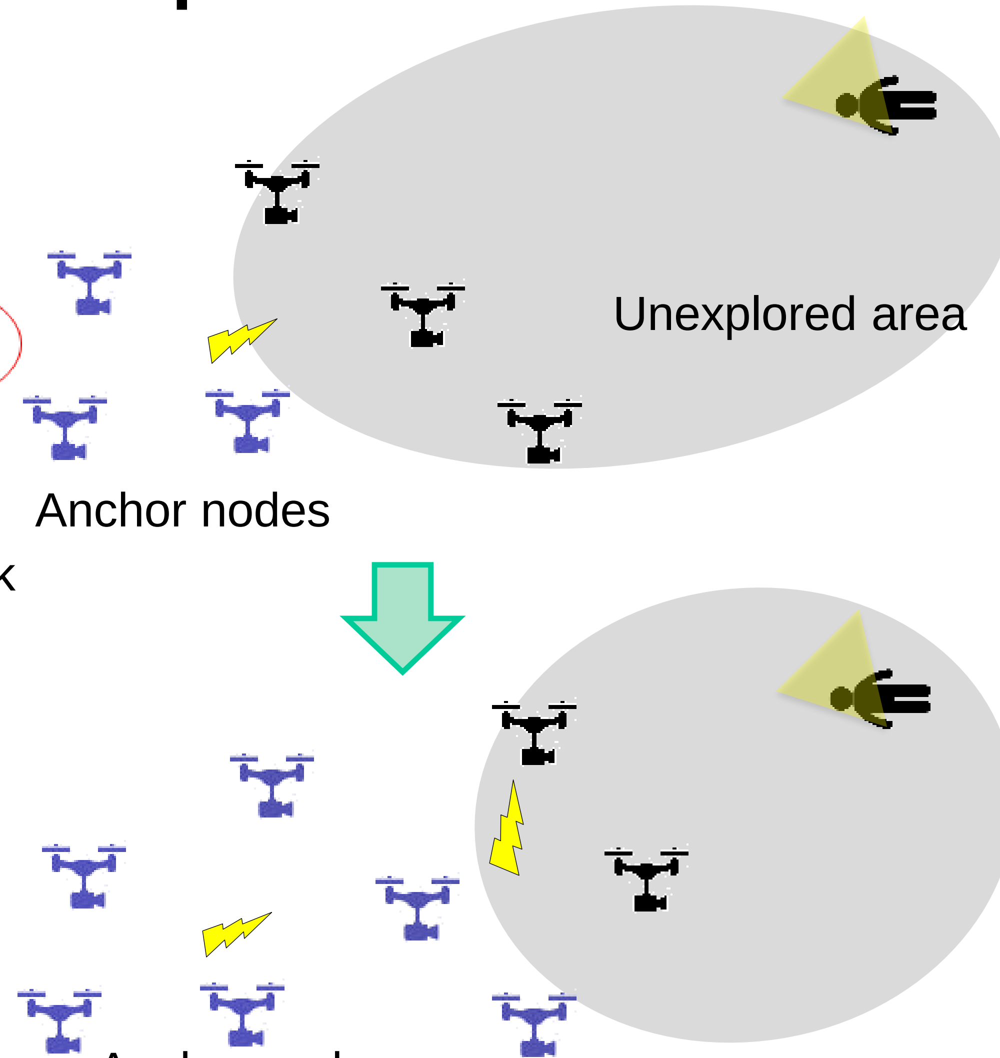
Spreading the seek area

Geolocation & Error Compensation for UAVs

Key Issues

How to search the victims trapped inside buildings where GNSS signals cannot be received?





Key Ideas

- Recursive process spreads the seek area.

Positioning for UAV in unexplored area by using UAVs in explored area

↓

Move UAVs to un explored area

(repeat)

Spreading the seek area

Geolocation & Error Compensation for UAVs

Schedule
1) Design UWB ranging and communication model in 3D area
2) Design searching algorithm
3) Write searching simulation program
↑Ongoing
4) Consider search precision and throughput
5) Experiment and evaluation

1) Design UWB ranging and communication model in 3D area

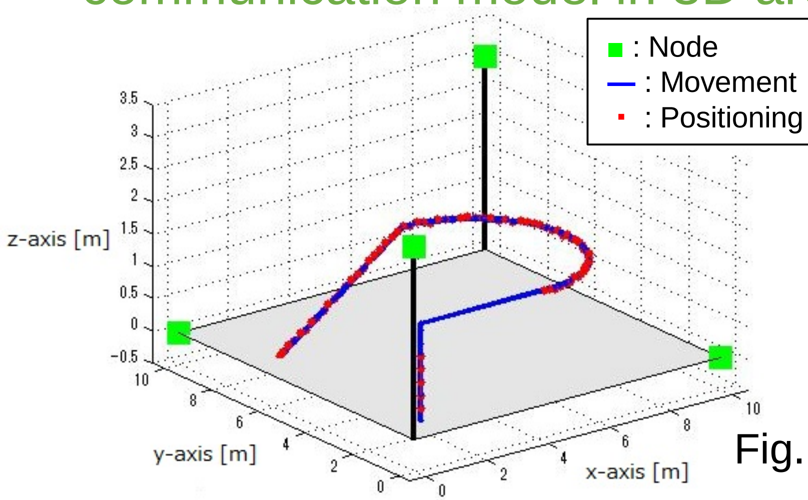


Fig.1 Positioning in 3D area

2) Design searching algorithm

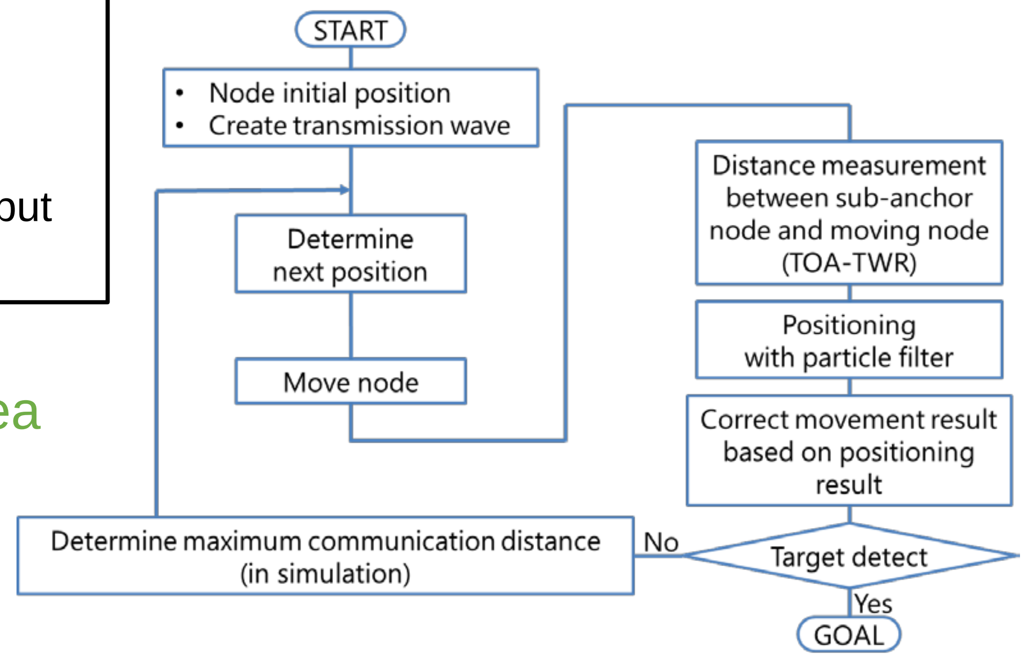


Fig.2 Flow chart

Spreading the seek area

Geolocation & Error Compensation for UAVs

Schedule

1) Design UWB ranging and communication model in 3D area
2) Design searching algorithm
3) Write searching simulation program
   ↑Ongoing
4) Consider search precision and throughput
5) Experiment and evaluation

