Dynamic Channel Model for Static Mobile Terminals in Indoor Environments

Yoshichika OHTA and Teruya FUJII
Softbank Telecom Corp.

SoftBank

Presentation Outline

- Background
- Proposed Model
- Theoretical Analysis
- Results
- Conclusions

Background

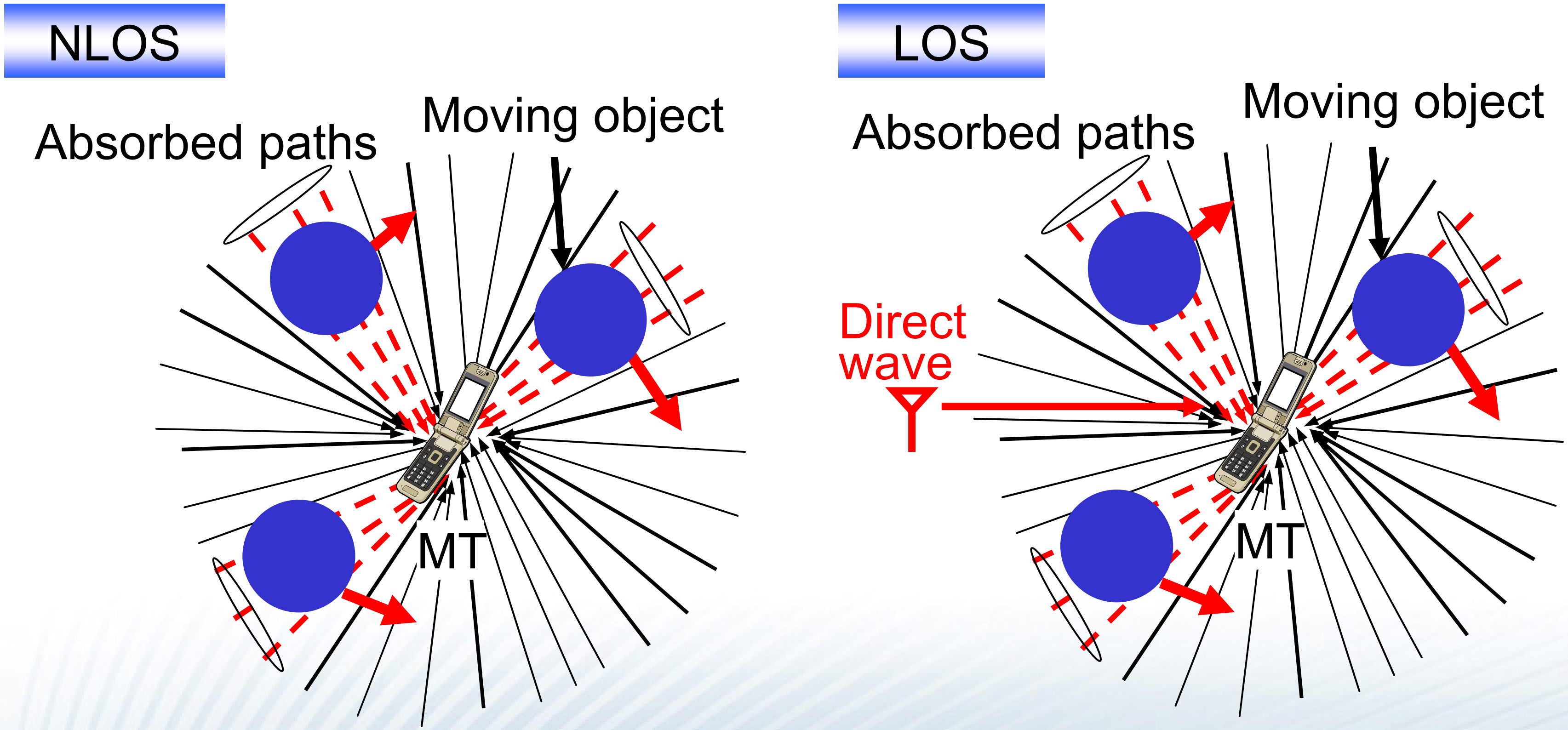
- Recently, customers who communicate with a cellular phone in indoor environments are rapidly increasing. In such a case, mobile terminals are used in static conditions rather than in moving conditions.
- In static usage, the terminal itself doesn't move, but the environment around it changes due to the moving objects such as people.
- In order to evaluate communication characteristics in static usage, a channel model for the terminal is necessary.

In this presentation, we propose a physical channel model for Indoor static usage.

Proposed Model

SoftBank

- In surrounding moving environment, we assume that moving objects block the radio waves and absorb the power of radio waves.
- When radio waves absorbed by moving objects are changed, the received level of terminal changes dynamically



Theoretical Analysis of LOS condition

SoftBank

Let the direct path's level and the ith multipath's level at the terminal with a position of x be $e_0(x)$ and $e_i(x)$, respectively as follows.

