Building Numerical Simulation Environment for WBAN Propagation

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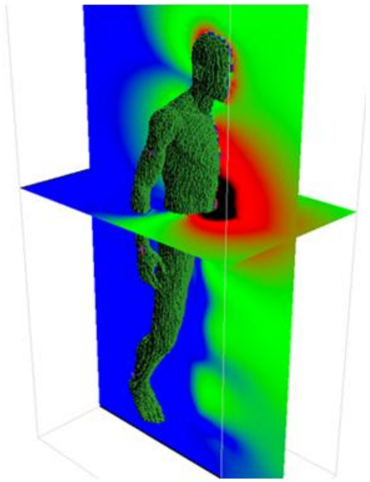
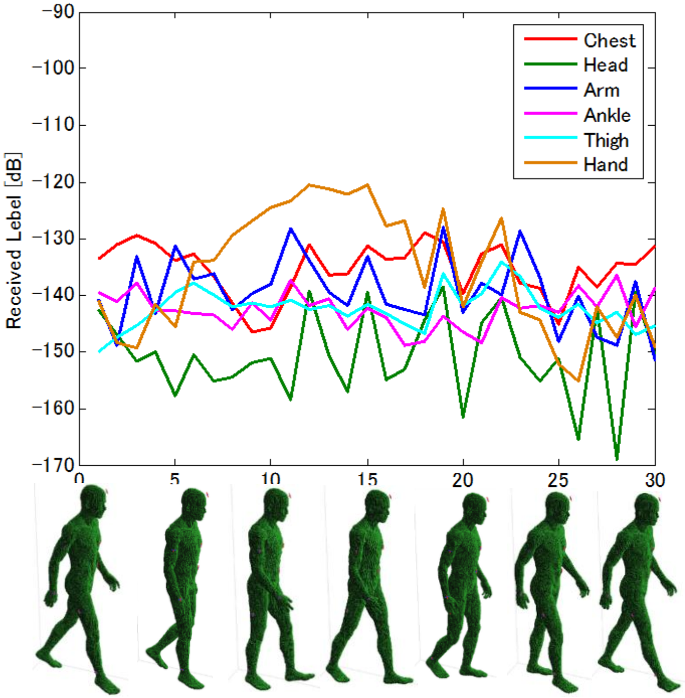
Background

Numerical Simulation of WBAN Channel

- WBAN (Wireless Body Area Network)
  - Mainly used for vital data monitoring
  - Links between on-body sensors and coordinators are studied

- Numerical simulation
  - Simulate dynamic fluctuation of pathloss
  - Electric field around human body is calculated using FDTD method for each frames



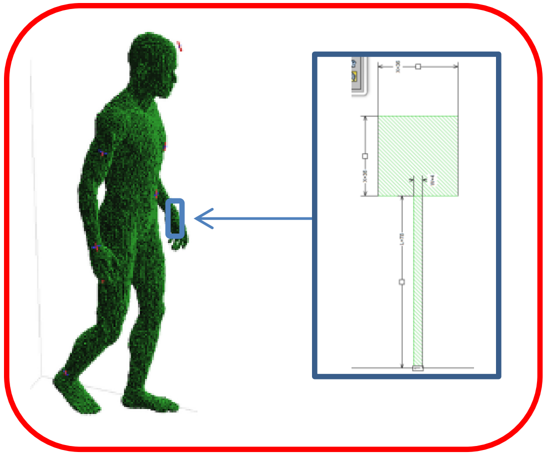


Challenges in Propagation Simulation

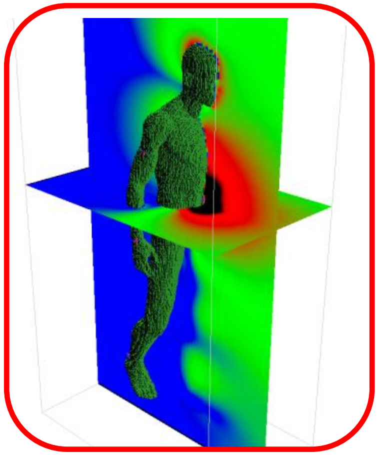
Antenna De-embedding

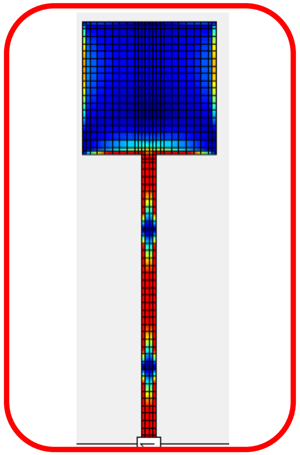
- Separated simulation for antenna and body
- Importance
  - For appropriate simulation parameter
    - E.g. mesh size of FDTD method
      - » Human body = bigger mesh size
      - » Antenna = smaller mesh size
  - For optimization of antenna design
    - Simulation of channel doesn't have to be repeated

Embedded simulation



De-embedded simulation





Purpose of this presentation

To present:

1. Antenna de-embedding framework

2. Demonstration using 3 electric dipoles
   - Dynamic pathloss simulation for walking motion

3. Preliminary study for more general cases
   - Excitation of spherical waves using multi-poles in FDTD grid

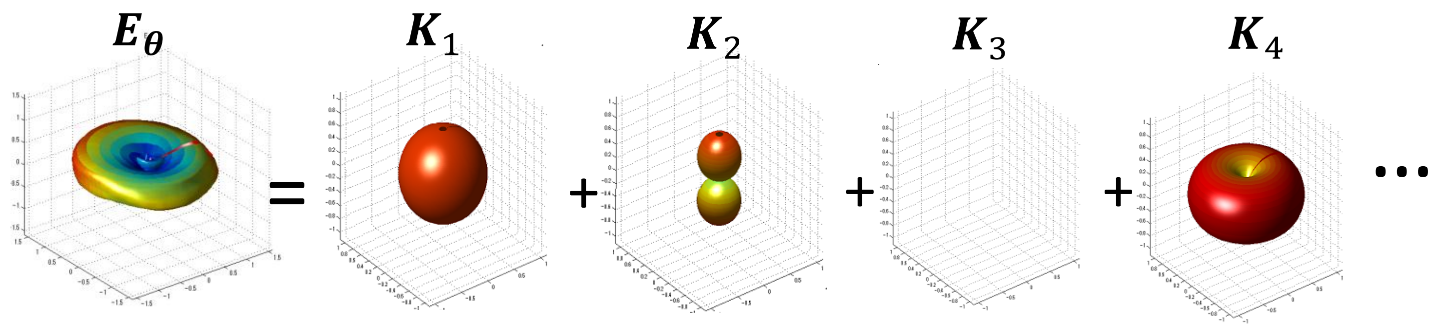
1. Antenna De-embedding Framework

Antenna De-embedding Framework

Utilization of spherical waves

Theory

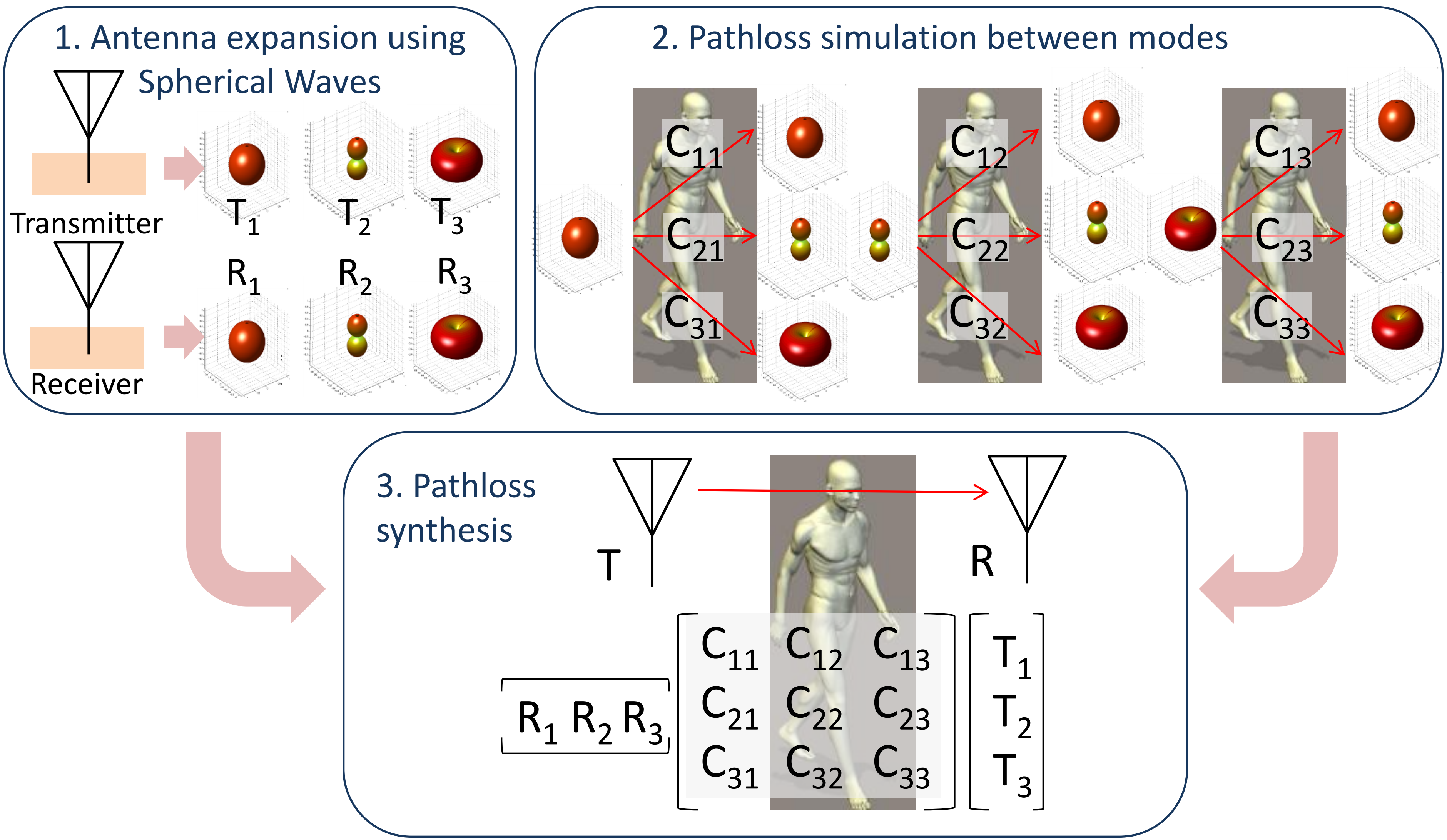
- Any antenna can be modeled as a summation of spherical waves K_j



