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Multi-Keyhole Model for MIMO Radio-Relay Systems

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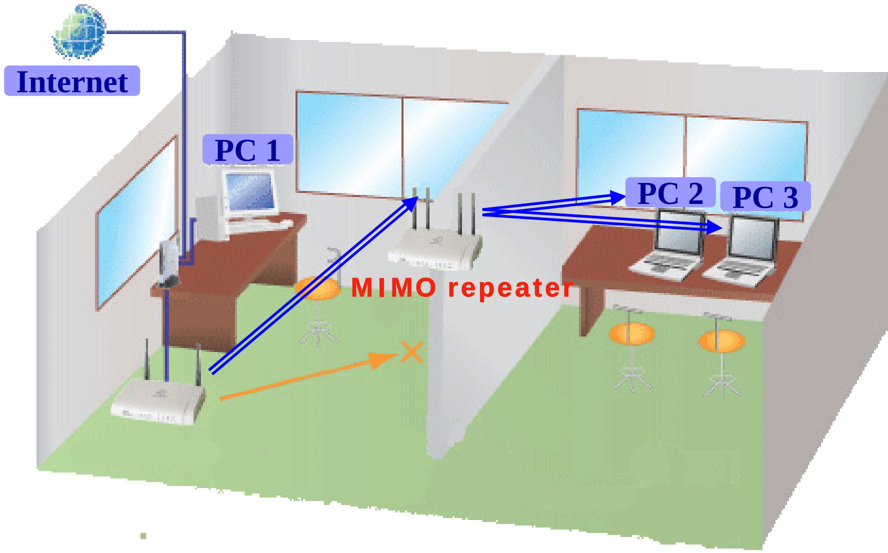
Outline of Presentation

1. Radio-relay system for MIMO service area expansion
2. Multi-keyhole model for the system performance evaluation
3. Empirical formula for PDF of the largest eigenvalue
4. Empirical formula for PDFs of all eigenvalues
5. Evaluation of the estimation accuracy
6. Conclusions

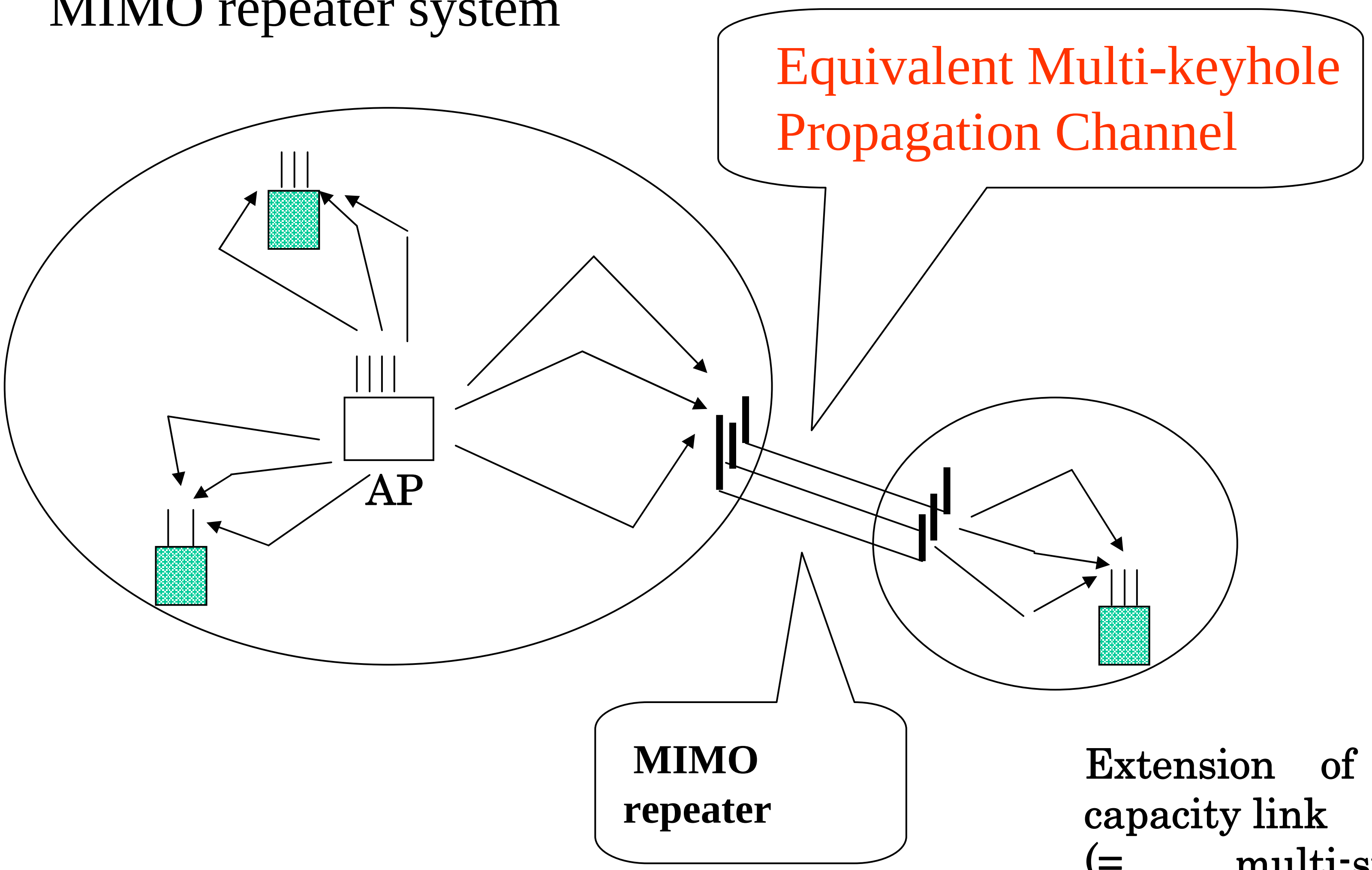
Motivation

- Why do we need MIMO channel models?
  - High data rate transmission (WLAN, WiMAX)