Direct path

$$e_0(x) = A_0 \exp\left[j\left(\frac{2\pi x}{\lambda}\cos\theta_0 + \phi_0\right)\right]$$

where A_0 , θ_0 and ϕ_0 represent the amplitude, arriving angle and phase

Multipaths

Each of Multipaths has the same power and arrives uniformly from all horizontal direction.

$$e_i(x) = A \exp\left[j\left(\frac{2\pi x}{\lambda}\cos\left(\frac{2\pi(i-1)}{N_{path}}\right) + \phi_i\right)\right] (i = 1, ---, N_{path})$$

where A , θ_i and ϕ_i represent the amplitude, arriving angle and phase of i-th radio wave

Total power of multipath

$$P_m = A^2 N_{path}$$

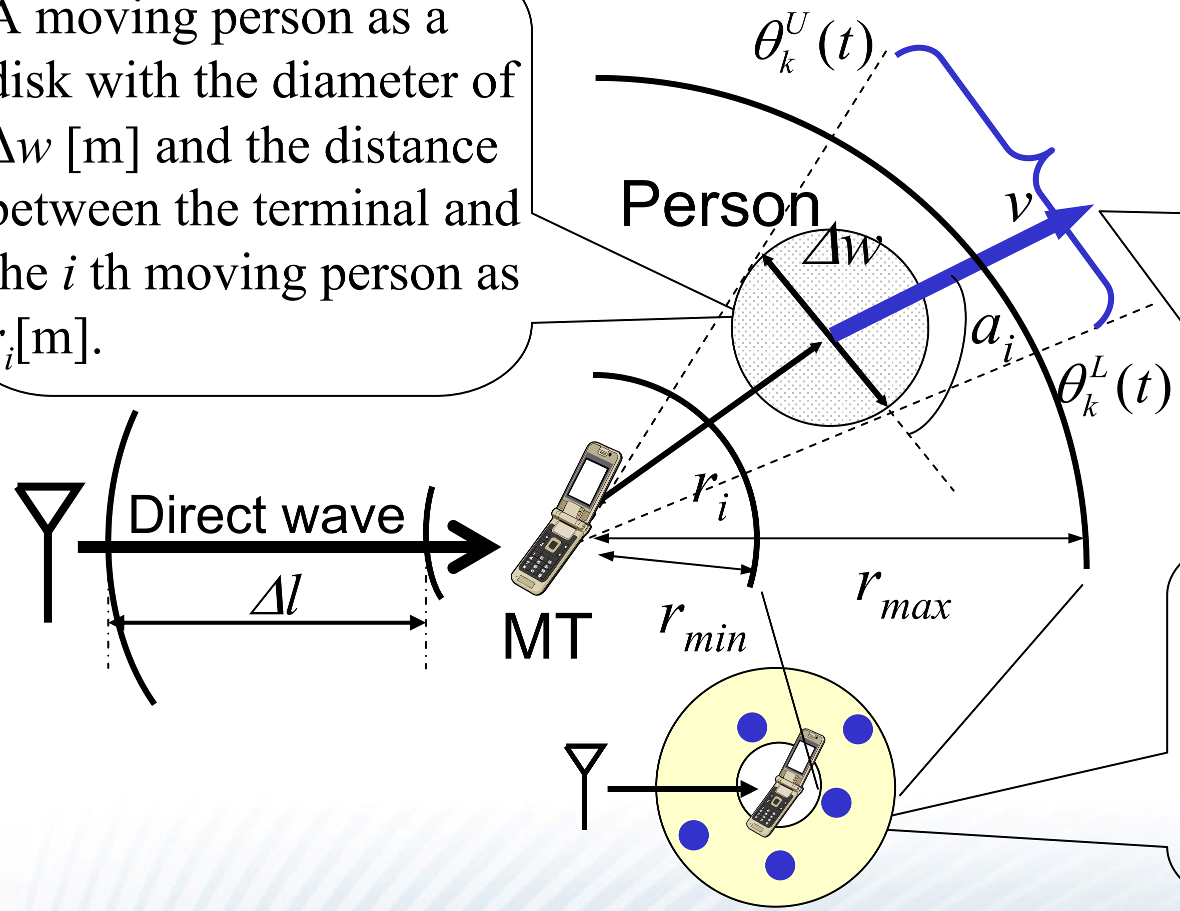
Analysis Model

SoftBank

Surrounding Moving Environment

A moving object assume as moving person and the number of person is N_{person}

A moving person as a disk with the diameter of Δw [m] and the distance between the terminal and the i th moving person as r_i[m].



Each moving person walks in an arbitrary direction between 0 and 2π with a constant speed of v [m/s].