3) Write searching simulation progra

Search by five drones

The case which rough information:

- 100m × 100m × 3m
- Flat
- No obstacle
- AWGN model

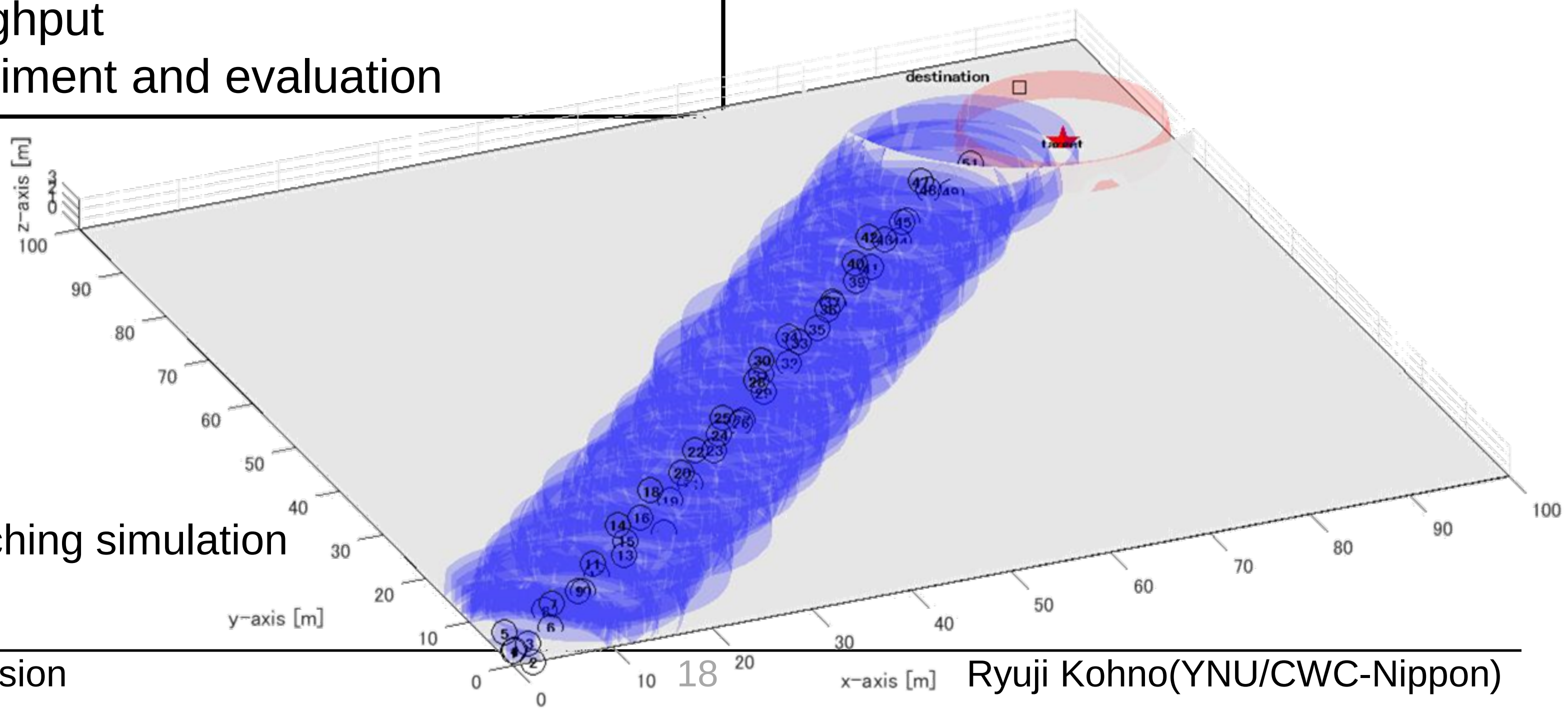
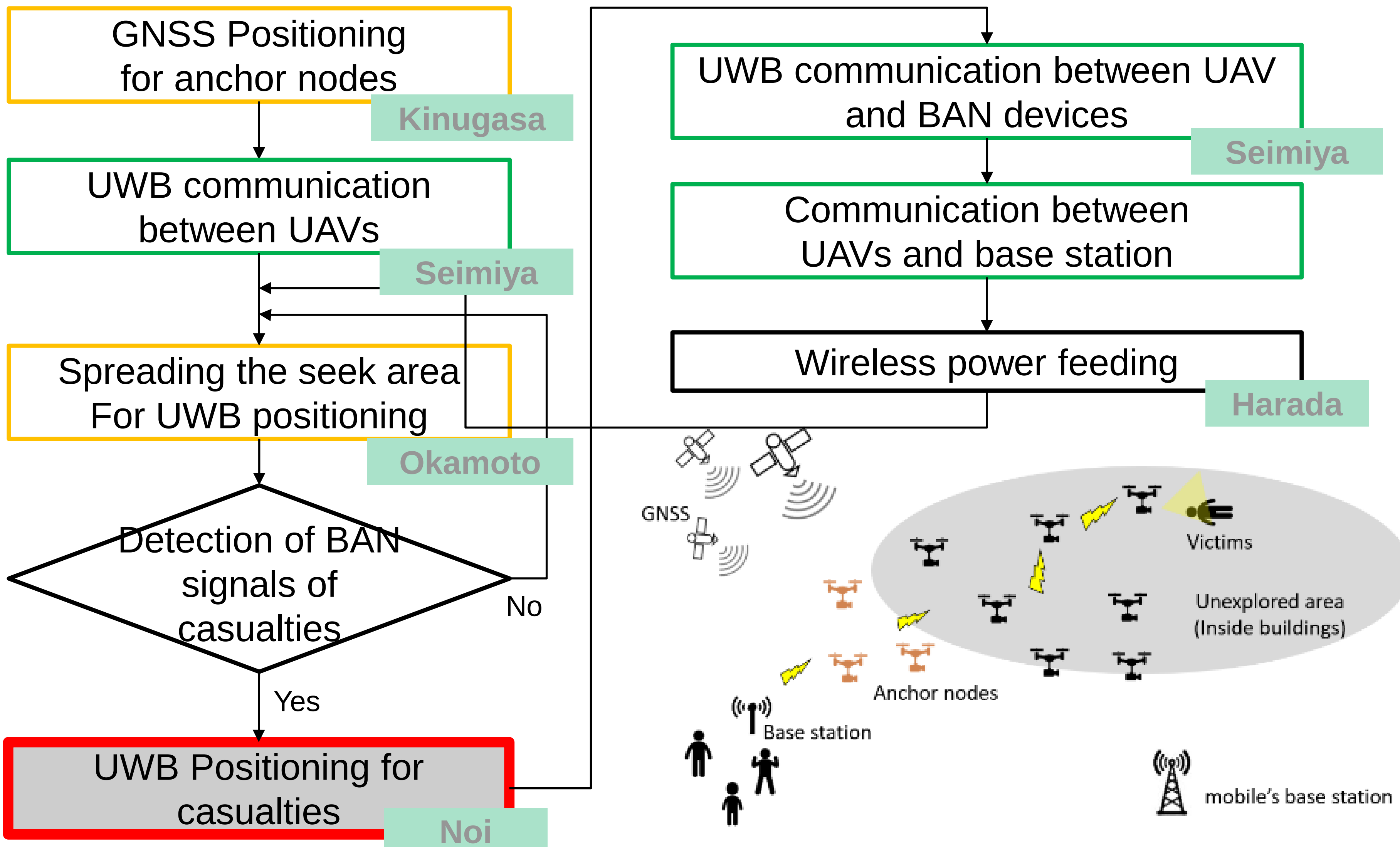


Fig.3 Searching simulation

Flowchart to Search Casualties



UWB positioning for casualties

Cooperative Localization of Casualties Using UWB-BAN

Key Issues

What is the best positional relation between anchor node (UAV) and target node (victim) for precise positioning?