$$\boldsymbol{E}(r,\theta,\phi) = \frac{k}{\sqrt{\eta}}\frac{1}{\sqrt{4\pi}}\frac{e^{ikr}}{kr}\sum_{j=1}^{J} Q_j \boldsymbol{K}_j(\theta,\phi)$$

- J is finite number determined by the size of antenna
    - » smaller antenna → smaller J

Antenna De-embedding Framework

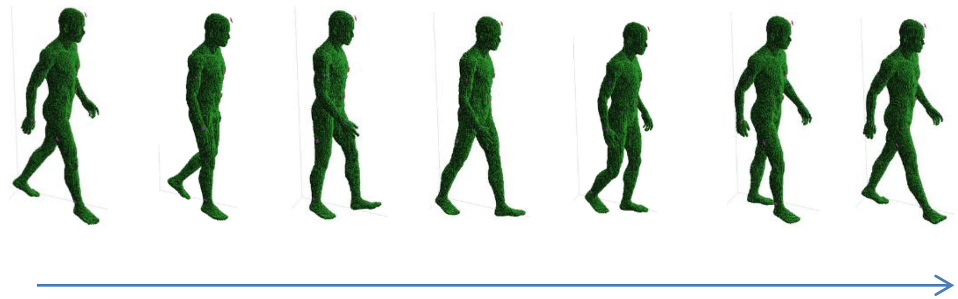


Demonstration using 3 electric dipoles

Simulation scenario

Simulation scenario

- Walking motion
  - 1sec divided by 30 frames
- Topology
  - Transmitter: Neval
  - Receiver :
    Head, Arm, Hand, Chest, Thigh, Ankle
- Pathloss fluctuation is calculated

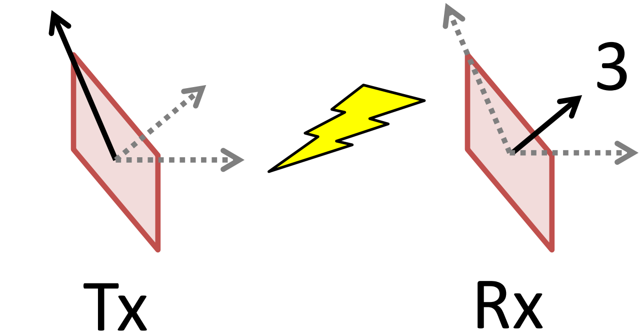


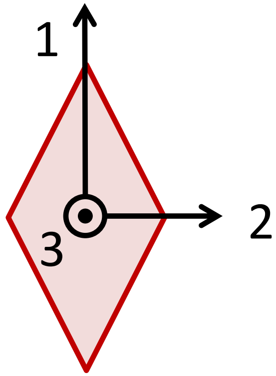
30 sec

Simulation Scenario

- Simulation scenario
  - Antenna
    - Infinitesimal dipole directing 1, 2, or 3 (→)
  - Antenna combination
    - Examine 3 x 3 = 9 combinations

