On-line and Dynamic Estimation of Rician Fading Channels in GSM-R Networks

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Outline

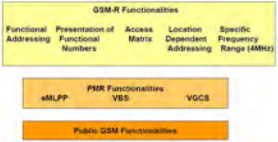
1. Introduction
    - Background
    - Problem Formulation
2. On-line Estimation
    - Measurement Framework
    - Local Power Estimation
3. Performance Evaluation
    - Implementation
    - Evaluation

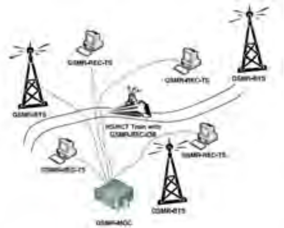
Outline

Background

1. GSM-R for high-speed railway

- The high-speed railway is critical for transporting commodities and passengers, and it has experienced rapid development recently.
- The primary consideration of high-speed railway is safety, which increasingly relies on the information and communication system.
- So it requires realtime measurement to ensure the reliability and stability of GSM-R networks and the high-speed railway system.[1]





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[1] G. Baldini et al. "An early warning system for detecting GSM-R wireless interference in the high-speed railway infrastructure". In: International Journal of Critical Infrastructure Protection (2010).

Background

2. **Require: On-line Monitoring System for GSM-R Networks**

1. It is crucial to reduce the estimation overhead so that the on-line monitoring can be implemented and ensure the realtime reliability.
2. It is necessary to make dynamic measurement due to the feature of propagation environments along the high-speed railway routes.

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- Difficulties:

Speed	250-300km/h for China's high-speed railway;
Terrains	mountains, viaducts, plains, etc. along the routes;
Interface	vulnerable to changes of propagation environments;
Services	the communication may be affected by measurement.

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Services	the communication may be affected by measurement.

- Advantages:

Flat	the propagation environments are generally flat;
Fixed	the trajectory and speed of trains are relatively fixed.

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Problem Formulation

1. Propagation Model

1. Since GSM-R networks are deployed along the railway routes with varied terrains, the propagation environments are very complex.
2. The cell radius is normally designed short, so the multi-path fading should be characterized by Rician fading in this case.

(a) Viaduct (b) Tunnel (c) Mountain (d) Plain

Figure 1: Propagation environments and terrains of GSM-R networks

Problem Formulation

1. Propagation Model: $p_r^2(x) = s(x)h(x)$

1. Shadowing fading:

$$s(x) \sim N\left(m(x), \sigma_s^2\right) \tag{1}$$

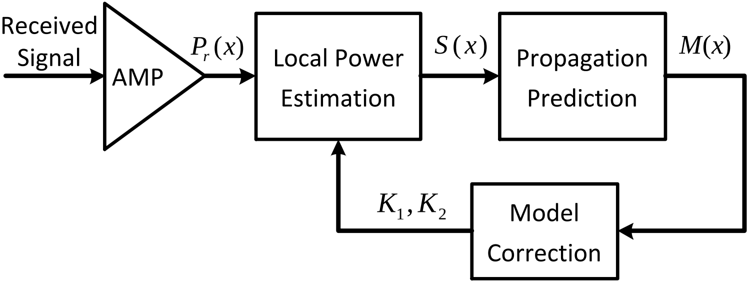
2. Multi-path fading:

$$h(x) = \underbrace{\frac{1}{\sqrt{1+K}} \lim_{M\to\infty} \frac{1}{\sqrt{M}} \sum_{m=1}^{M} a_m e^{j\left(\frac{2\pi}{\lambda}\cos(\theta_m x)+\phi_m\right)}}_{\text{NLOS Components}} + \underbrace{\sqrt{\frac{K}{1+K}} e^{j\left(\frac{2\pi}{\lambda}\cos(\theta_0 x+\phi_0)\right)}}_{\text{LOS Component}} \tag{2}$$

Problem Formulation

2. Measurement Procedures

The procedures of propagation measurement in GSM-R networks is typically composed of the local mean power estimation, propagation prediction and model correction, as is demonstrated in Fig. 2.