Key Ideas

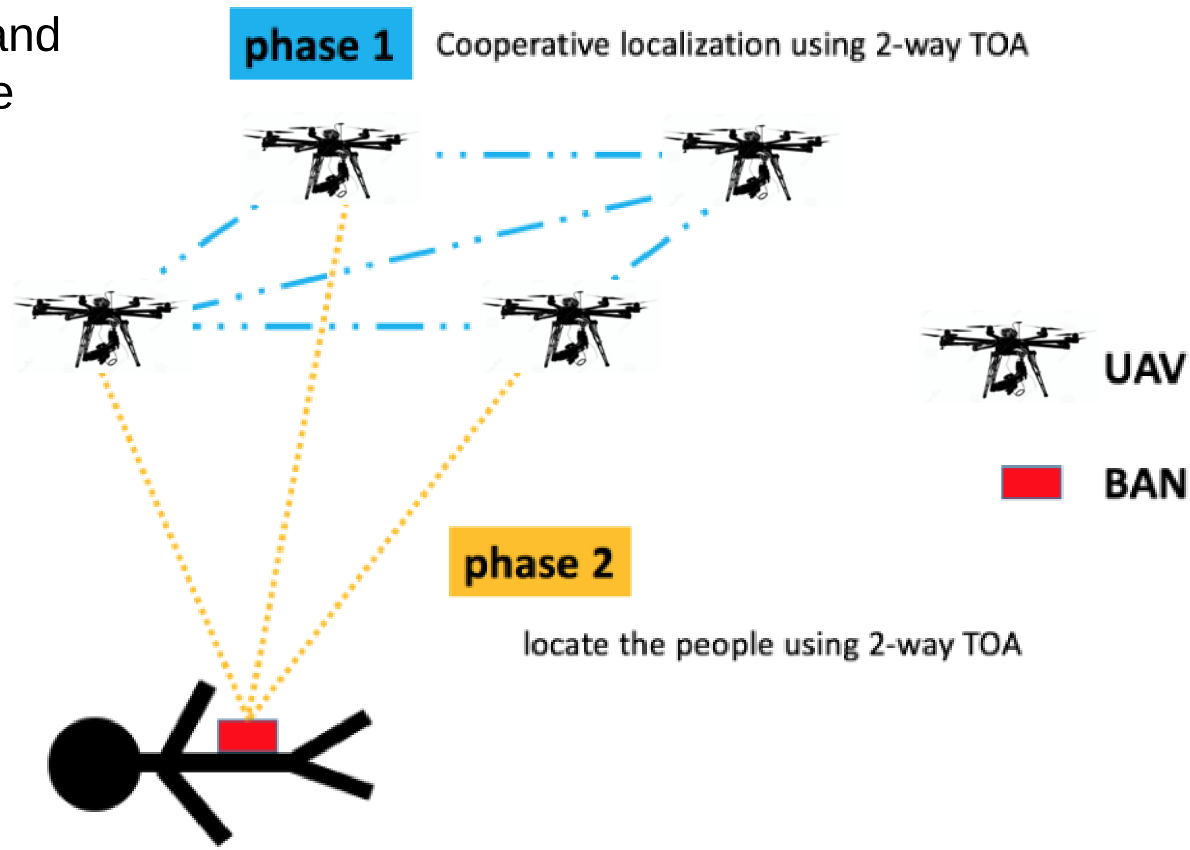
Rough

Identify the area, where victim is, using UWB ranging

↓

Fine

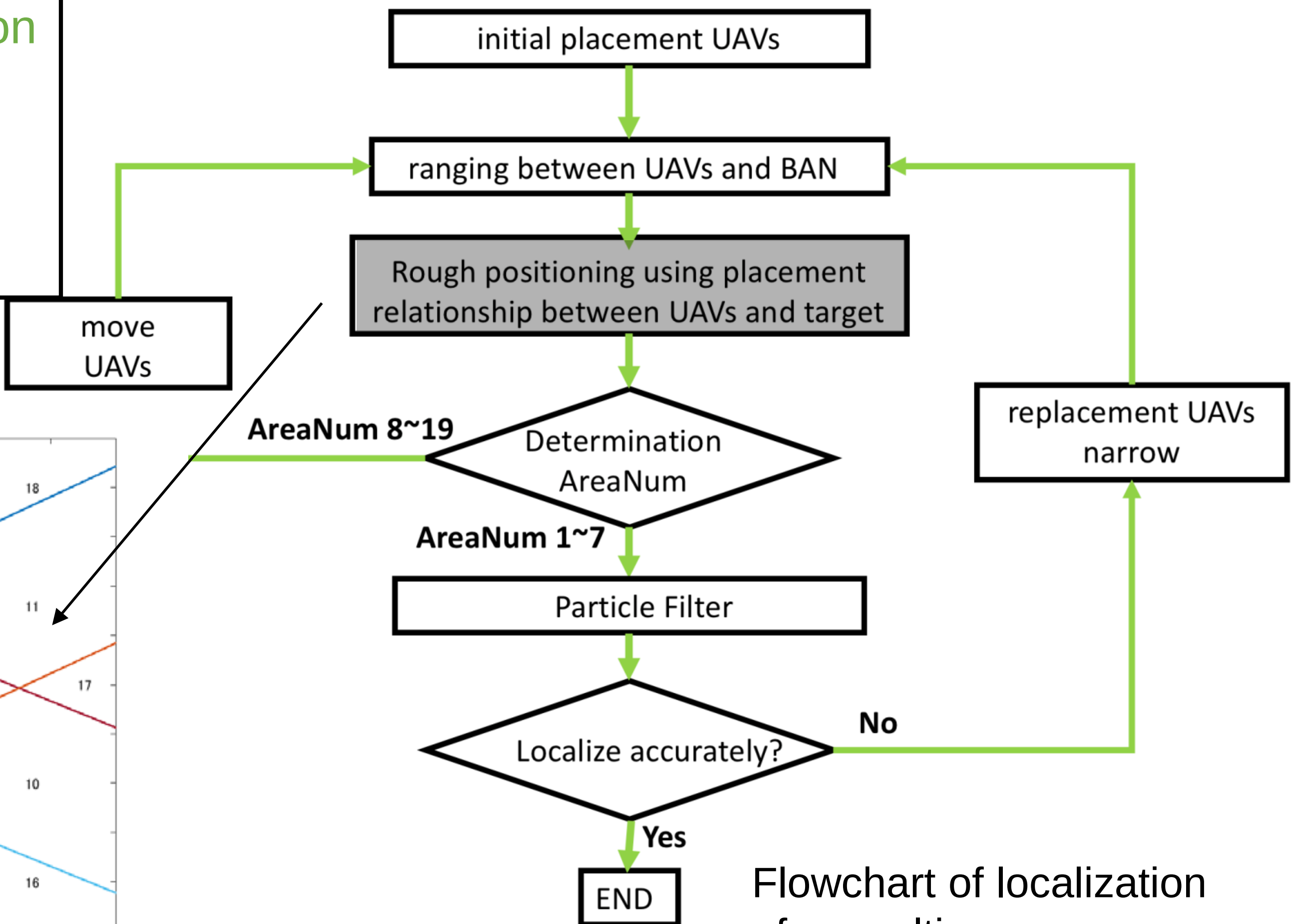
Precise localization using particle filter