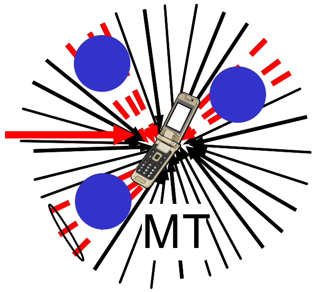
Each moving person locates the area between circles at the center of terminal with the radius of r_{min} and r_{max}.

Received Level of LOS

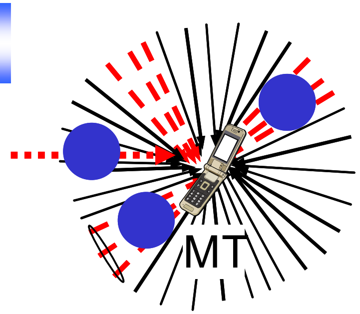
SoftBank

The received level of terminal can be presented as two conditions;
LOS (direct wave is not blocked) and NLOS (direct wave is blocked).

LOS



NLOS



When the number of absorbed paths is large, the complex amplitude of absorbed paths follows the complex Gaussian distribution due to "the Central Limited Theory".

LOS

$$E(t,x) = \underbrace{\left(e_0(x) + \sum_{i=1}^{N_{path}} e_i(x)\right)}_{\text{The level of the surrounding static environment}} - \underbrace{\sum_{k=1}^{N_{person}} \eta_k(t)}_{\text{The level absorbed by moving People}} = \left(e_0(x) + e(x)\right) - \sum_{k=1}^{N_{person}} \eta_k(t)$$

The value doesn't depend on time t.

The value depends on time t.

NLOS

$$E(t,x) = \overbrace{\left(e_0(x) + \sum_{i=1}^{N_{path}} e_i(x)\right)} - \overbrace{\left(\zeta e_0(x) + \sum_{k=1}^{N_{person}} \eta_k(t)\right)} = \left((1-\zeta)e_0(x) + e(x)\right) - \sum_{k=1}^{N_{person}} \eta_k(t)$$

Distribution of Received Level of LOS and NLOS

Constant + Complex Gaussian ⇒ **Nakagami-Rice** distribution

Analysis of Received Level Distribution

SoftBank

The received level of terminal can be presented as the combined **Nakagami-Rice** distributions with two conditions;
- LOS (direct wave is not blocked).
- NLOS (direct wave is blocked)

To calculate the received level of terminal, it is necessary two key parameters
- K-factors of **Nakagami-Rice** distributions for two conditions
- the ratio of two conditions.

Distribution of Received Level (1/2)

SoftBank

Nakagami-Rice Distribution

$$p(r_P, K) = \frac{1}{s^2}\exp[-(\frac{r_P}{s^2} + K)]I_0(\sqrt{4K\frac{r_P}{s^2}})$$

The level of the surrounding static environment

K-factor

The total power of the absorbed paths

$$K_{LOS} = \left|e_0(x) + e(x)\right|^2 / \left|\sum_{k=1}^{N_{person}} \eta_k(t)\right|^2 = \left|e_0(x) + e(x)\right|^2 / \left|e_G(t)\right|^2$$

$$K_{NLOS} = \left|(1-\zeta)e_0(x) + e(x)\right|^2 / \left|\sum_{k=1}^{N_{person}} \eta_k(t)\right|^2 = \left|(1-\zeta)e_0(x) + e(x)\right|^2 / \left|e_G(t)\right|^2$$

When all moving people are distributed uniformly in the moving area, total power of the absorbed paths $e_G(t)$ is as follows.

$$\left|e_G(t)\right|^2 = \left(\frac{N_{person} P_m \left|\zeta\right|^2 \Delta w}{\pi(r_{max} + r_{min})}\right)$$

K factor depends on the level of the surrounding static environment.

Distribution of Received Level (2/2)

Distribution of Received Level

The probability of received level can be presented as a combination of two Nakagami-Rice distributions with different K-factores.

$$p_{LOS}(r_P) = \underbrace{a_{LOS}\, p(r_P, K_{LOS})}_{\text{LOS}} + \underbrace{a_{NLOS}\, p(r_P, K_{NLOS})}_{\text{NLOS}}$$

The Ratio of Two Conditions

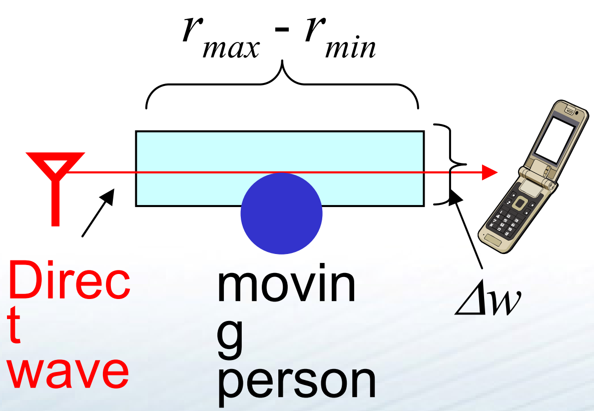
q_{NLOS} can be expressed as the probability that the center of moving person locates within the square with the width of Δw and the length of Δl

$$q_{NLOS} = \frac{\Delta w \Delta l}{S_a}$$

The probability that the direct wave is not cut off, Q_{LOS}, can be expressed as all moving people don't locate in the square

$$\alpha_{LOS} = (1 - q_{NLOS})^{N_{person}}$$

$$\alpha_{NLOS} = 1 - \alpha_{LOS}$$



Autocorrelation coefficient of complex amplitude(1)