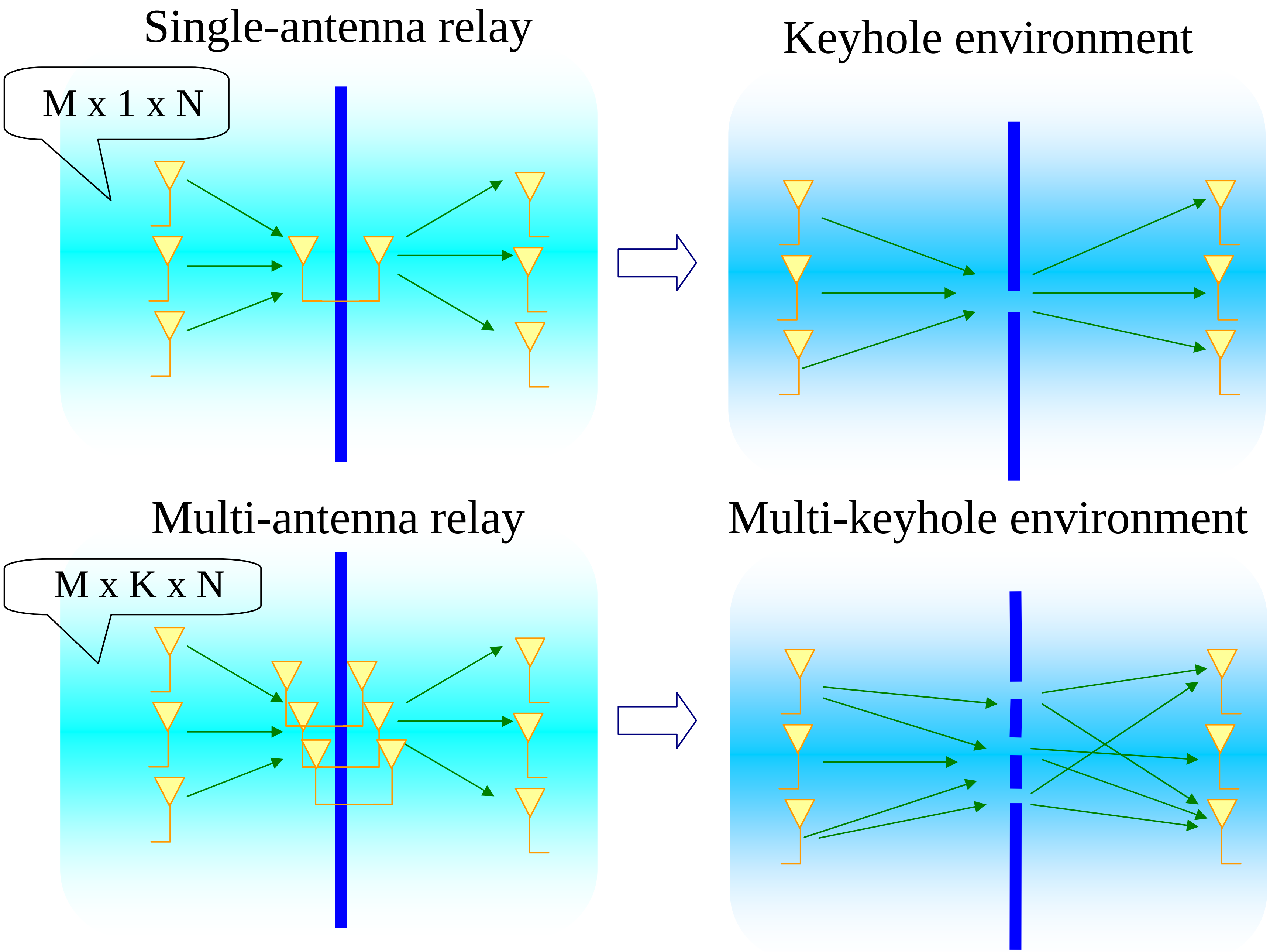
- Service expansion to isolated areas
  - MIMO repeater system (MIMO radio-relay system)
  - Ad Hoc Network