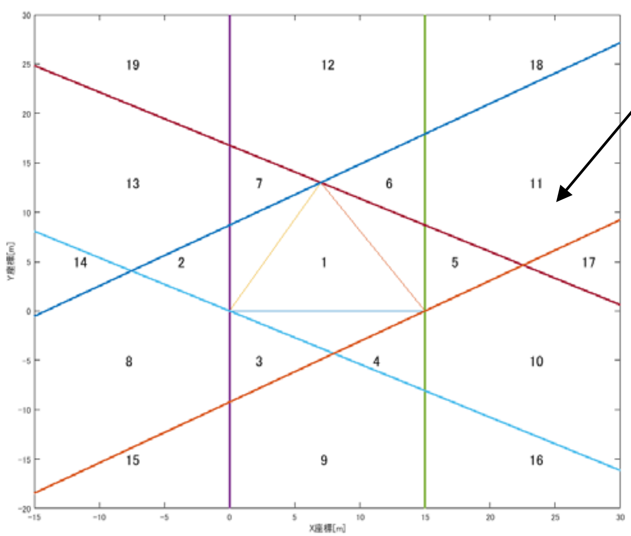


UWB positioning for casualties

Cooperative Localization of Casualties Using UWB-BAN

Schedule
1) Algorithm construction
2) Simulation
←Ongoing
3) Performance evaluation



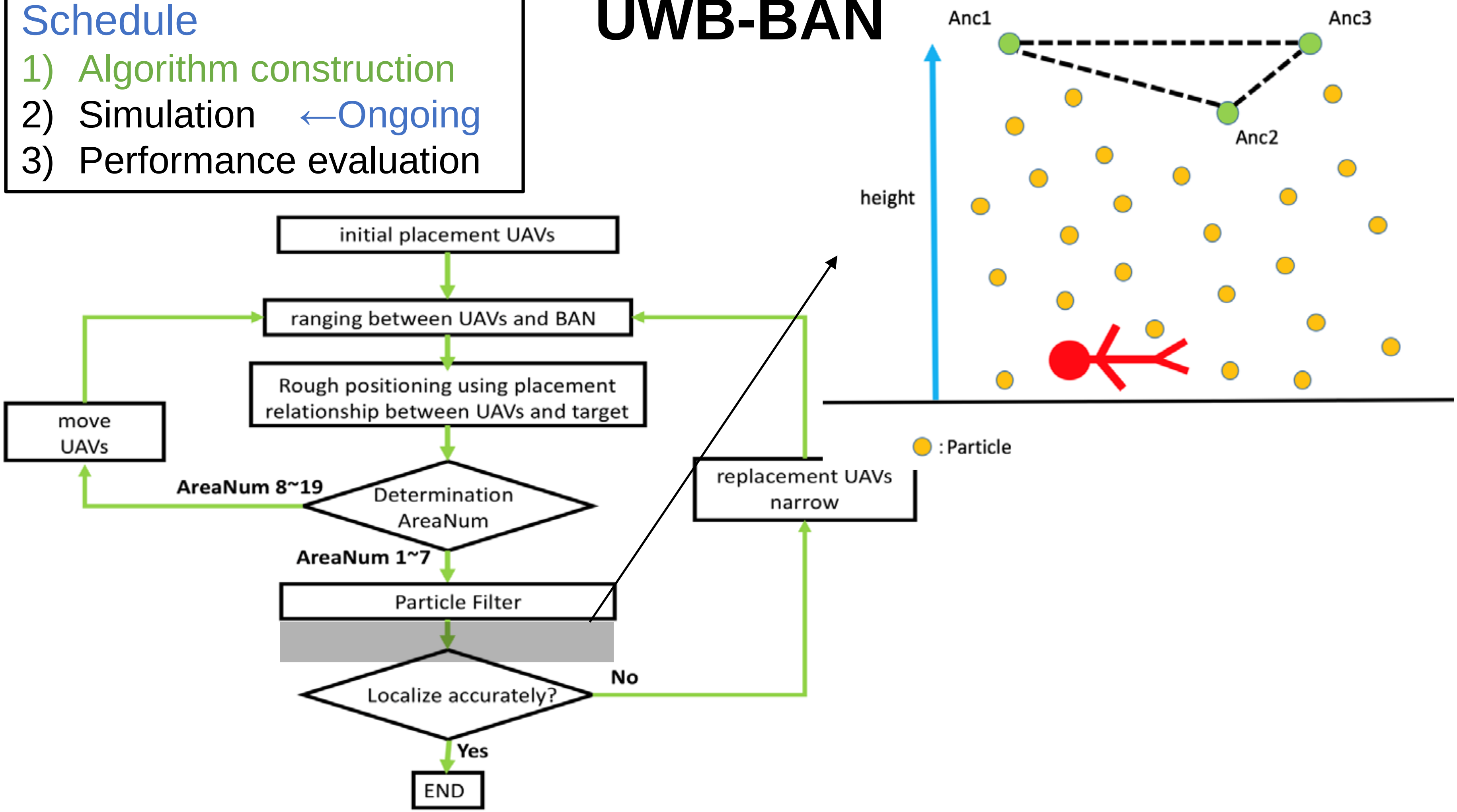


Flowchart of localization of casualties

UWB positioning for casualties

Cooperative Localization of Casualties Using UWB-BAN

Schedule
1) Algorithm construction
2) Simulation ←Ongoing
3) Performance evaluation



UWB positioning for casualties

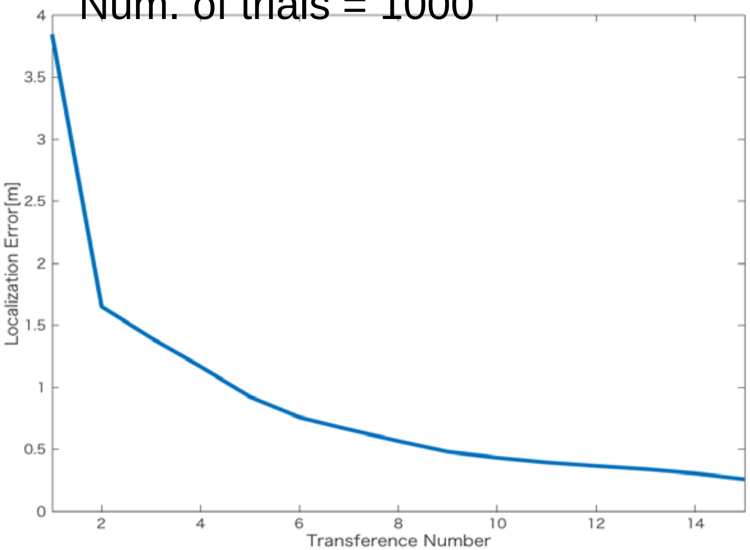
Cooperative Localization of Casualties Using UWB-BAN