Autocorrelation coefficient of complex amplitude

$$R(\Delta t) = \langle E(t,x)E(t+\Delta t,x)^{*} \rangle$$
$$= \langle \left(E_d(t,x) + E_m(t,x)\right)\left(E_d(t+\Delta t,x) + E_m(t+\Delta t,x)\right)^{*} \rangle$$
$$= \langle E_d(t,x)E_d(t+\Delta t,x)^{*} \rangle + \langle E_d(t,x)E_m(t+\Delta t,x)^{*} \rangle + \langle E_m(t,x)E_d(t+\Delta t,x)^{*} \rangle + \langle E_m(t,x)E_m(t+\Delta t,x)^{*} \rangle$$

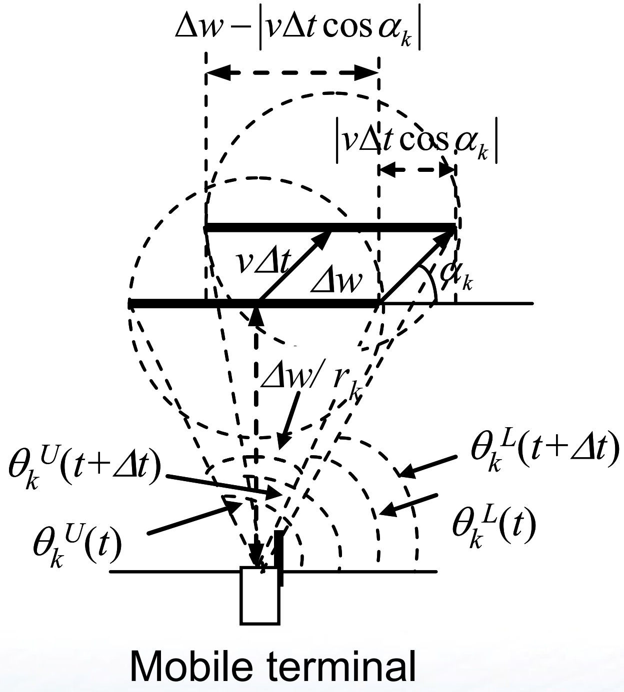
Here, from $E(t,x)$,

Path interception angle of each moving person

$$E_d(t) = e_0(x) - \sum_{k=1}^{N_{person}} \sum_{i=\theta_k^L(t)}^{\theta_k^U(t)} \zeta e_0(x)\delta(i)$$

$$E_m(t) = e(x) - \sum_{k=1}^{N_{person}} \sum_{i=\theta_k^L(t)}^{\theta_k^U(t)} \zeta e_i(x)$$

$$\theta_k^U(t) \approx \theta_k^L(t) + \Delta w / r_k$$
$$\theta_k^L(t+\Delta t) \approx \theta_k^L(t) + v\Delta t \cos\alpha_k / r_k$$
$$\theta_k^U(t+\Delta t) \approx \theta_k^L(t) + \Delta w / r_k + v\Delta t \cos\alpha_k / r_k$$



Auto-covariance coefficient

SoftBank

Autocorrelation coefficient of complex amplitude

$$R(\Delta t) = \frac{N_{person}}{\pi(r_{max}{}^2 - r_{min}{}^2)} \int_{r_{min}}^{r_{max}} R(\Delta t) 2\pi r dr$$

$$= \begin{cases} |e_0(x)|^2 \left\{ 1 - \dfrac{2\,\mathrm{Re}[\zeta] N_{person} \Delta w}{\pi(r_{max}+r_{min})} + \dfrac{N_{person}|\zeta|^2 \Delta w}{\pi(r_{max}+r_{min})} \left(1 - \dfrac{2 f_T |\Delta t|}{\pi} \right) \right\} & (v|\Delta t| \le \Delta w) \\ |e_0(x)|^2 \left\{ 1 - \dfrac{2\,\mathrm{Re}[\zeta] N_{person} \Delta w}{\pi(r_{max}+r_{min})} + \dfrac{N_{person}|\zeta|^2 \Delta w}{\pi(r_{max}+r_{min})} \left(1 - \dfrac{2 f_T \Delta t}{\pi} - \dfrac{2}{\pi}\cos^{-1}\left(\dfrac{1}{f_T|\Delta t|}\right) + \dfrac{2 f_T \Delta t}{\pi} \sin\left(\cos^{-1}\left(\dfrac{1}{f_T|\Delta t|}\right)\right)\right)\right\} & (v|\Delta t| > \Delta w) \end{cases}$$