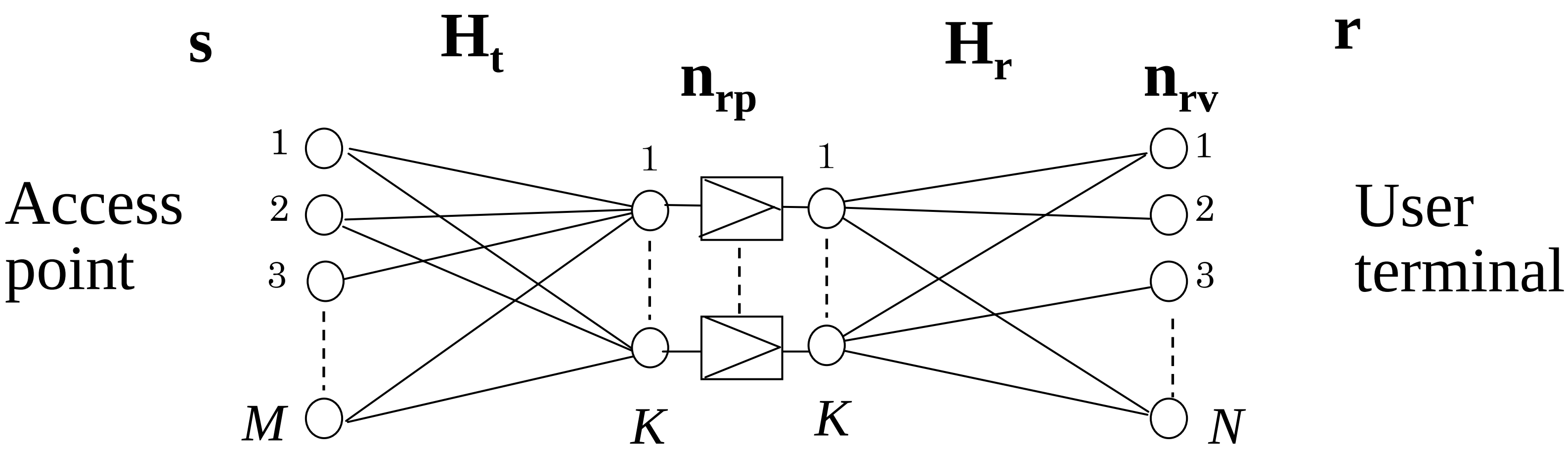
MIMO repeater system



Extension of high capacity link (= multi-stream transmission) to isolated areas


Single-antenna relay
M x 1 x N
Keyhole environment
Multi-antenna relay
M x K x N
Multi-keyhole environment

Channel Expression of Radio-Relay Systems



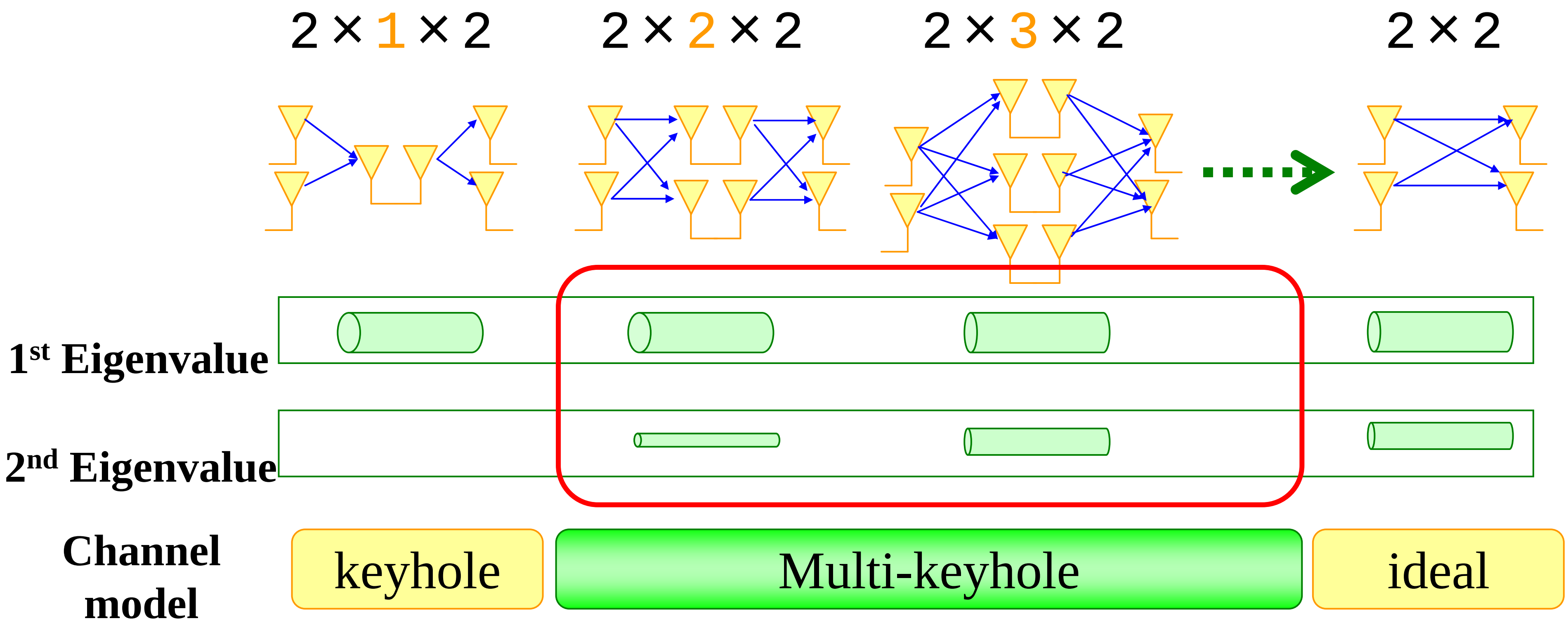
Received signal $\mathbf{r} = \mathbf{H}_r \mathbf{G}\left(\mathbf{H}_t \mathbf{s} + \mathbf{n}_{rp}\right) + \mathbf{n}_{rv}$

Eqivalent channel (CSI) when the effect of thermal noise power in RS is negligible.

$$\mathbf{H}_e = \frac{1}{\sqrt{K}} \mathbf{H}_r \mathbf{H}_t$$

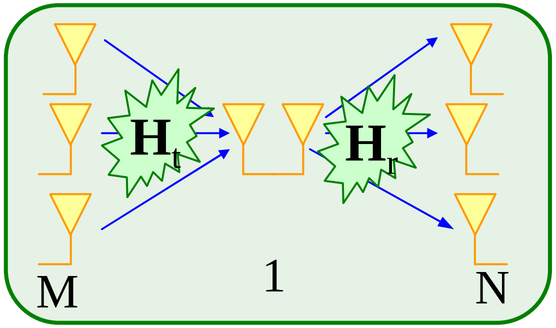
Hereafter, we discuss PDFs of eigenvalues for $\mathbf{R} \equiv \mathbf{H}_e \mathbf{H}_e^{\mathrm{H}}$

Eigenvalues in MIMO repeater system



Rayleigh fading environment with i.i.d.