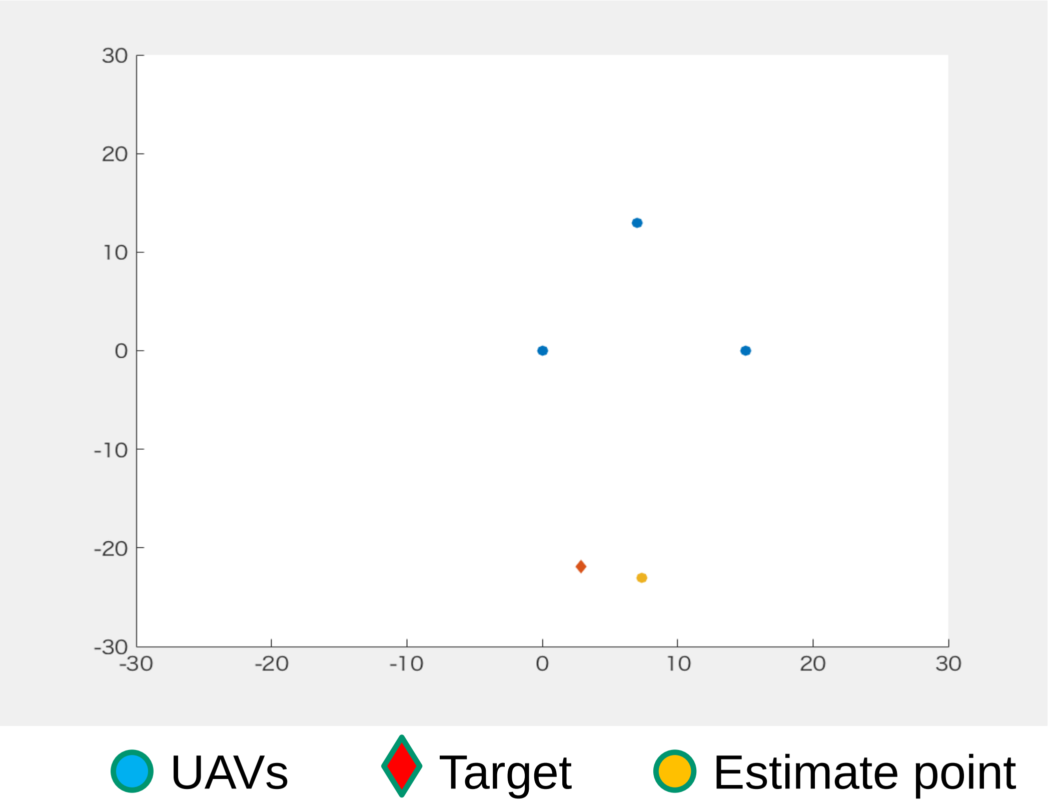
Schedule

1) Algorithm construction
2) Simulation ←Ongoing
3) Performance evaluation

2) Simulation

UAVs, arranged in a triangle shape, fly at same height
Num. of trials = 1000

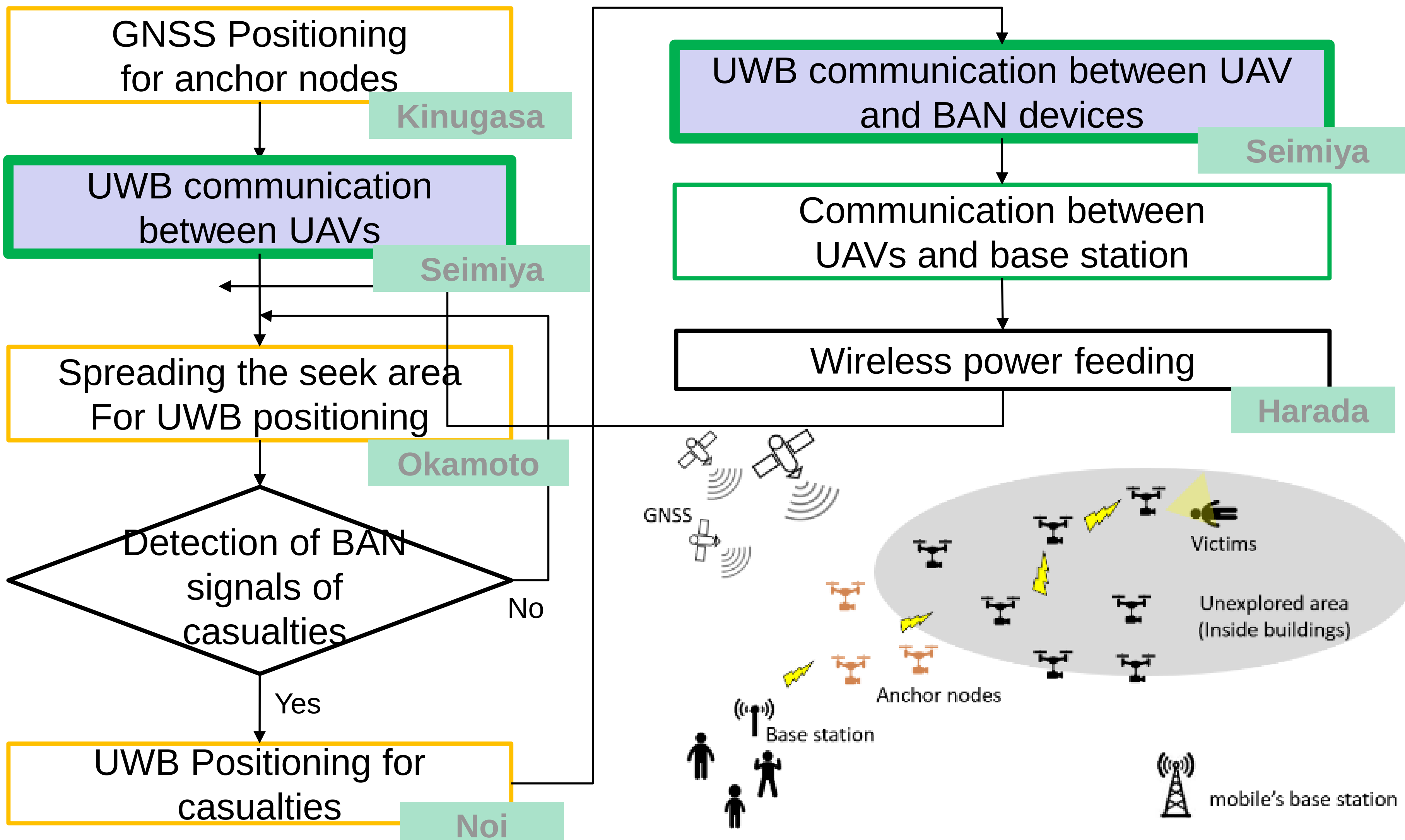




Future Works

- Evaluation in NLOS environment
- Algorithm to search multi-casualties

Flowchart to Search Casualties



Communication between BAN device and UAVs

Estimating Channel Conditions to Realize Dependable Wireless Control among Multi-Drone Environment

Schedule for

Experiments

1) Position Estimation using a Drone with the Existing UWB System ← Ongoing
2) Trials to Synchronize among Drones, Wirelessly
3) Position Estimation with Multi Drones inside the Building
4) Experiment outside the Building

◎ Drone + UWB Tag

Movie: A Drone with A UWB Tag

× Drone + Anchor Node

Movie: A Drone with an Anchor Node

Movie: Practice of Controlling a Drone

START

Manual Distance Measurement for d_{01} and d_{03}

1000 Trials

Manual Delay Time Measurement for T_{01}, T_{02} and T_{03} with the app. of "**MeasRng**"

Derivation of d_{02} and off-set with the calculation program of "keisan.m"

Filling all of the data into the Positioning Software "TDOAv3", then push the start button

END

Communication between BAN device and UAVs

Estimating Channel Conditions to Realize Dependable Wireless Control among Multi-Drone Environment

Key Issues

How to keep the connections (1)among Multi Drones and (2)between a Drone and a tag as long as possible?

Changing the Capability of Error Correction depending on the QoS and the channel environment

Key Ideas

- By using QoS-HARQ, the unequal error protection(UEP) will be realized.
- QoS-HARQ will reduce the power consumption of each drone and expand the searching time.