$$+ \begin{cases} |e(x)|^2 + \dfrac{P_m N_{person}|\zeta|^2 \Delta w}{\pi(r_{max}+r_{min})} \left(1 - \dfrac{2 f_T |\Delta t|}{\pi} \right) & (v|\Delta t| \le \Delta w) \\ |e(x)|^2 + \dfrac{P_m N_{person}|\zeta|^2 \Delta w}{\pi(r_{max}+r_{min})} \left\{ 1 - \dfrac{2 f_T |\Delta t|}{\pi} - \dfrac{2}{\pi}\cos^{-1}\left(\dfrac{1}{f_T|\Delta t|}\right) + \dfrac{2 f_T |\Delta t|}{\pi} \sin\left(\cos^{-1}\left(\dfrac{1}{f_T|\Delta t|}\right)\right)\right\} & (v|\Delta t| > \Delta w) \end{cases}$$

$$+ 2\,\mathrm{Re}\left[e_0(x) e^*(x)\right] - 2\,\mathrm{Re}\left[\zeta e_0(x) e^*(x)\right] \frac{N_{person}\Delta w}{\pi(r_{max}+r_{min})}$$

Auto-covariance coefficient of complex amplitude

$$\rho(\Delta t) = \frac{R(\Delta t) - |m|^2}{R(0) - |m|^2}$$

where, $m = e_0(x)\left(1 - \dfrac{\zeta N_{person}\Delta w}{\pi(r_{max}+r_{min})}\right) + e(x)$

Maximum frequency shift for the static mobile terminal

$$f_T = v / \Delta w$$

Auto-covariance coefficient of received power

$$\rho_P(\Delta t) = \frac{2K\,\mathrm{Re}[\rho(\Delta t)] + |\rho(\Delta t)|^2}{2K+1}$$

Re[ ] is real part

Analysis

First, we analyze the received level distribution and correlation by theoretical analysis and computer simulation
Then, we compare them with measurements.

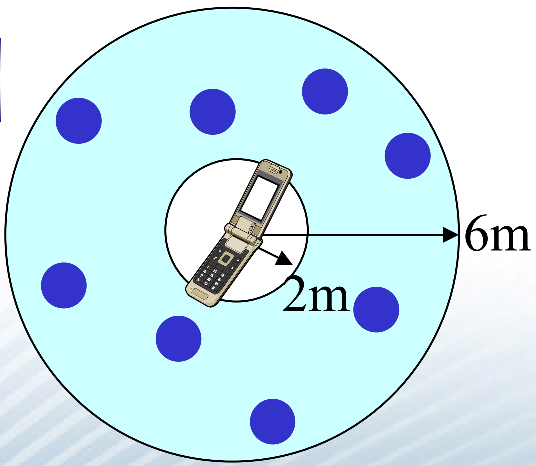
Major Parameters of calculation

In the calculations, we set parameters as follows.

- The number of person is N_{person}= 8
- The diameter of moving person is Δw=0.3m
- The moving speed is v=1m/s
- The moving area is within the annular area with radii of r_{min}=2m, r_{max} =6m
- The Rx antenna is omni directional in the horizontal plane.

In the calculations, we obtain the received characteristics

The condition



Measurement

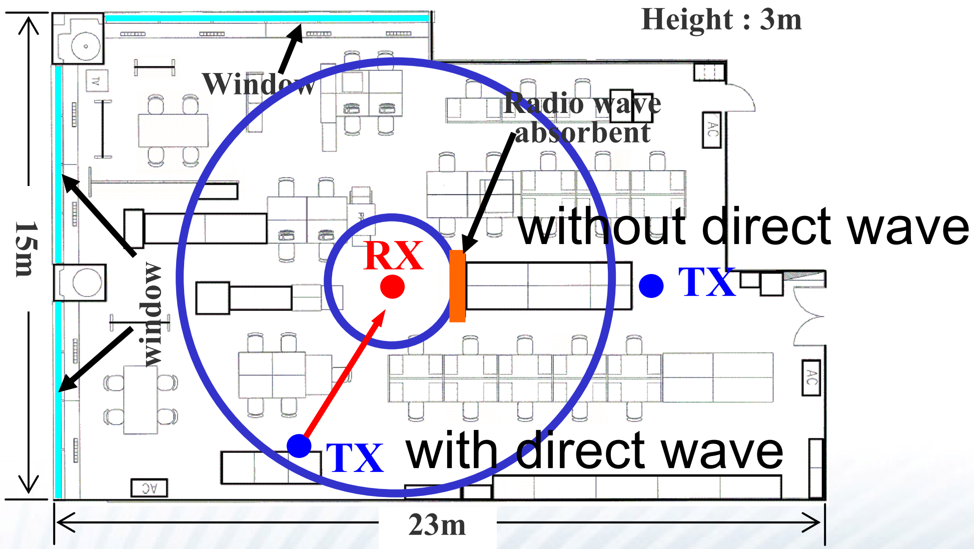
In order to confirm the accuracy of analysis model, measurements was carried out in our laboratory space at the same condition of calculations.