E.g. 1-3

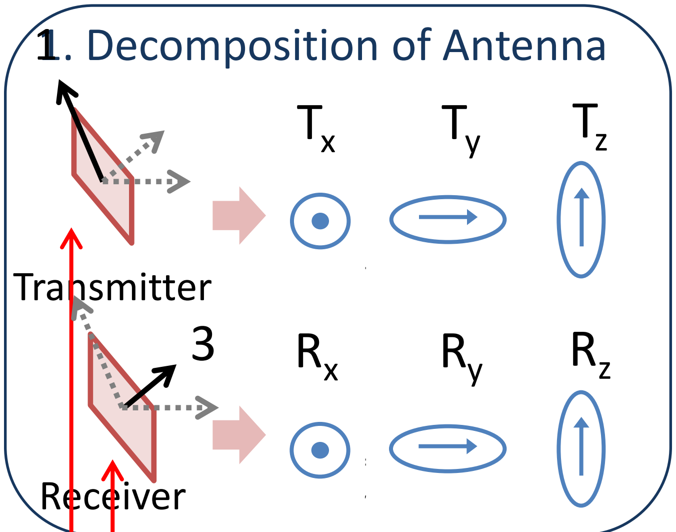


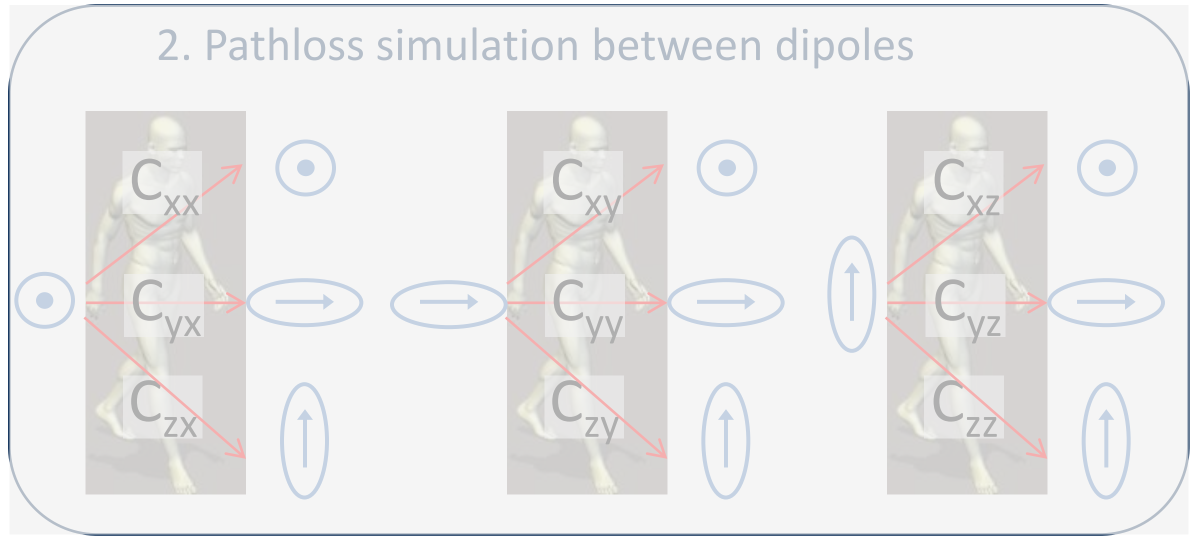


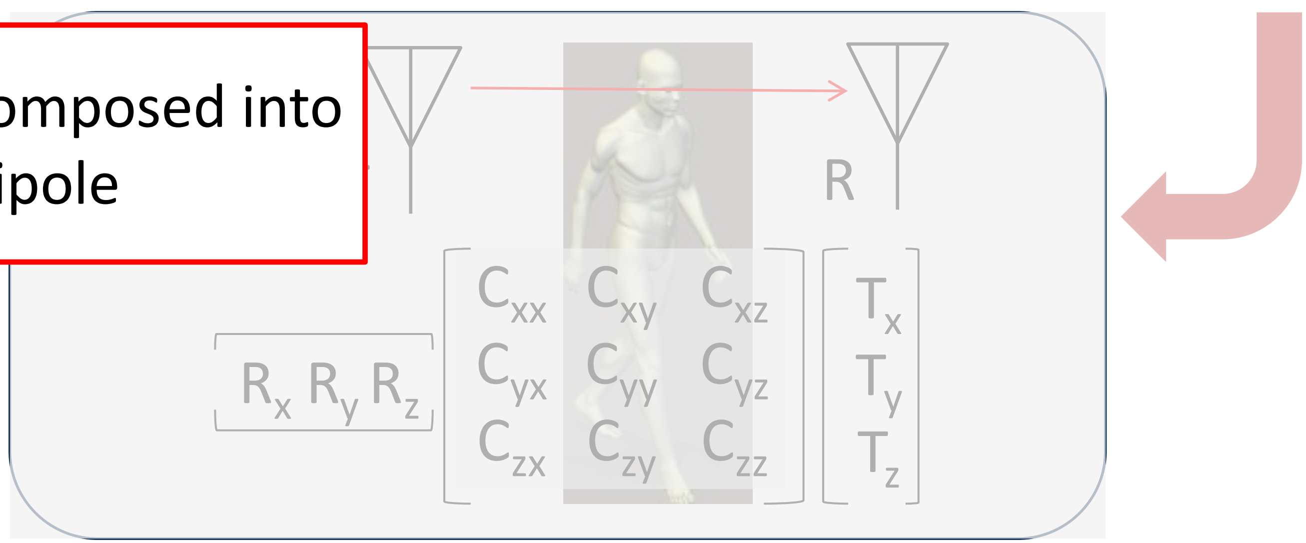
1. Normal to the ground (long axis)
2. Tangential to the ground (short axis)
3. Normal to the human body

Simulation

- Demonstrate our frame work using 3 electric dipole



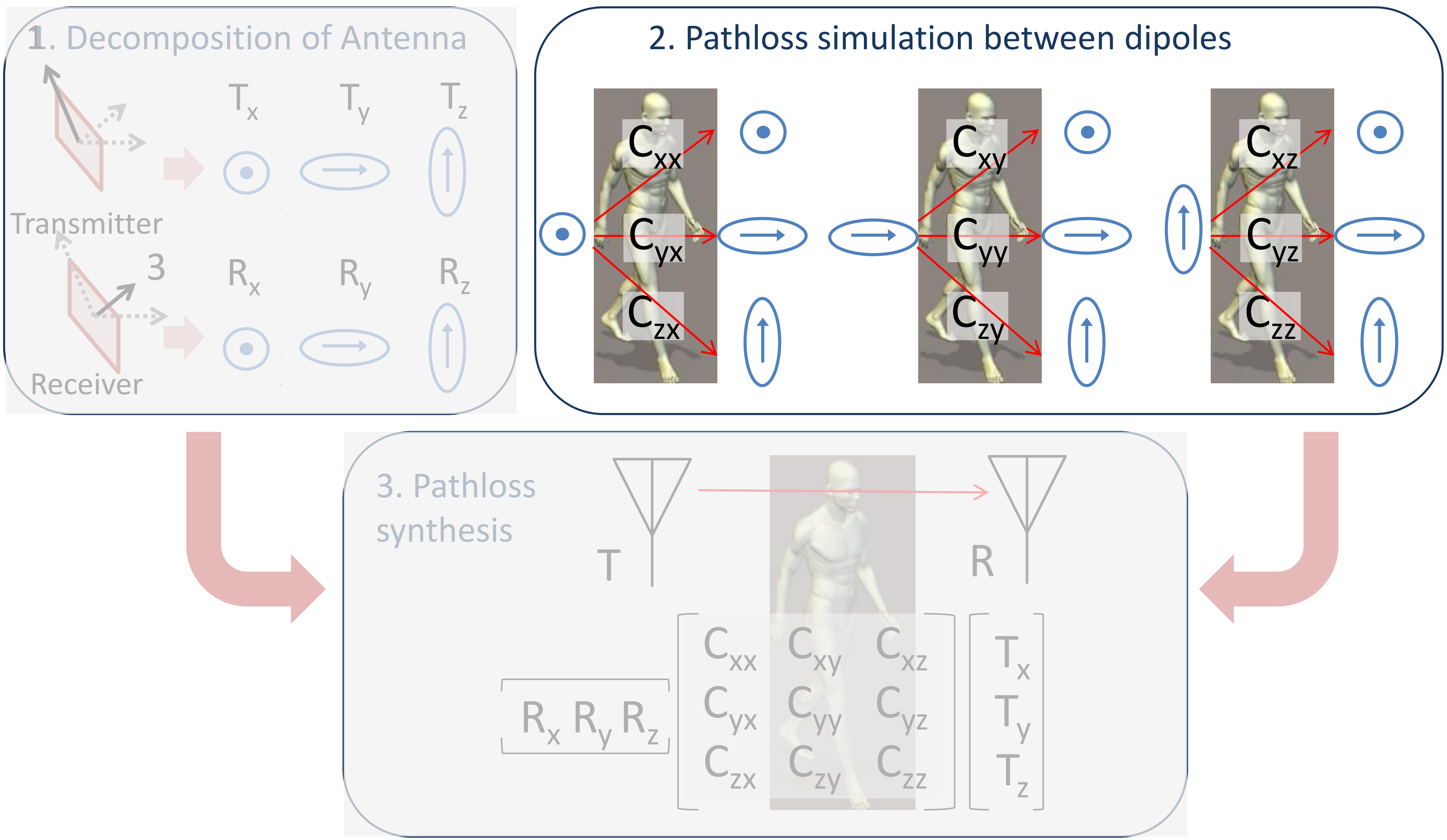




Dipole are decomposed into x,y,z dipole

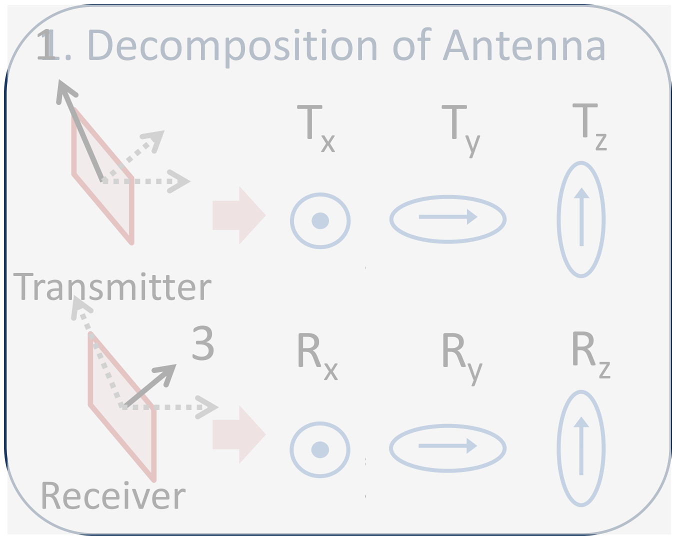
Simulation

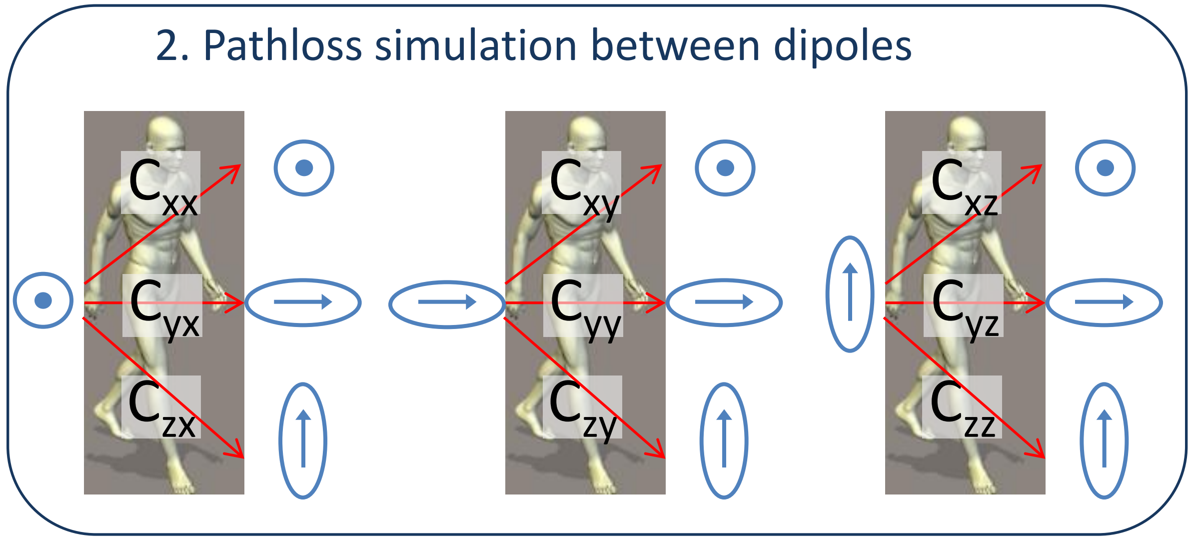
- Demonstrate our frame work using 3 electric dipole