PDF of the largest eigenvalue in single keyhole environment



Channel response matrix

$$\mathbf{H}_e = \mathbf{H}_r \mathbf{H}_t$$
$$= \begin{bmatrix} h^r_{11} & h^r_{21} & \cdots & h^r_{N1} \end{bmatrix}^T \begin{bmatrix} h^t_{11} & h^t_{12} & \cdots & h^t_{1M} \end{bmatrix}$$

$$\lambda_1 = Trace(\mathbf{H}_e \mathbf{H}_e^H)$$

The p.d.f. of eigenvalue

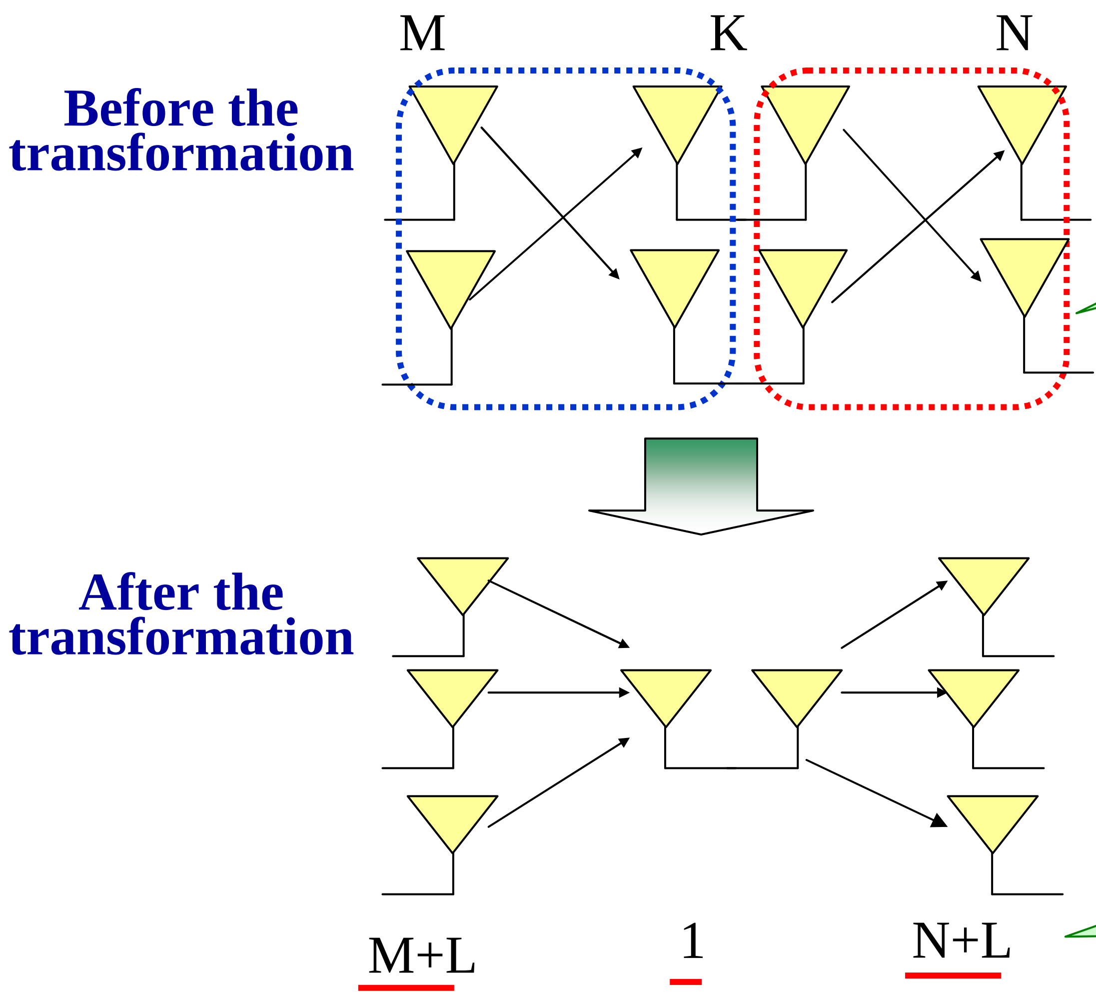
$$p(\lambda_1) = \int_0^\infty \frac{1}{u} p_{2N}(u) p_{2M}\left(\frac{\lambda_1}{u}\right) du$$
$$= \frac{2\lambda_1^{\frac{N+M}{2}-1}}{\Gamma(N)\Gamma(M)} K_{M-N}\left(2\sqrt{\lambda_1}\right)$$

(K$_v$: v-th order modified Bessel function of the second kind)