-The carrier frequency is 5.7GHz.

-This room holds common office equipment such as desks, tables, and shelves.

-We made people walk around the received antenna at the speed of 1 m/s.

Laboratory Space

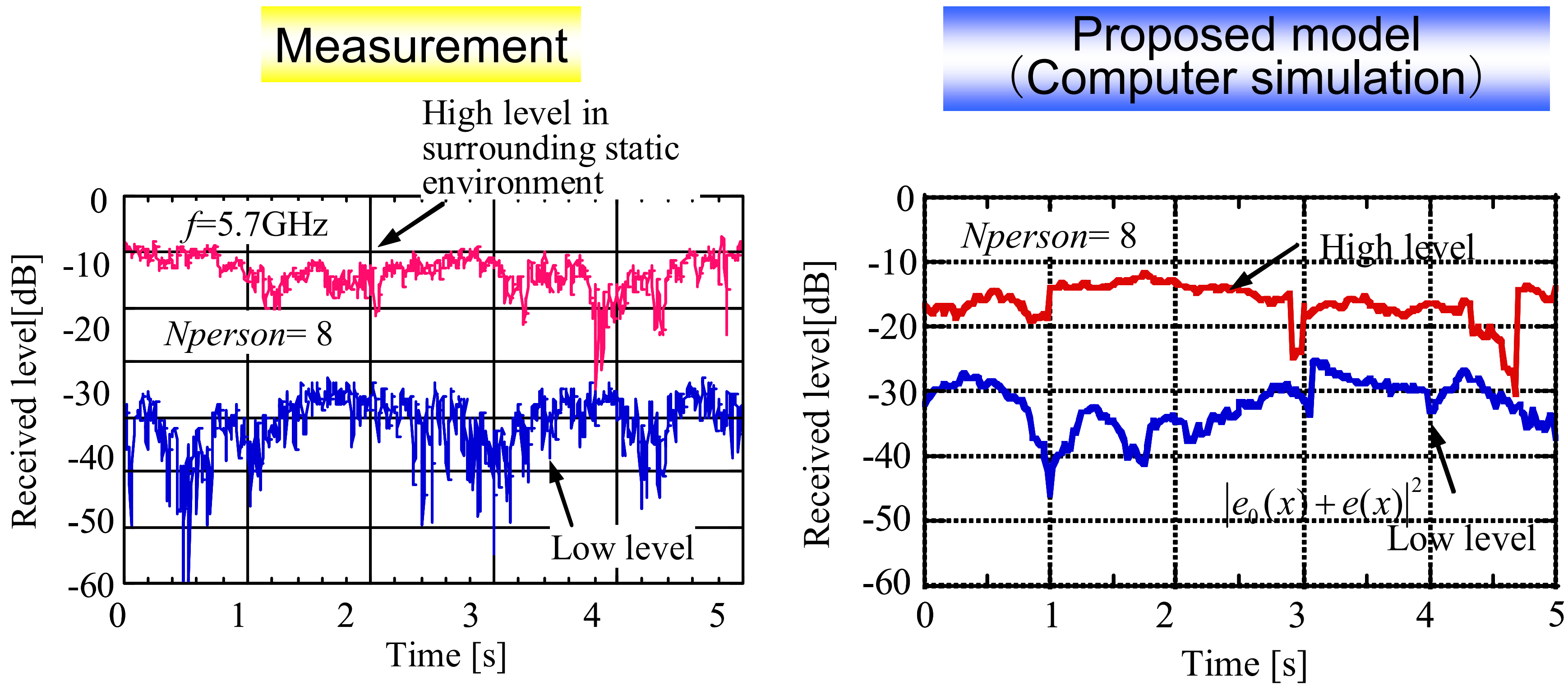


Measurement Scene

Simulation vs. Measurement with Direct Wave

SoftBank

In order to confirm visually the variation of proposed model, we carried out computer simulation at the same condition of calculation.