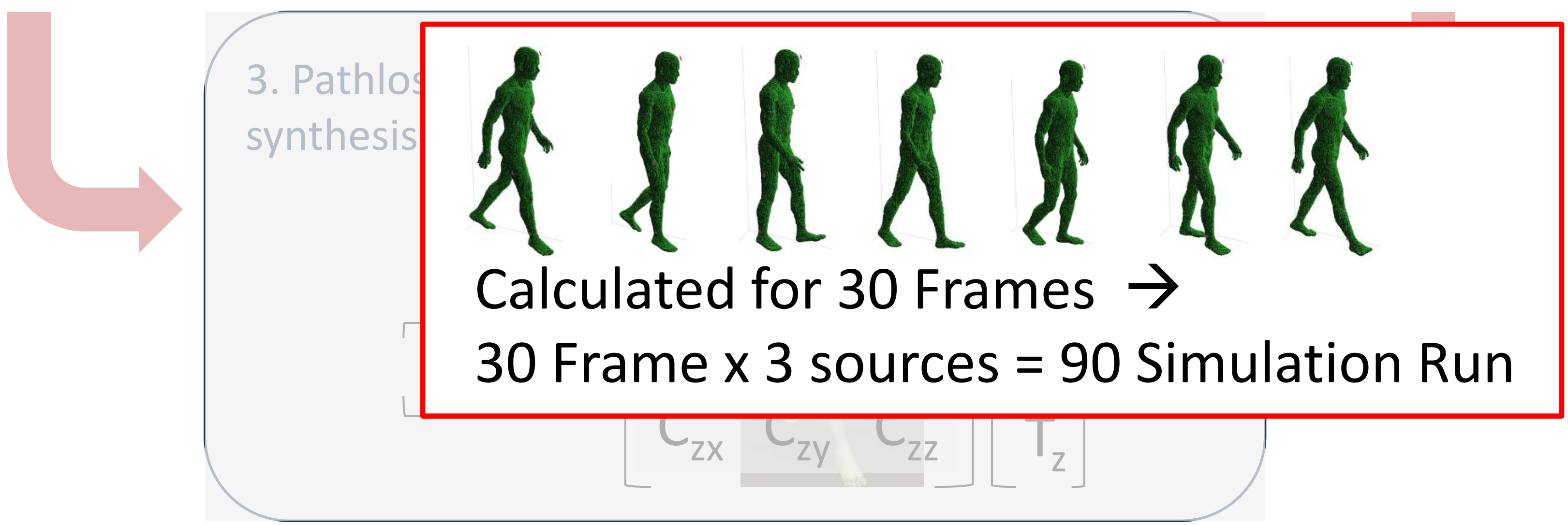


Simulation

- Demonstrate our frame work using 3 electric dipole

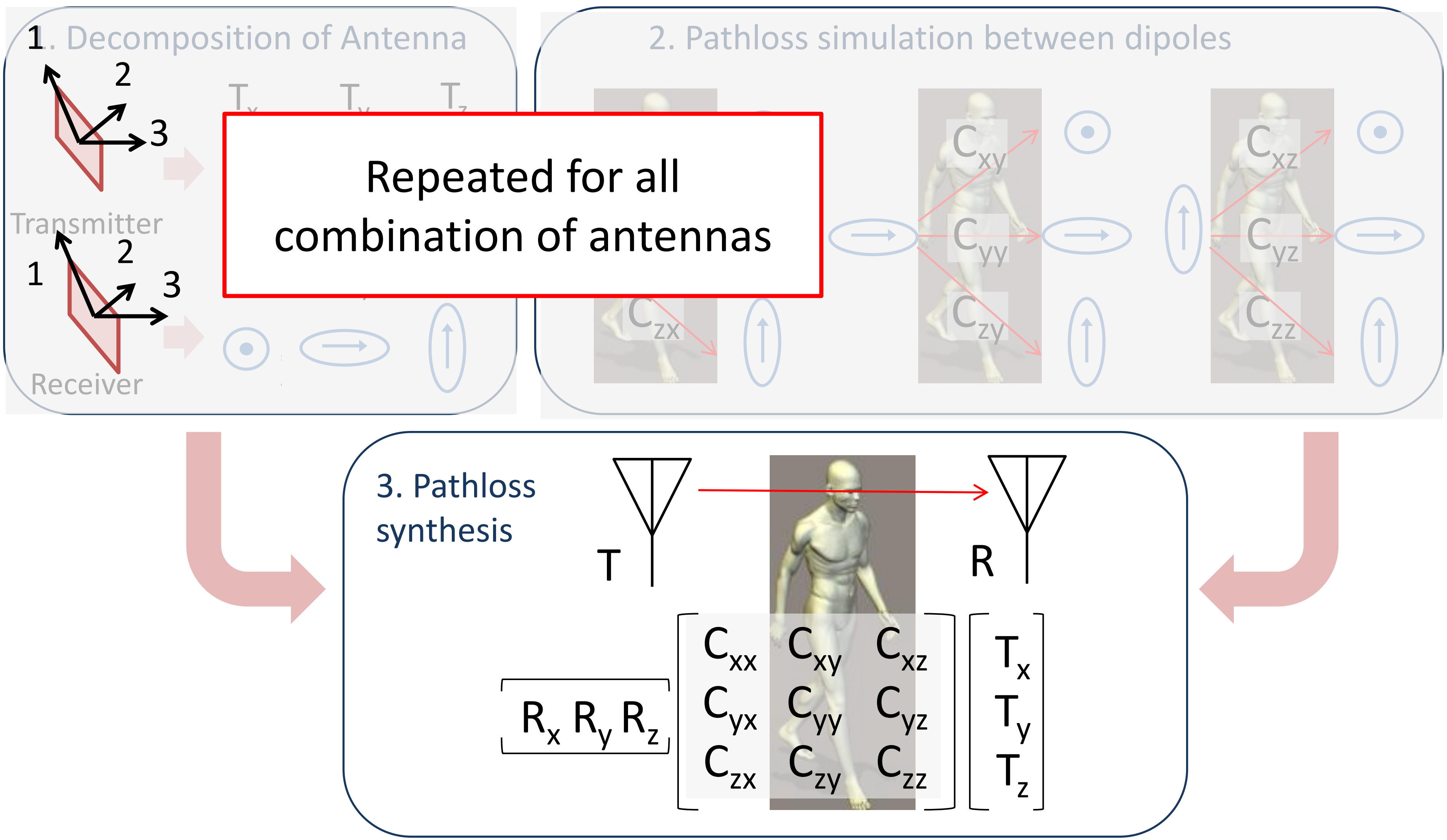






Simulation

- Demonstrate our frame work using 3 electric dipole

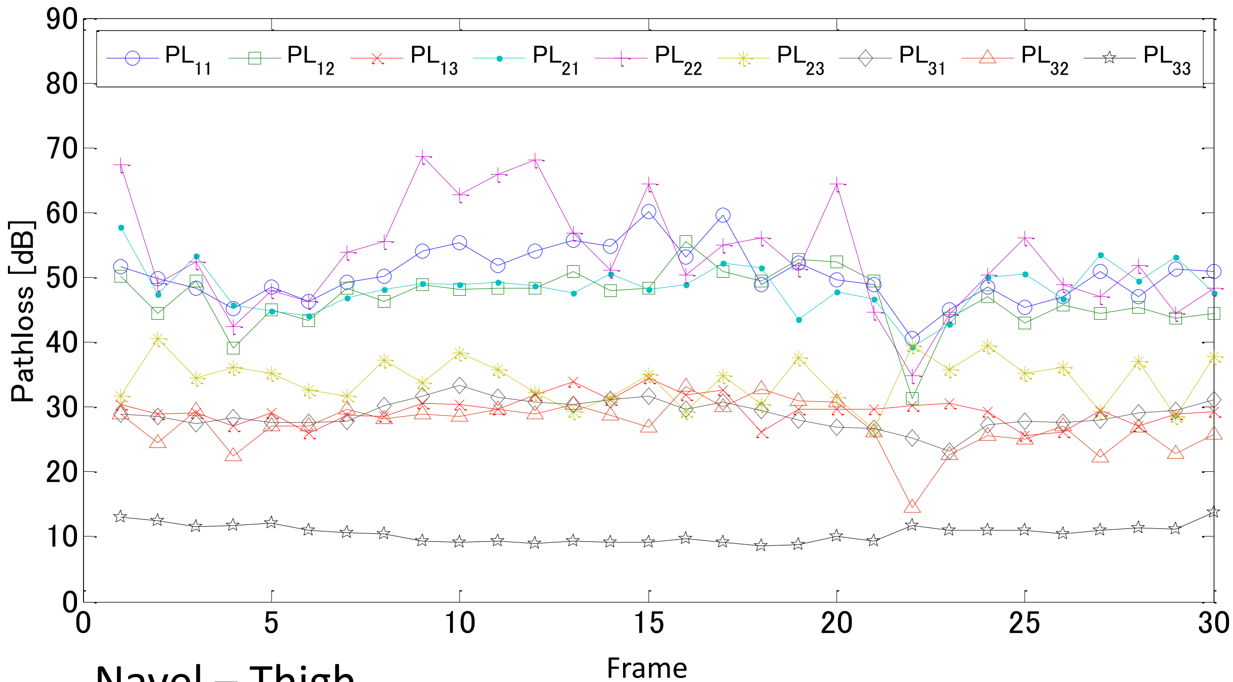


Simulation

- FDTD Method is used
- We developed In-house code using GPGPUs
- Simulation parameters