p_{2N} — central chi-square distributed with 2N degrees of freedom

p_{2M} — central chi-square distributed with 2M degrees of freedom

Approximated PDF of the largest eigenvalue



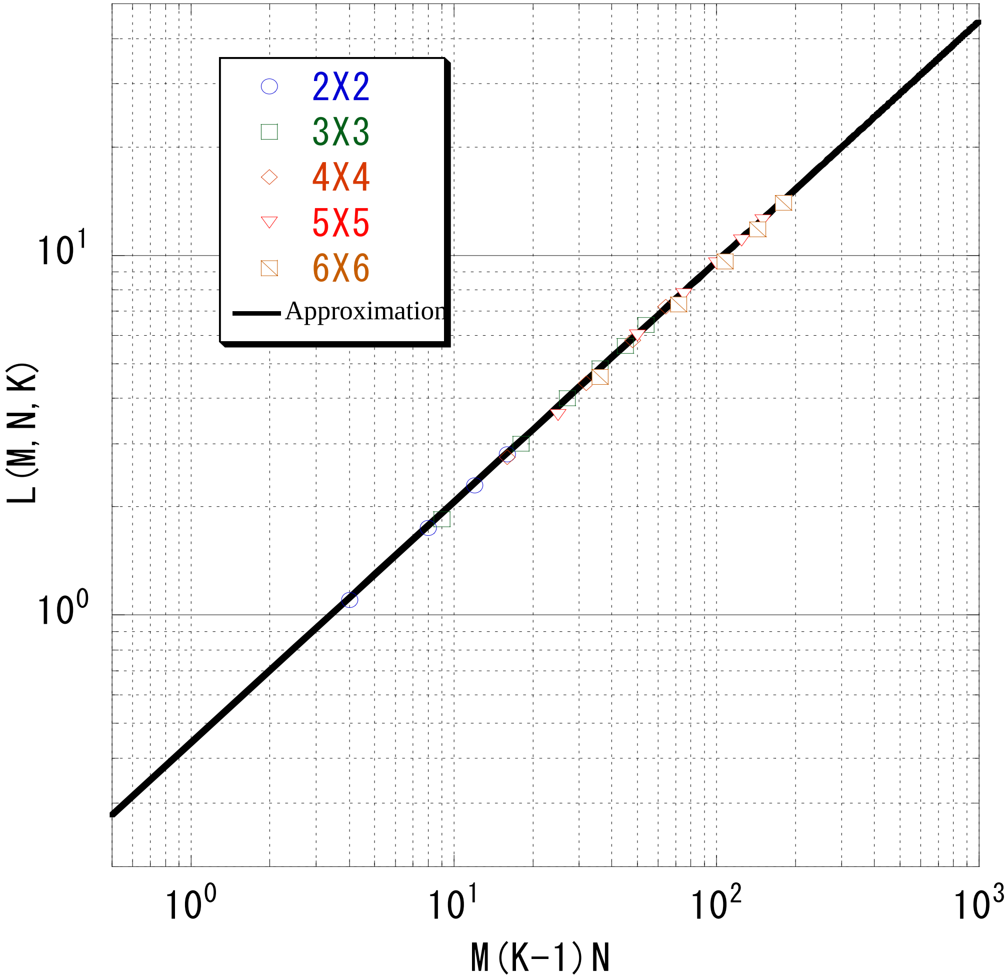
linked to the theory of space diversity at transmission and reception sides, respectively

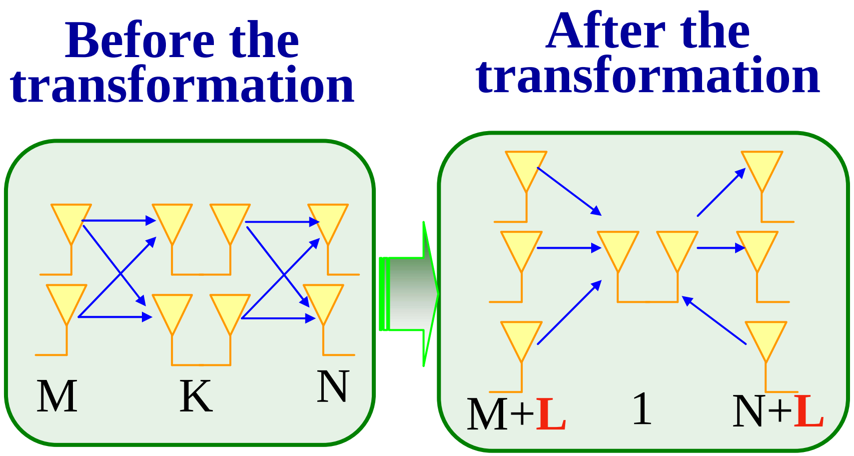
Converting the number of repeater antennas to 1

It results to p.d.f. of keyhole

introduction of the number of effective increment antennas *L*

Introduction of the number of effective increment antennas *L*





the number of effective increment antennas *L*

$$L(M,N,K)=\alpha(NM(K-1))^{\beta}$$

$$\alpha=0.4343, \beta=0.6681$$

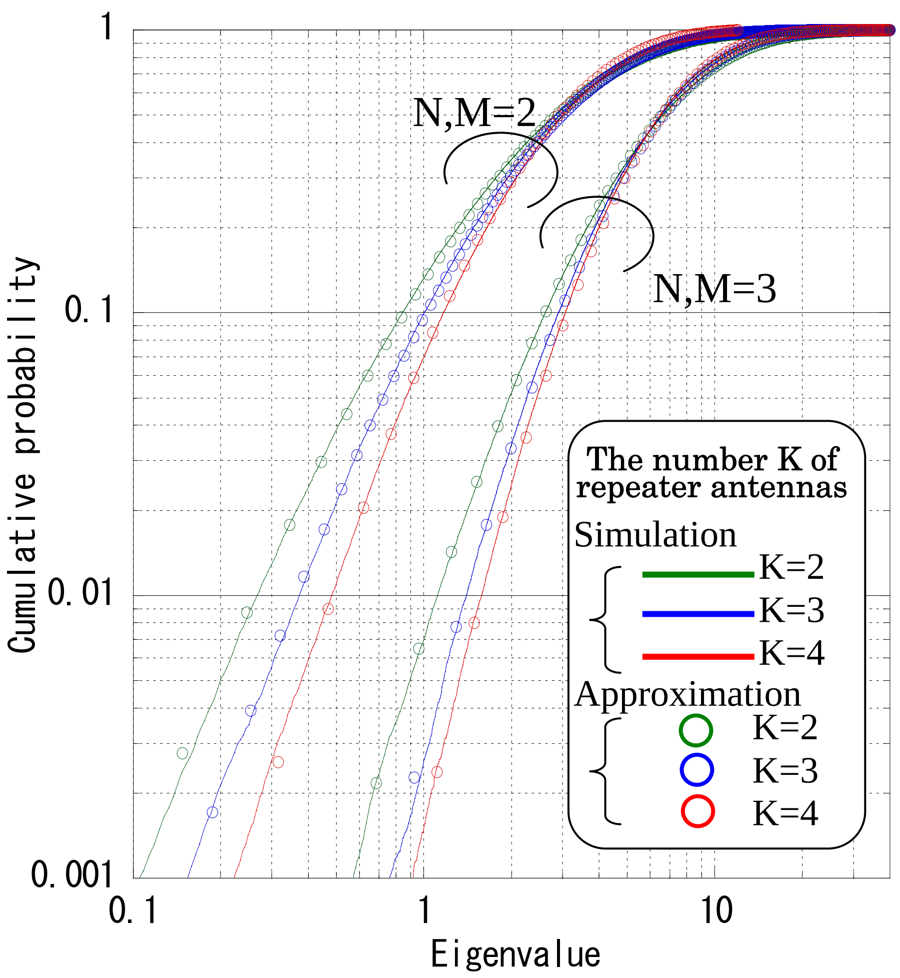
- ***It is the resonable approximation.***