Schedule for **Theoretical Analysis**

1) With **the rotary inverted pendulum**, propose the unequal error protection scheme
2) Changing the controlled object into **the rotary camera model**, which has several sensing data and control variables← Ongoing
3) Apply our UEP scheme for **multi drones**

:

Schedule for **Experiments**

1) Position Estimation using a Drone with the Existing UWB System ← Ongoing
2) Trials to Synchronize among Drones, Wirelessly
3) Position Estimation within Multi Drones inside/outside the Building
4) Position Estimation outside Multi Drones inside/outside the Building

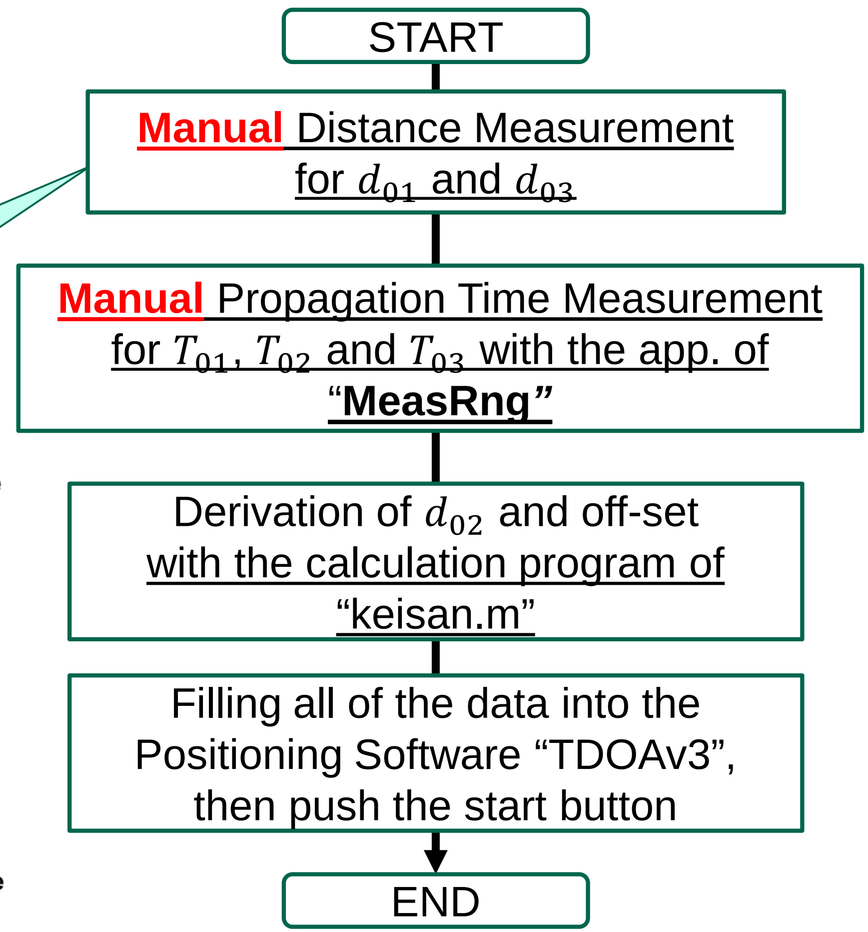
:

Communication between BAN device and UAVs

Estimating Channel Conditions to Realize Dependable Wireless Control among Multi-Drone Environment

In case of applying the conventional UWB positioning system, we have to set the environment as below, and we need to set up the system with the process as the right figure.

Average Time of 1000 Trials



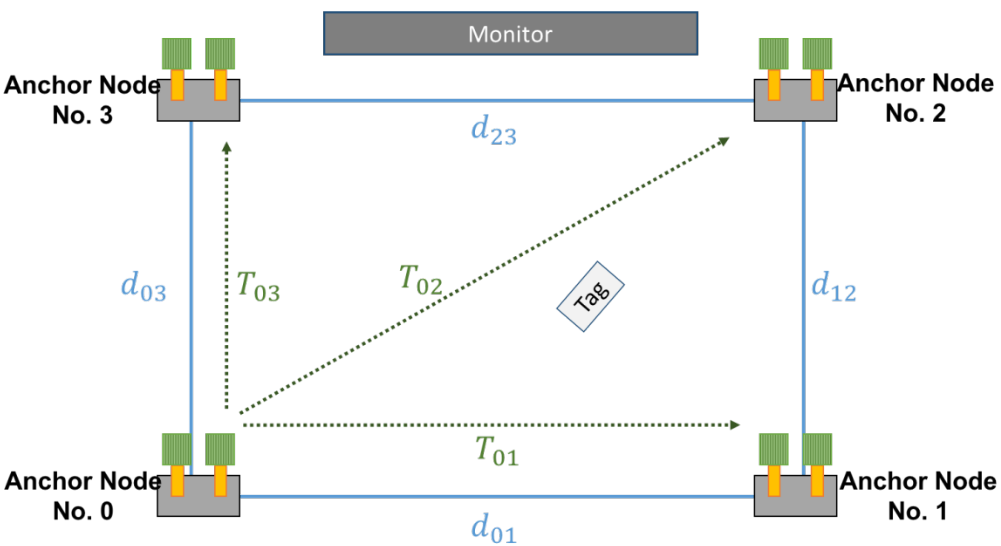
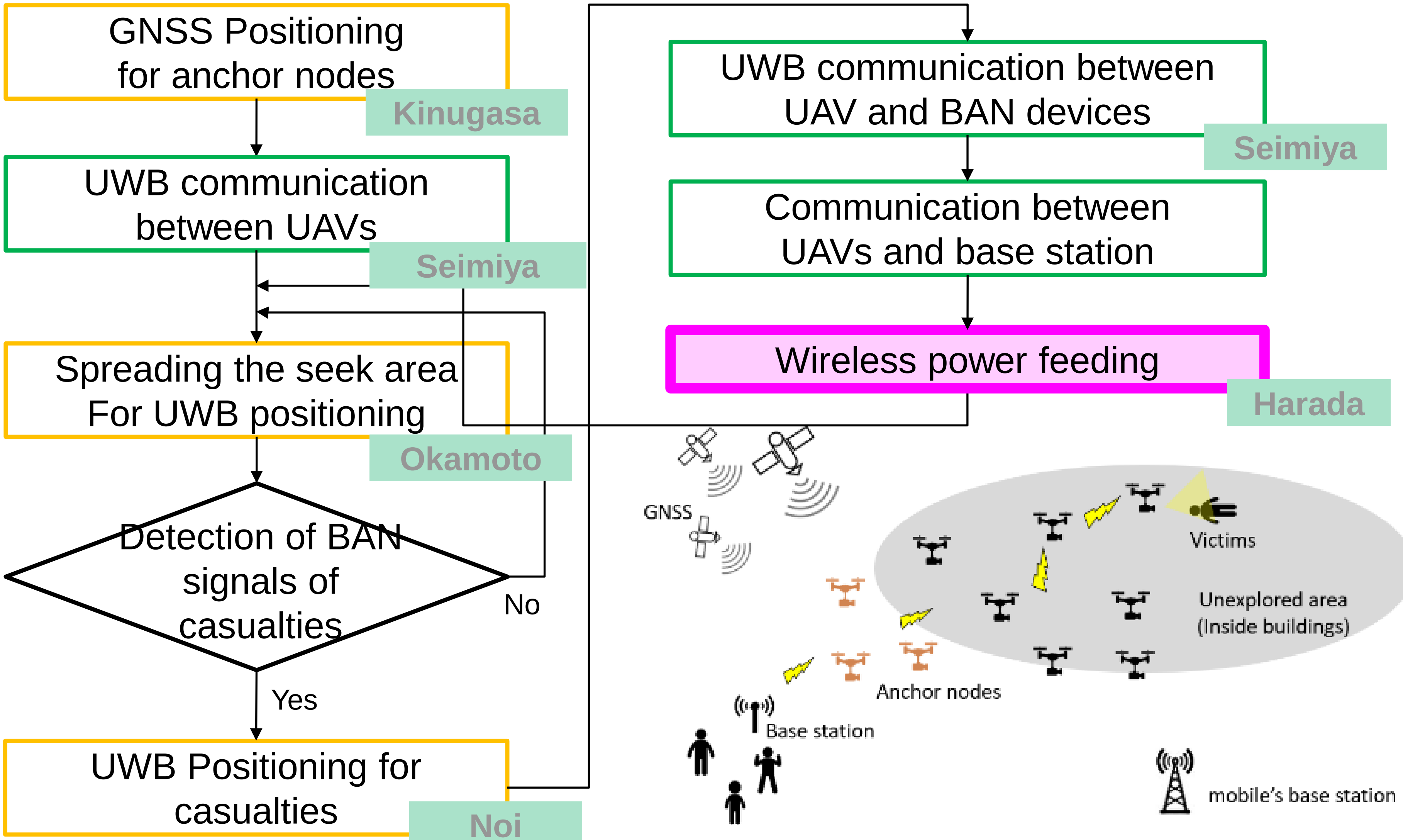