Frequency	403.5 MHz
Analytical space	170 x 400 x 250 (1.1λ x 2.7λ x 1.7λ)
Cell size	0.5 cm x 0.5 cm x 0.5 cm (6.72 x 10^{-3} λ)
Absorbing boundary	10 layers PML
Time step	0.01 nsec
# of steps	5000

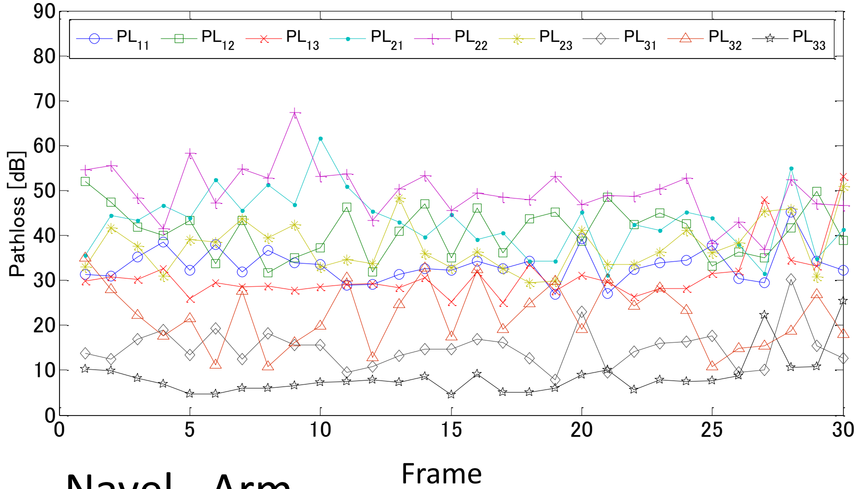
Simulation result



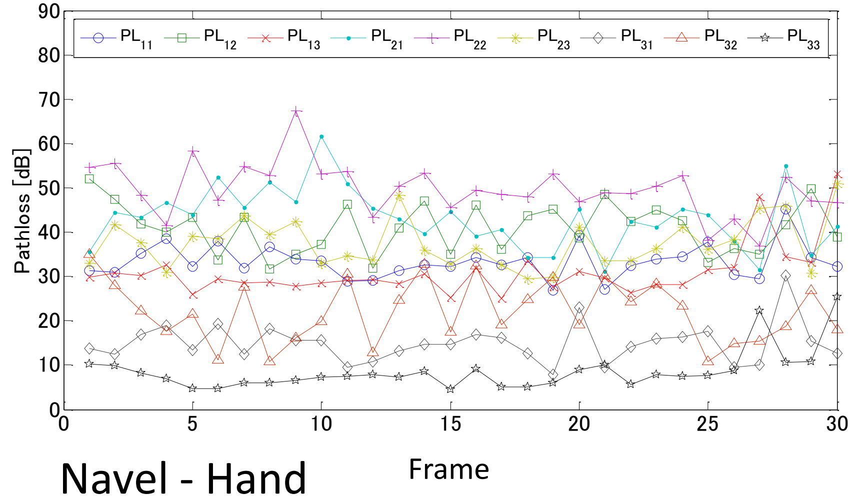
Navel – Thigh

- PL_{33} is smallest
  - Transmitter and receiver should be both normal to the human body
- PL_{13}, PL_{31}, PL_{23}, PL_{32} are also smaller than others
  - Either of the transmitter or the receiver should be normal to the human body.
- This trend is same in other links