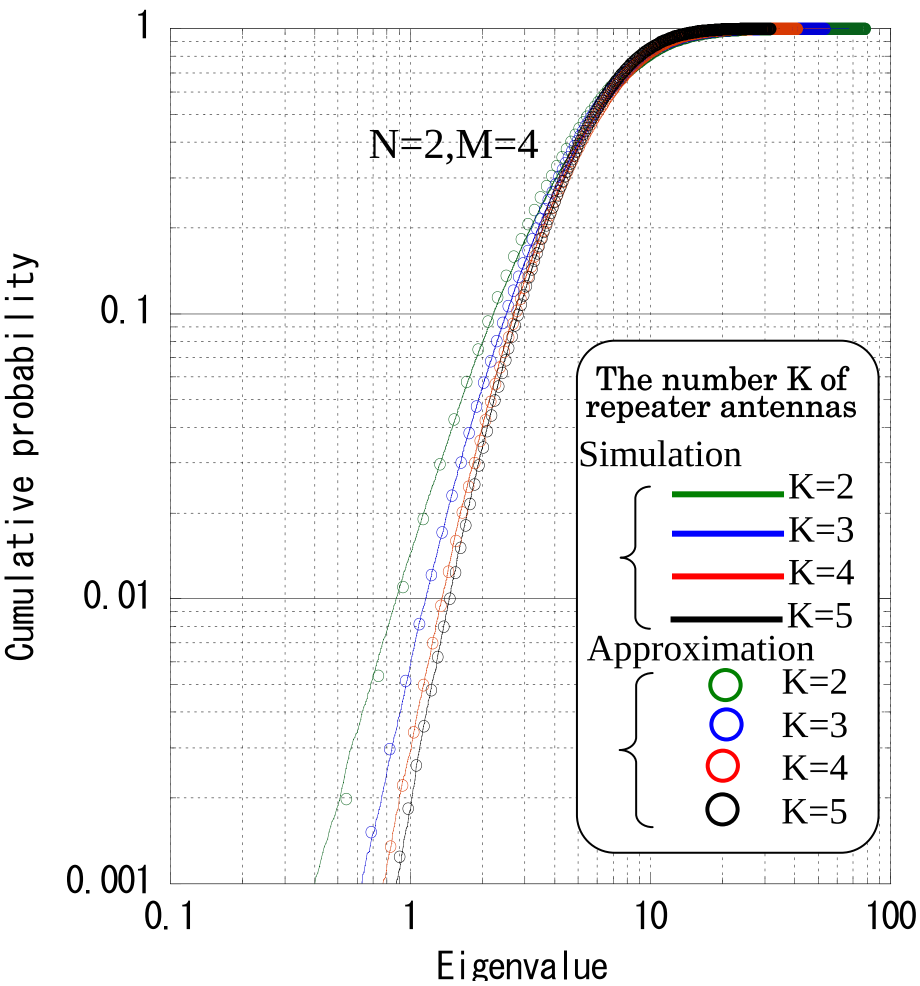
Approximation equation of p.d.f. of largest eigenvalue for MxKxN case

$$p(\lambda_1) = \frac{2\left(\frac{\lambda_1}{\Lambda}\right)^{\frac{N+M+2L}{2}-1}}{\Lambda\Gamma(N+L)\Gamma(M+L)} K_{M-N}\left(2\sqrt{\frac{\lambda_1}{\Lambda}}\right)$$