Fig: Layout of Anchor Nodes and a Tag @Mitsui Building

Fig: Flowchart of the UWB Measurement with TDOA

Flowchart to Search Casualties



Wireless power feeding

Feedback Control of Wireless Power Transfer to UAVs

Key Issues

How to supply power high efficiency?

Key Ideas

- Receiver transmits UWB signals to transmitters. (Fig.1)
- Transmitters calculate Receiver's position.
- One of transmitter transmits power to receiv (Fig.2)

Fig.1

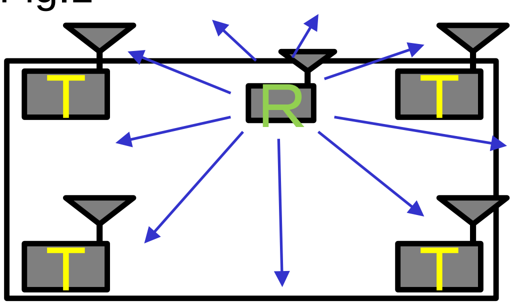
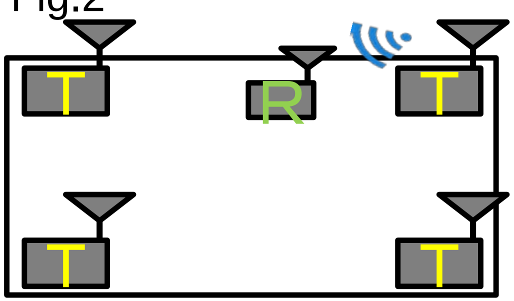
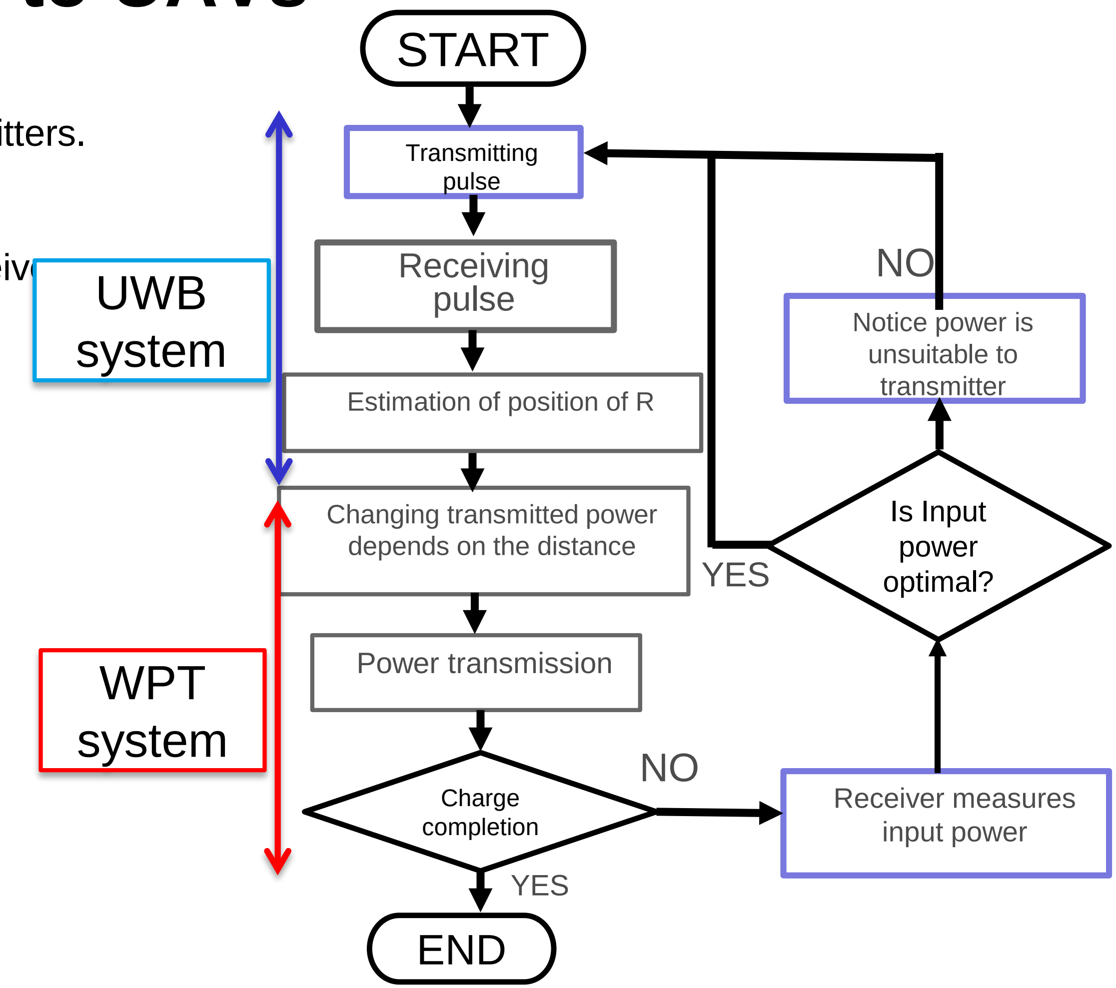


Fig.2





Communication between BAN device and UAVs

Estimating Channel Conditions to Realize Dependable Wireless Control among Multi-Drone Environment

Key Issues

How to supply power high efficiency?