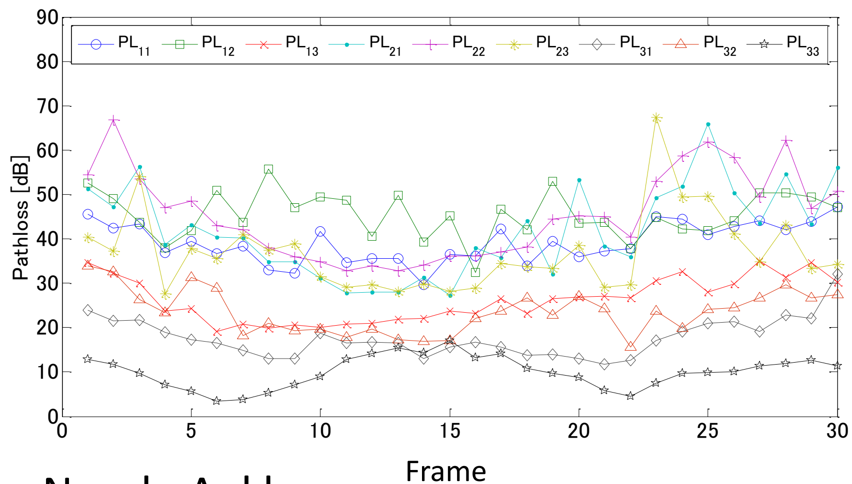
Simulation result



Navel - Arm

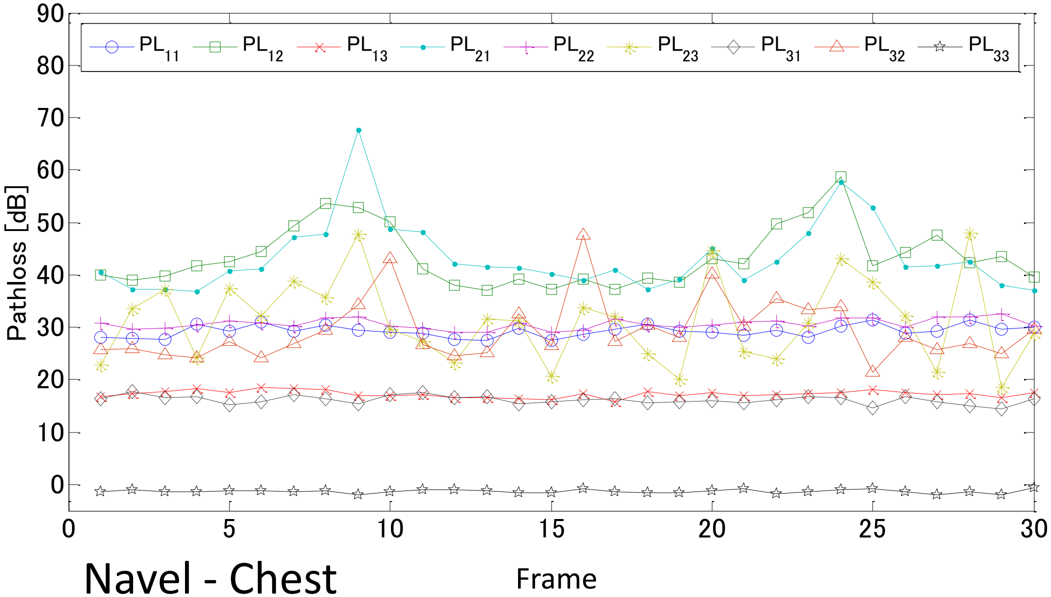


Navel - Hand

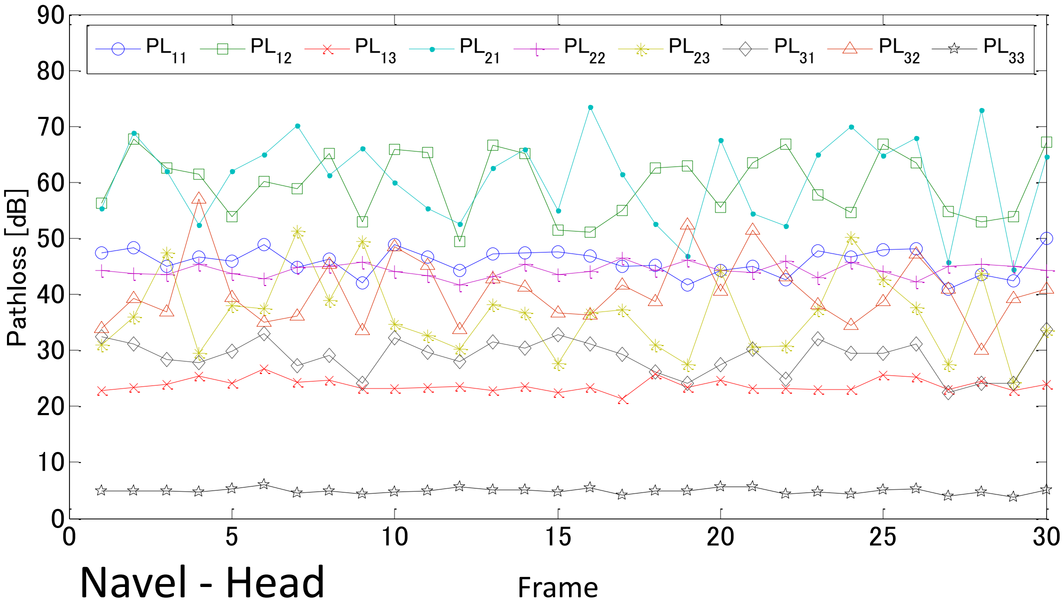


Navel - Ankle

Simulation result



Navel - Chest

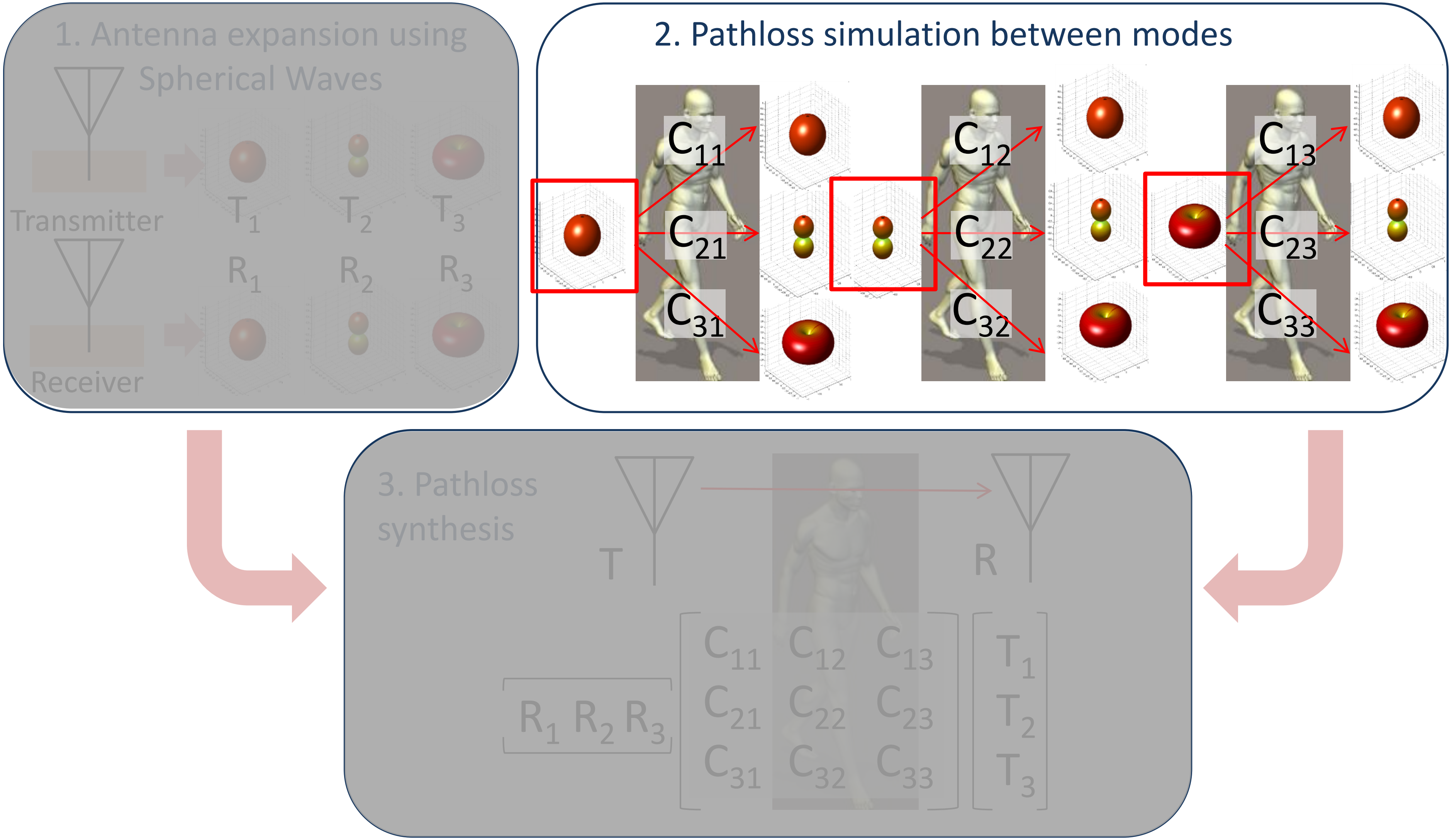


Navel - Head

Towards more general case

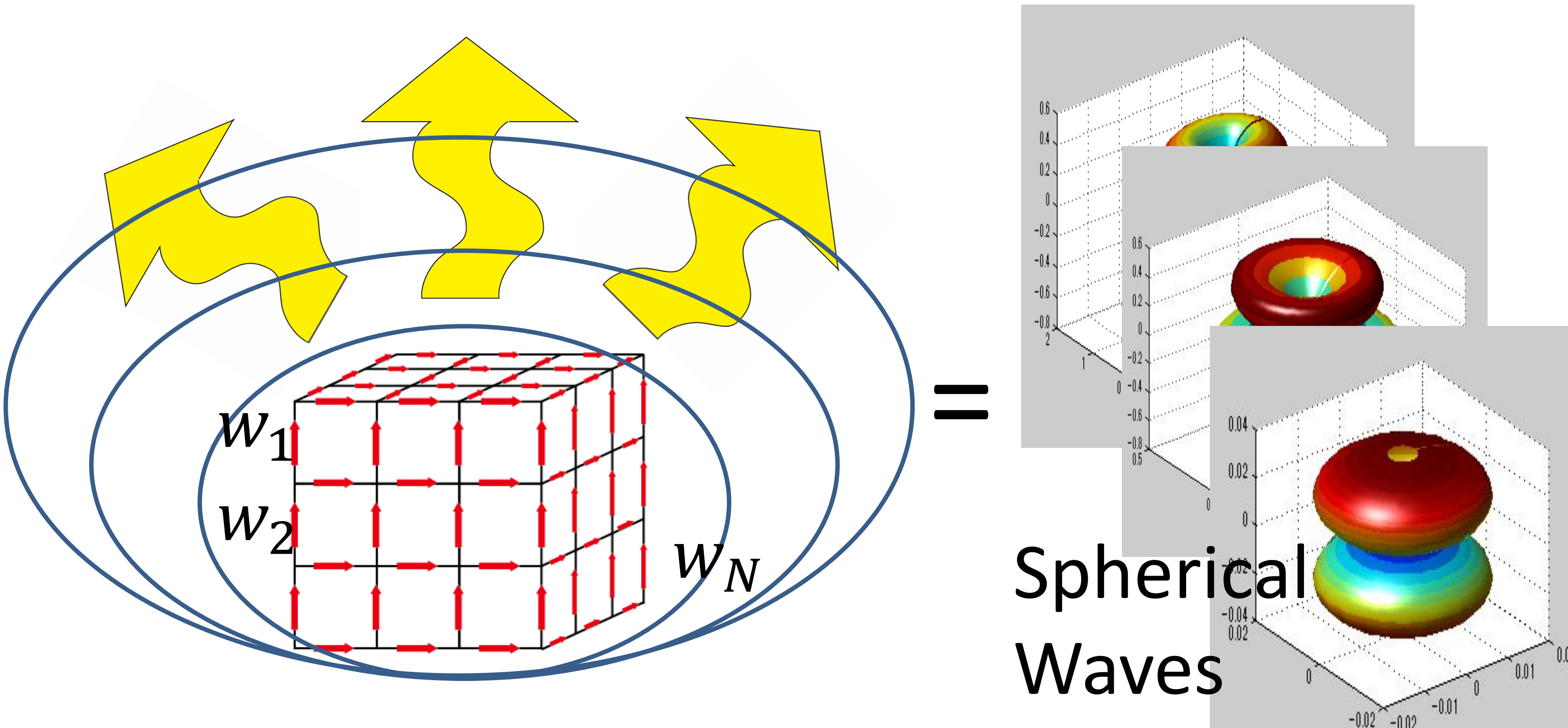
Towards general case

- How to generate spherical wave in FDTD is the key issue



Approach

- Control Electric and magnetic current on FDTD grid to radiate desired spherical wave.