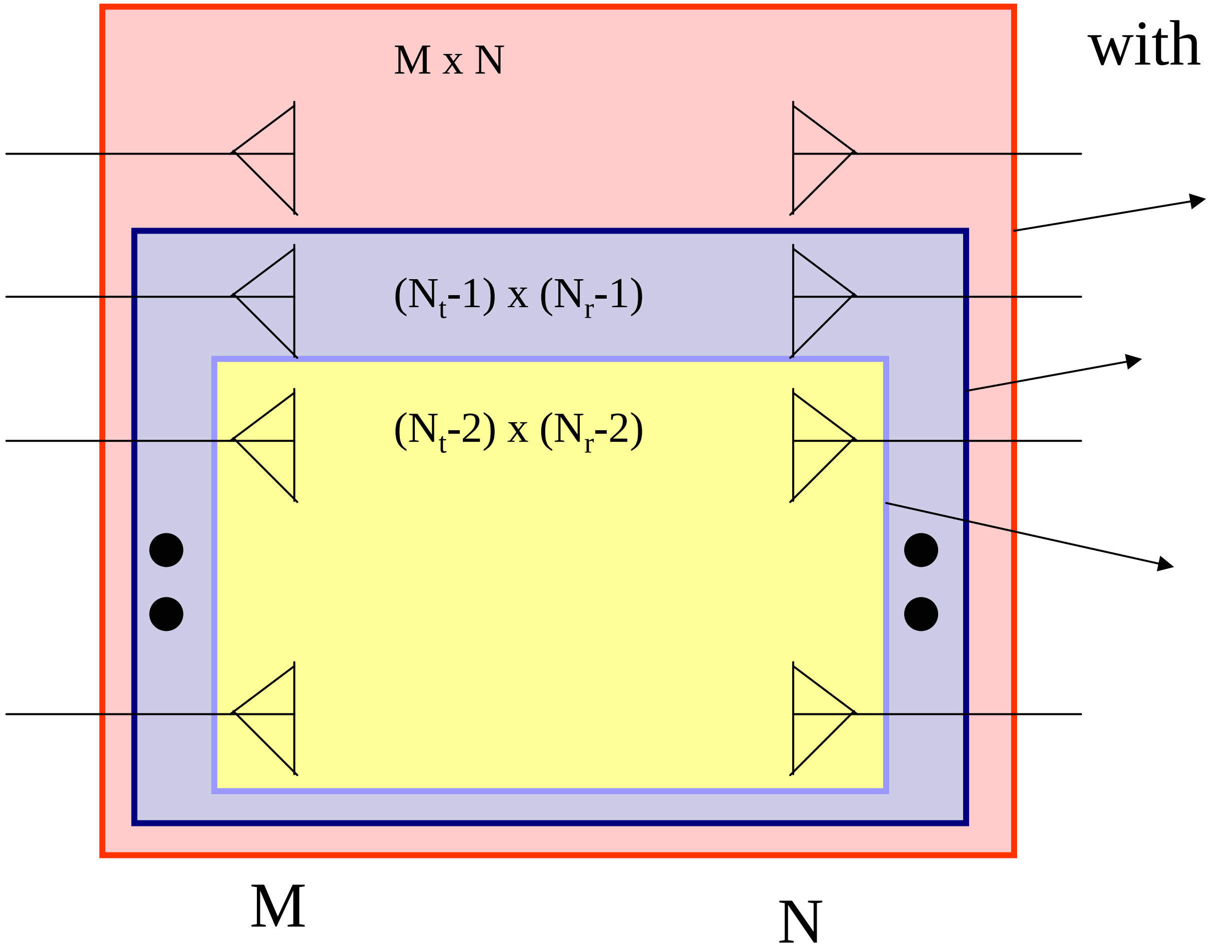
Λ: Power adjustment factor (average value of eigenvalue)

Comparison between simulated values and calculated values ~the largest eigenvalue~





PDF of each Eigenvalue in i.i.d. Environment (approximated)



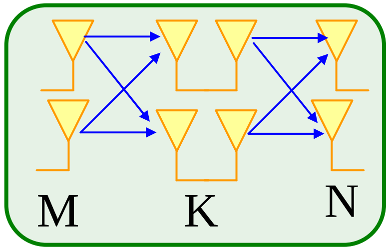
Gamma distribution with diversity order of

$\lambda_{1:}$: M x N

$\lambda_{2:}$: (M-1) x (N-1)

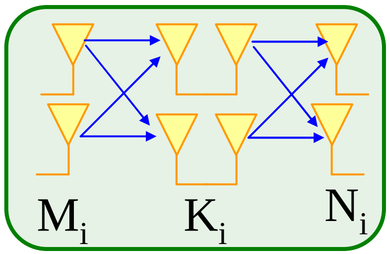
$\lambda_{3:}$: (M-2) x (N-2)

Approximate Formulas of PDFs for All Eigenvalues



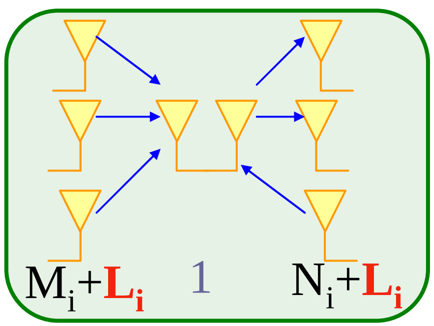
Equivalent transformation:
Reduce each antenna number by i-1