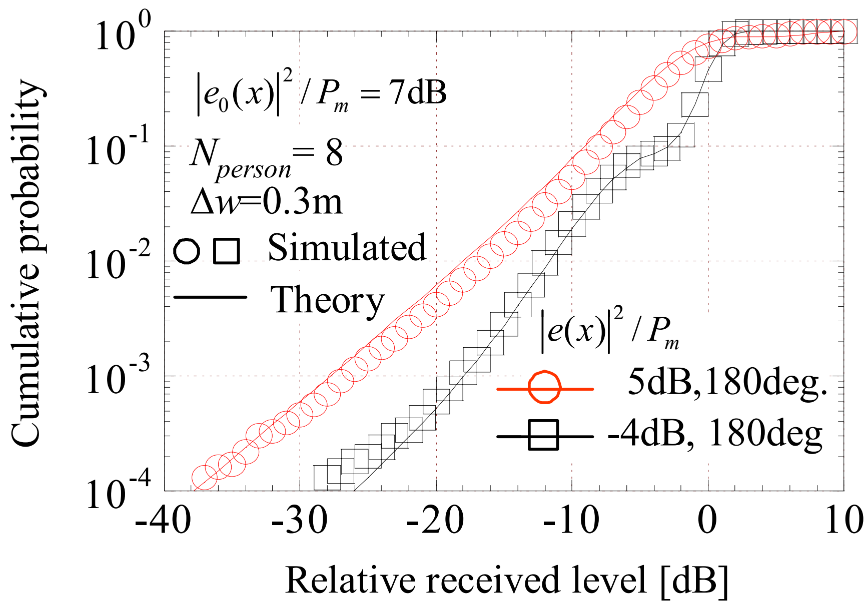
Received level with direct wave

We find that the measurement results are very similar to the simulation results

Simulation vs. Analysis with Direct Wave

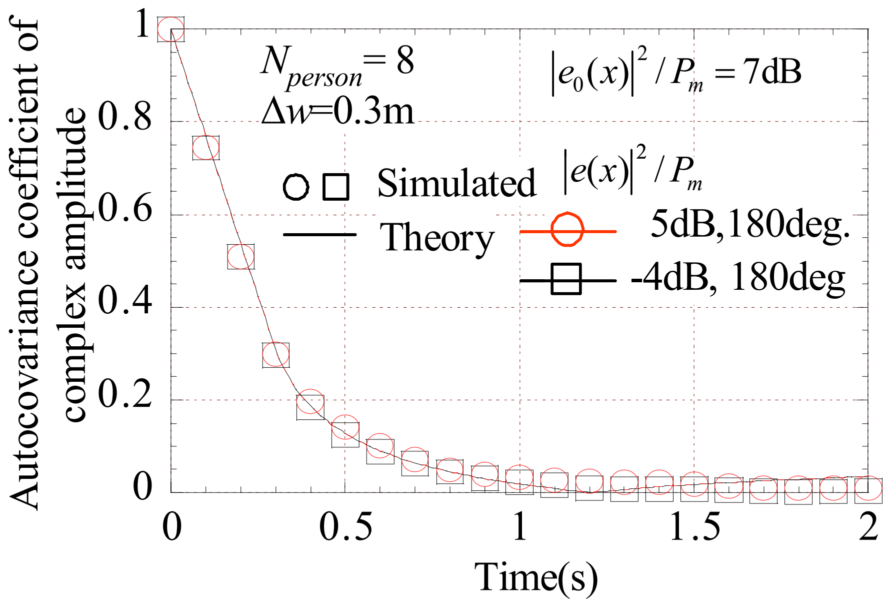
SoftBank

CDF of received level



Auto-covariance coefficient

(Complex amplitude)

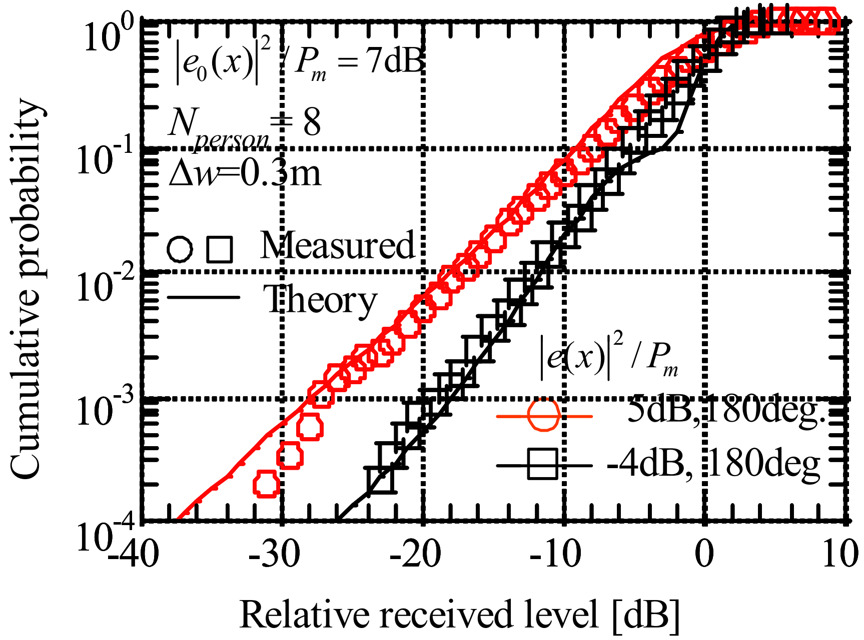


The proposed model is in extremely good agreement with the simulated results.