$$\boldsymbol{w} = [w_1 \quad \cdots \quad w_N]$$

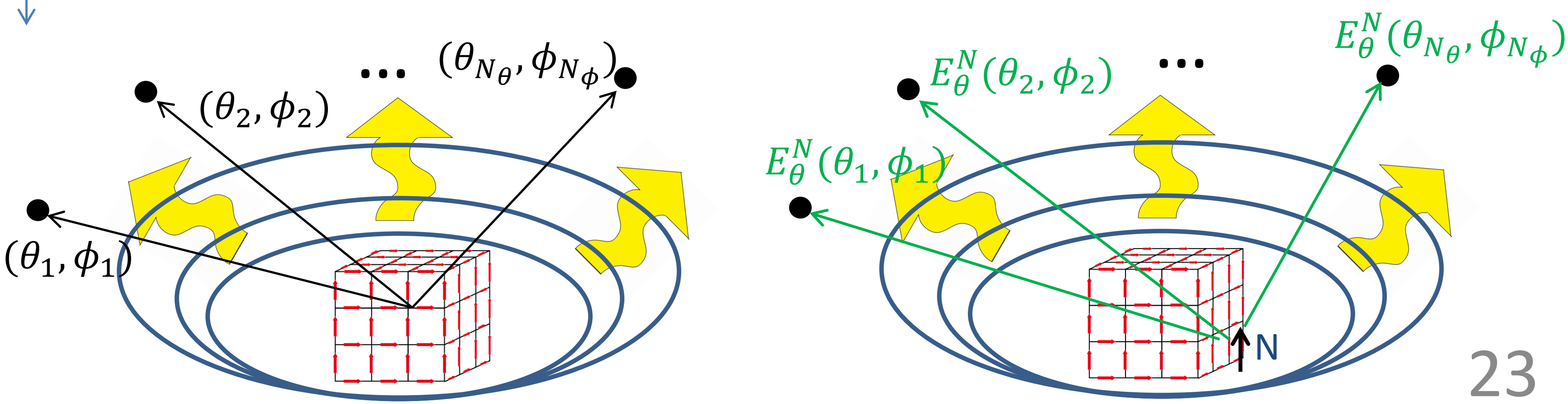
Approach in Detail

Step1: setup of dipole array

- Dipoles : 1, 2, 3, …., N
- Excitation weights $\boldsymbol{w} = [w_1 w_2 \ \ldots \ w_N]$

- Observation points $(\theta_1, \phi_1) \ldots (\theta_{N_\theta}, \phi_{N_\phi})$
- Radiation pattern of dipole arrays

$$\mathbf{E}_\mathrm{c} = \begin{bmatrix} E_\theta^1(\theta_1,\phi_1) & \cdots & E_\theta^N(\theta_1,\phi_1) & E_\phi^1(\theta_1,\phi_1) & \cdots & E_\phi^N(\theta_1,\phi_1) \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ E_\theta^1(\theta_{N_\theta},\phi_{N_\phi}) & \cdots & E_\theta^N(\theta_{N_\theta},\phi_{N_\phi}) & E_\phi^1(\theta_{N_\theta},\phi_{N_\phi}) & \cdots & E_\phi^N(\theta_{N_\theta},\phi_{N_\phi}) \end{bmatrix}$$



Approach in Detail

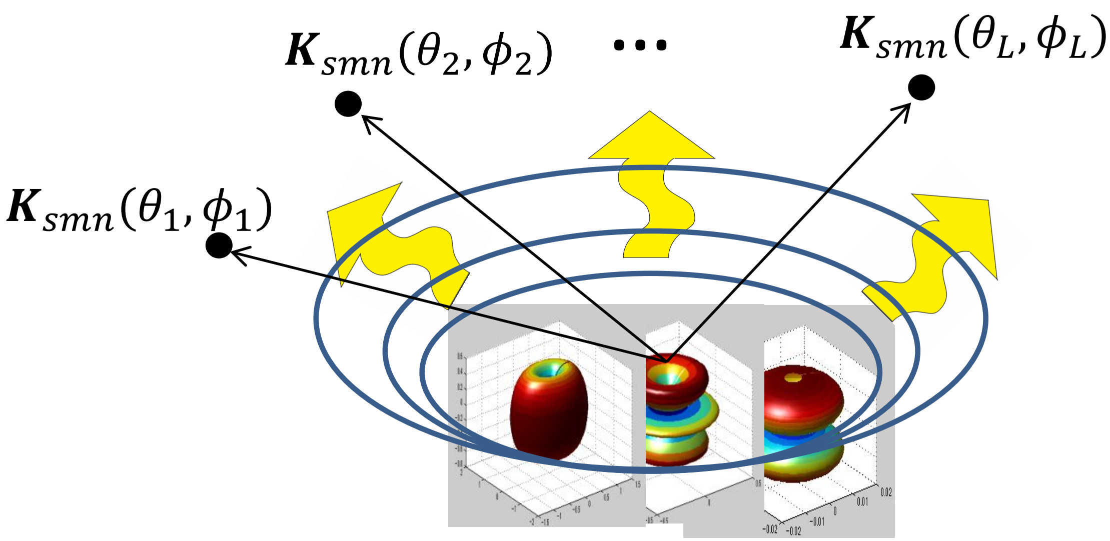
Step 2: setup of spherical wave

- Desired spherical wave

$$\boldsymbol{K}_{smn}(\theta,\phi) = K_{\theta,smn}(\theta,\phi)\hat{\theta} + K_{\theta,smn}(\theta,\phi)\hat{\phi}$$

- Desired E-fields

$$\boldsymbol{E}_t = [K_{smn}(\theta_1,\phi_1)\ \ldots K_{smn}(\theta_1,\phi_1)]^{\boldsymbol{T}}$$



Approach in Detail

Step 3: Calculating excitation coefficients

- Relationship to be satisfied

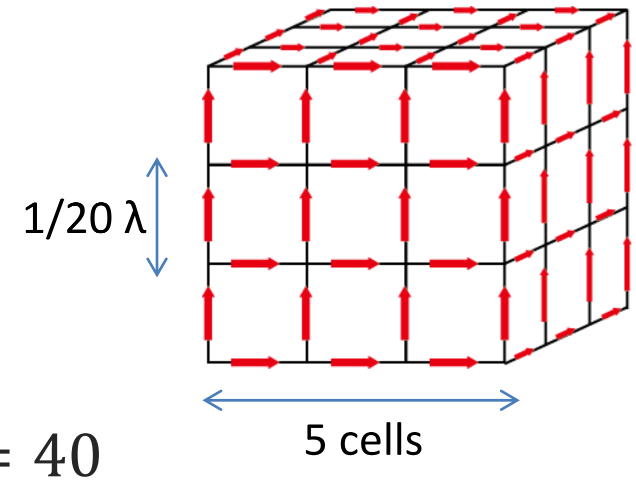
$$\boldsymbol{E}_c \boldsymbol{w} = \boldsymbol{E}_t$$

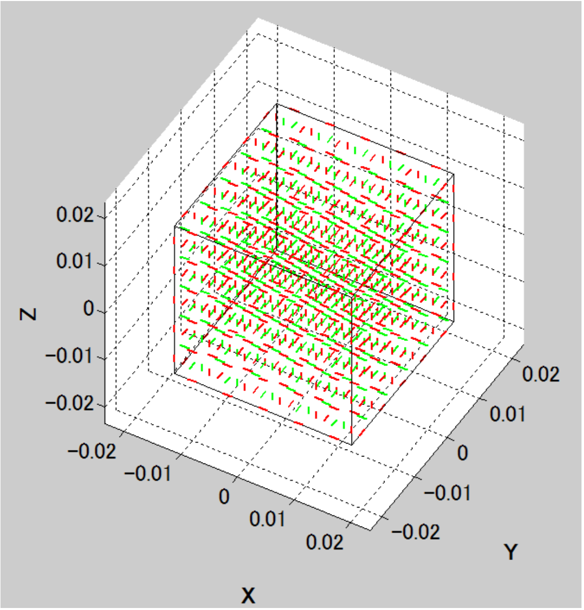
- Derive excitation weights by using pseudo-inverse

$$\boldsymbol{w} = \boldsymbol{E}_c^{-1} \boldsymbol{E}_t$$

Example

- **Parameters**
  - FDTD cel size = 1/20λ
  - Array size = 5 cells
  - Observation distance = 10λ
  - Obsdrvation Points, $N_\theta = 20$, $N_\phi = 40$
  - Number of dipoles = 990
    - Magnetic and Electric
    - Consider the dipoles inside cube