Key Ideas

- Receiver transmits UWB signals to transmitters. (Fig.1)
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Fig.1

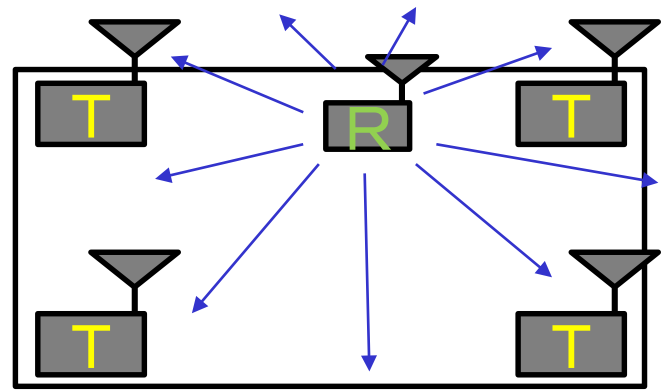
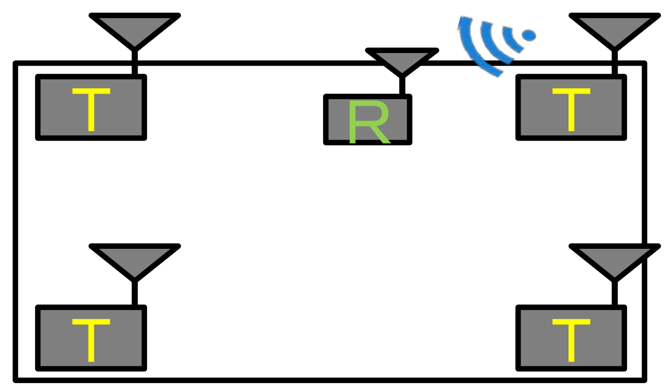


Fig.2



Communication between BAN device and UAVs

Estimating Channel Conditions to Realize Dependable Wireless Control among Multi-Drone Environment

Schedule

1) Mathematical model construction
2) Performance evaluation in ideal evaluation← Ongoing
3) Performance evaluation in consideration of errors
4) Increasing the getting power

Array antenna model

$$\frac{P_r}{P_t} = G_{Array} * G_{element} * G_r * \frac{1}{4\pi d^2} * A_r$$

$$G_{Array} = \frac{|g(\theta)|^2}{P} = \frac{|\sum_{n=-N}^{N} a_n|^2}{\sum_{m=-N}^{N}\sum_{n=-N}^{N} r_{nm} a_n a_m^*}($$

$$r_{n,m} = \frac{\sin\psi}{\psi}$$

$$\psi = k_0 d(n-m)$$

Rectenna's model

$$\eta = \frac{1}{1+A+B+C}$$

$$A = \frac{R_L}{\pi R_s}(1+\frac{V_{bi}}{V_o})^2(\theta_{on}(1+\frac{1}{2\cos^2\theta_{on}}) - \frac{3}{2}\tan\theta_{on})$$

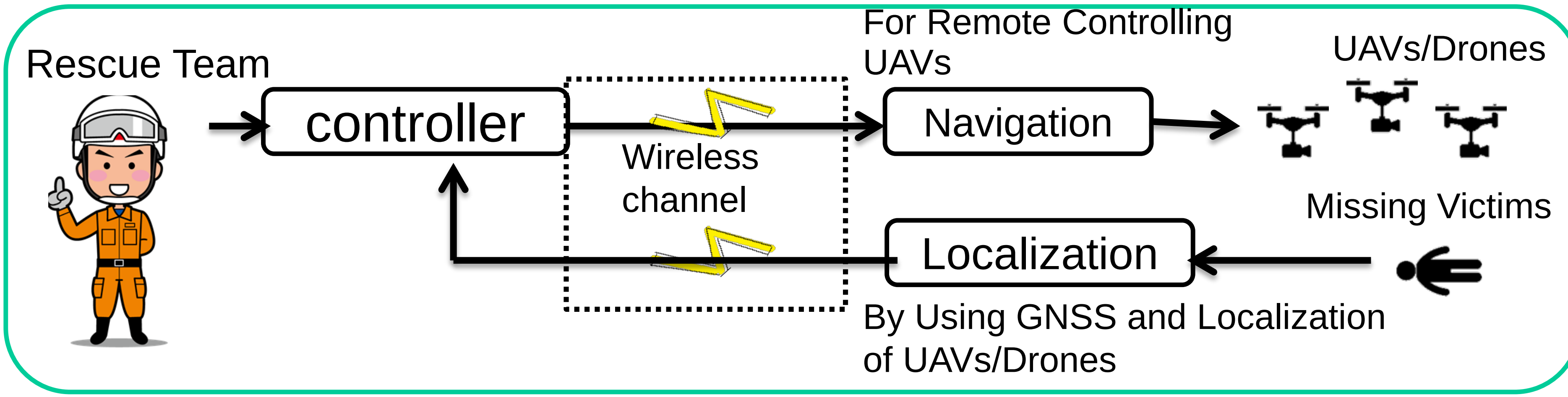
$$B = \frac{R_s R_L C_j^2 \omega^2}{2\pi}(1+\frac{V_{bi}}{V_o})(\frac{\pi-\theta_{on}}{\cos^2\theta_{on}} + \tan\theta_{on})$$

$$C = \frac{R_L}{\pi R_s}(1+\frac{V_{bi}}{V_o})\frac{V_{bi}}{V_o}(\tan\theta_{on} - \theta_{on})$$

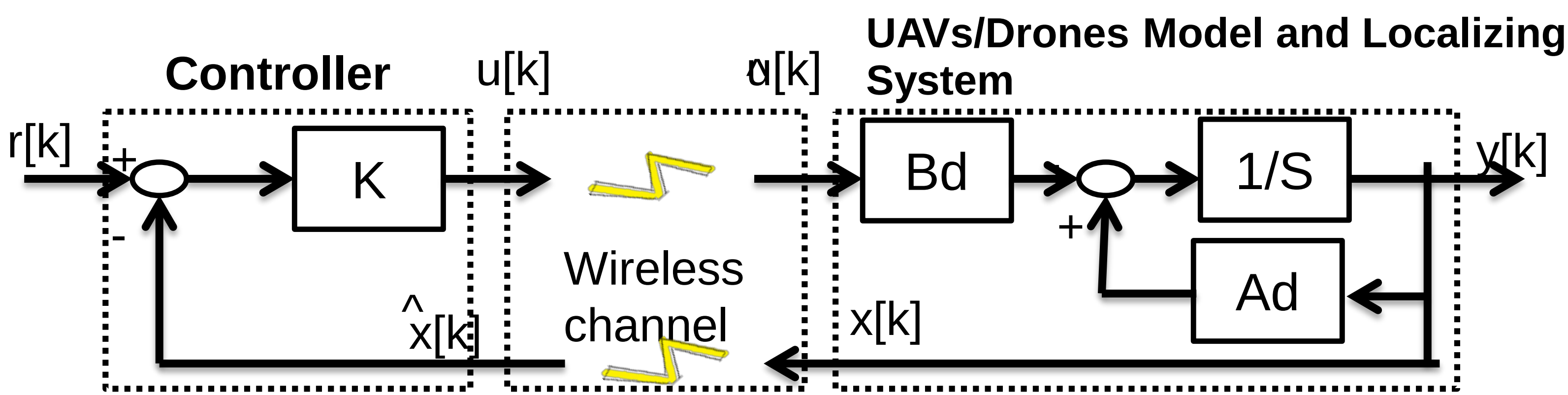
$$C_j = C_{j0}\sqrt{\frac{V_{bi}}{V_{bi}+|V_o|}}$$

$$\tan\theta_{on} - \theta_{on} = \frac{\pi R_s}{R_L(1+\frac{V_{bi}}{V_o})}$$

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

Concluding Remarks

(1) UAV or drone is an example of machine for us to research and develop dependable remote sensing and controlling, and to extend to apply the same technologies to autonomous driving cars.

(2) We can apply our established dependable and trustworthy wireless networking, computing and data mining for remote medicine to these remote sensing and controlling UAVs, cars, robots and other machines which all are life critical applications.

(3) The joint team between New Zealand and Japan has submitted the next project on Dependable Remote Monitoring All Social Infrastructures to be extended from the current project.

(4) Japanese team is coordinating more projects with USA and EU.

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