Measurement vs. Analysis with Direct Wave

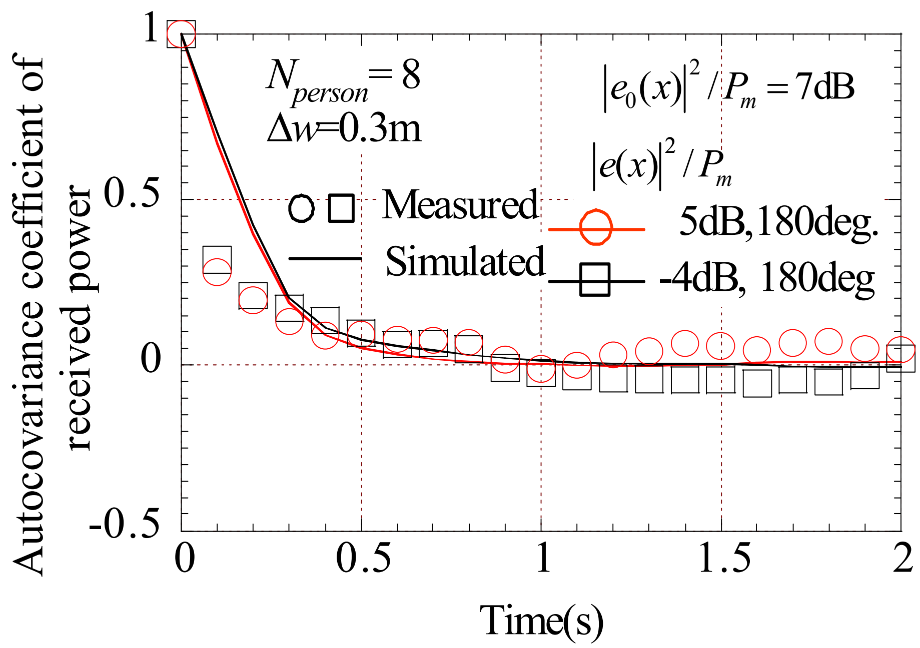
SoftBank

CDF of received level



Auto-covariance coefficient

(Received power)



The proposed model is in good agreement with the measured results.

Conclusions

SoftBank

— We proposed a channel model for static terminals used indoors in LOS and NLOS conditions.

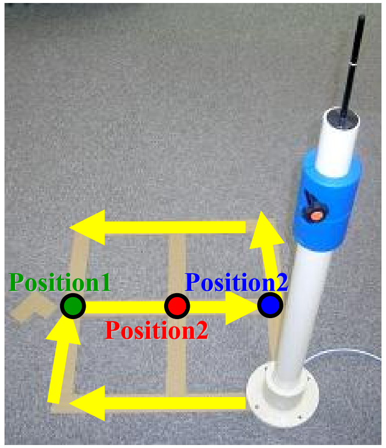
— The received level probability and its autocorrelation coefficient of the proposed model were theoretically analyzed.

— The analysis results of the proposed model were compared to measured results and we showed that proposed model was in good agreement with the measured results.

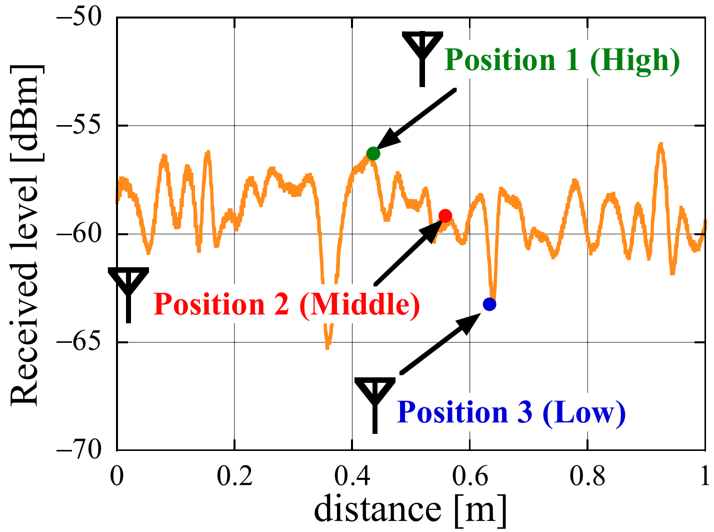
— From these, we confirmed that the proposed model is sufficiently valid.

Thank you for your kind attention.

Received level in static condition (no one moving around Rx antenna)



Movement of antenna position



Received level variation of antenna position