M_i=M-i+1
K_i=K-i+1
N_i=N-i+1



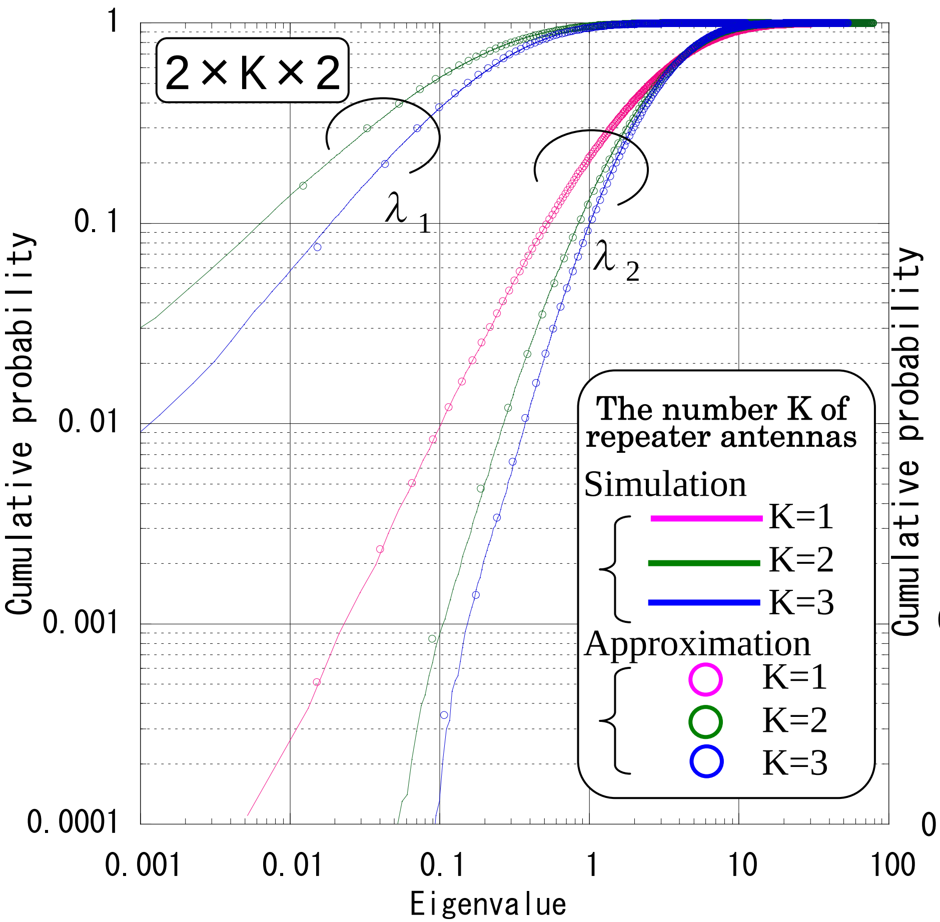
$$p(\lambda_i)=\frac{2\left(\frac{\lambda_i}{\Lambda_i}\right)^{\frac{N_i+M_i+2L_i}{2}-1}}{\Lambda_i\Gamma(N_i+L_i)\Gamma(M_i+L_i)}K_{M_i-N_i}\left(2\sqrt{\frac{\lambda_i}{\Lambda_i}}\right)$$

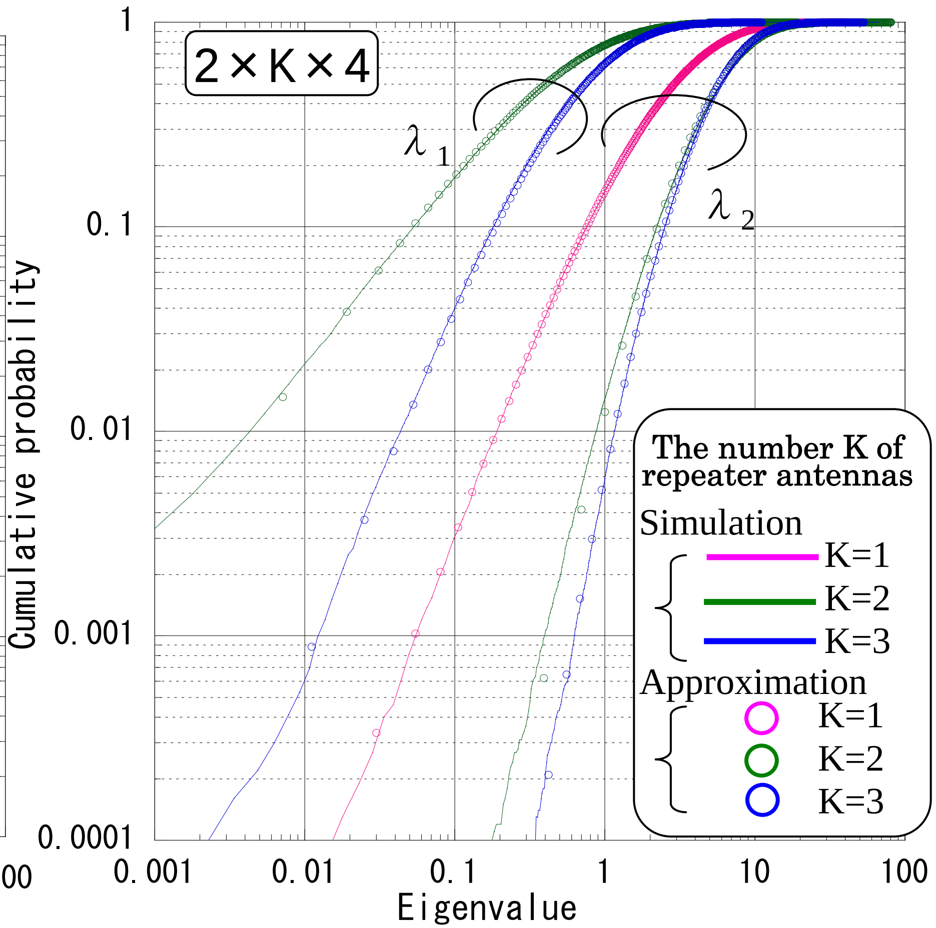
L_i=L-i+1



Similar way when obtaining the largest eigenvalue for (M-i+1) x (K-i+1) x (N-i+1)

Comparison between simulated values and calculated values ~all eigenvalues~





Conclusion

- MIMO radio-relay system (or MIMO repeater system) which can expand service area to isolated areas is introduced.
- For the system designing, channel model is important. A channel model named multi-keyhole model for this purpose is presented.
- An empirical calculation method for PDFs of eigenvalues in the channel is developed.
- The proposed scheme realizes very accurate estimate of the PDFs.
- We are ready to evaluate digital transmission characteristics of radio-relay systems using the proposed channel model.