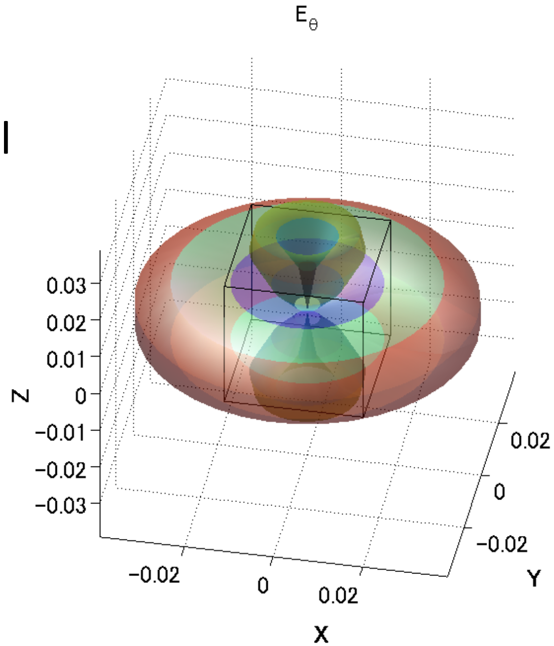


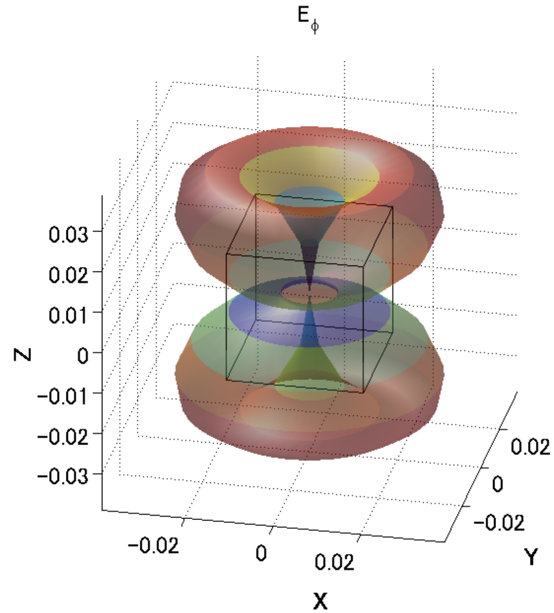


Example

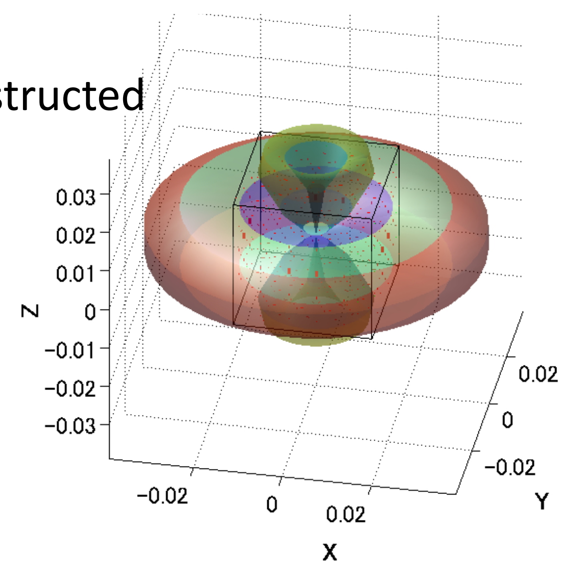
- J=20

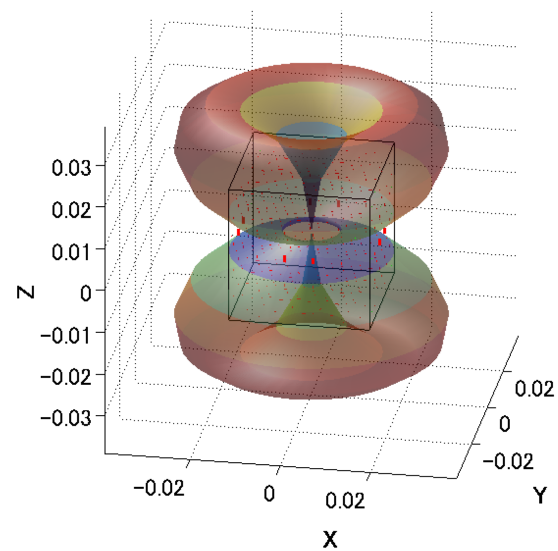
Original





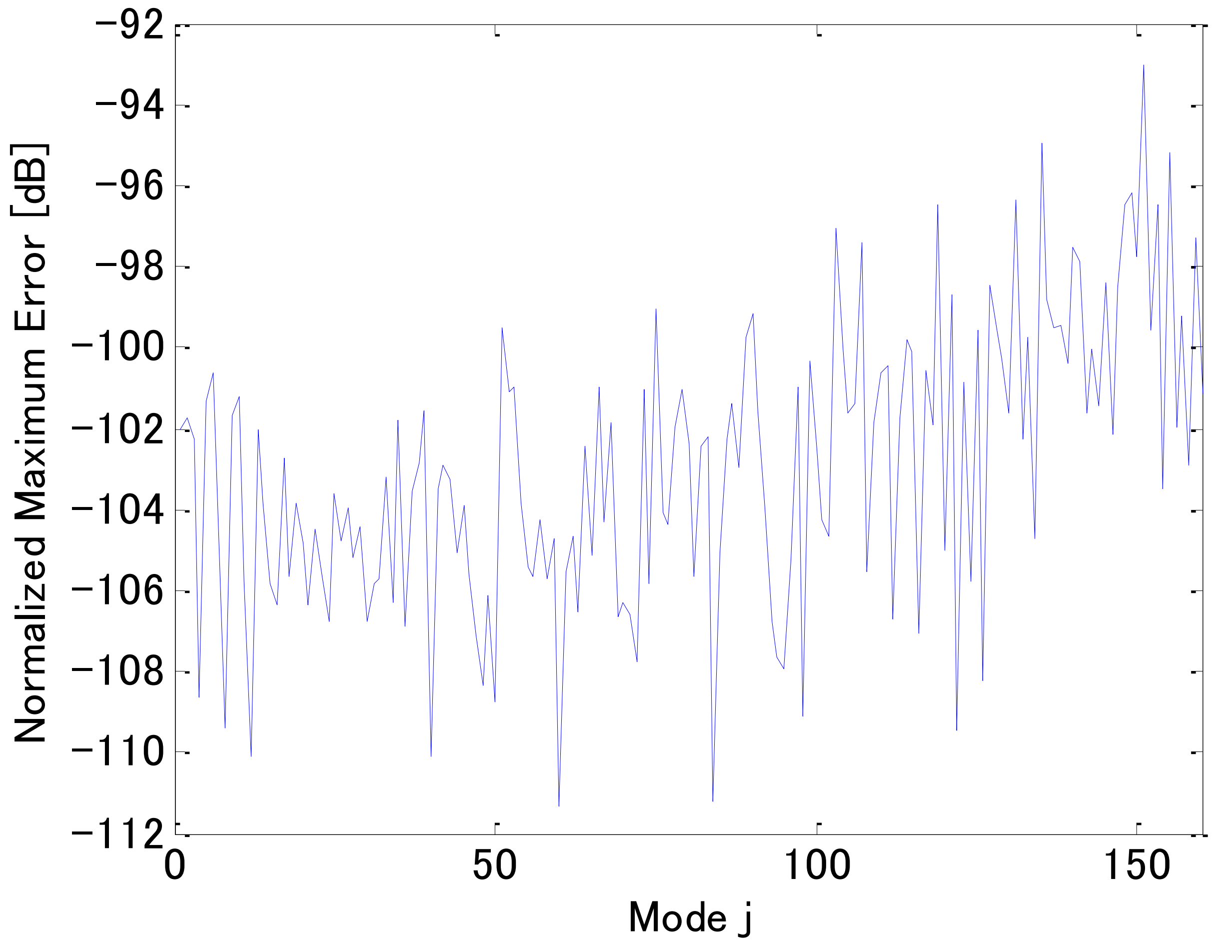
Reconstructed





Accuracy

- Maximum error at observation points



Summary

- Antenna de-embedding for BAN Channel Modeling

1. Antenna de-embedding framework
   1. Antenna expansion using spherical waves
   2. Pathloss simulation between modes
   3. Pathloss Synthetis
2. Demonstration using 3 electric dipoles
   - Dynamic pathloss simulation for walking motion
3. Preliminary study for more general cases
   - Excitation of spherical waves using multi-poles in FDTD grid