Received Signal

AMP

$P_r(x)$

Local Power Estimation

$S(x)$

Propagation Prediction

$M(x)$

Model Correction

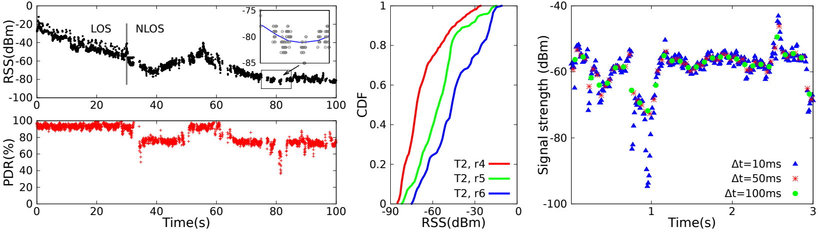
K_1, K_2

Figure 2: Basic Procedures of Radio Propagation Measurement

Problem Formulation

3. Sampling Frequency

1. $P_r(x)$ is influenced by different environments as shown in Fig. 3a and Fig. 3b, it should be adaptive to the networks status.
2. $P_r(x)$ is changing in both large and small time scale as shown in Fig. 3c, it should also be adaptive to this realtime fluctuation.



(a) (b) (c)

Figure 3: Character of RSS in mobile networks, composed of both of LOS and NLOS scenarios.

Problem Formulation

Traditional Algorithms on Local Power Estimating

- Lee's method proposed a standard process of local mean power estimation, which is determined in Rayleigh fading channels.[2]
- Other works are based on confidence degree or ML estimation, but are also analyzed in Rayleigh channels.[3]
- For the estimation of the received signal strength in Rician fading channels, the estimation overhead are usually high for GSM-R.[4]
- The Generalized Lee method does not need a priori knowing of distribution function, but the optimal length of averaging interval is calculated by all the routes of the data with high overhead.[5]

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[2] W.C.Y. Lee. "Estimate of local average power of a mobile radio signal". In: IEEE Trans. on Vehicular Technology (1985), pp. 22–27.

[3] Bo Ai et al. "Theoretical analysis on local mean signal power for wireless field strength coverage". In: WCSP '2009.

[4] C. Tepedelenlioğlu et al. "Estimation of Doppler spread and signal strength in mobile communications with applications to handoff and adaptive transmission". In: Wireless Commun. and Mobile Computing (2001), pp. 221–242.

[5] D. de la Vega et al. "Generalization of the Lee Method for the Analysis of the Signal Variability". In: IEEE Trans. on Vehicular Technology 58.2 (2009), pp. 506 –516.

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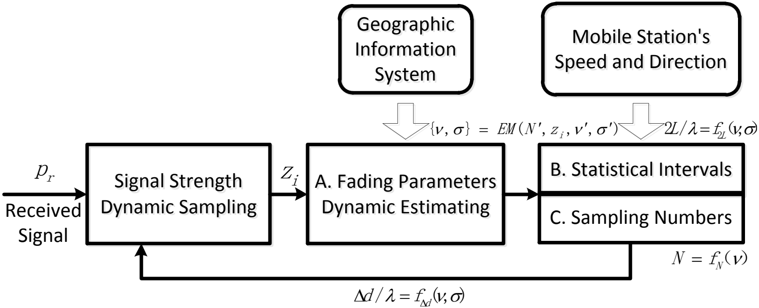
Measurement Framework

On-line Estimating Procedure

The on-line estimating algorithm adopts the Lee's standard procedure in the case of Rician fading channels. Fig. 4 illustrates the basic steps which mainly consist of the determination of proper length of statistical interval and required number of averaging samples.



Geographic Information System

Mobile Station's Speed and Direction

$\{\nu, \sigma\} = EM(N', z_i, \nu', \sigma')$

$2L/\lambda = f_{2L}(\nu,\sigma)$

p_r

Received Signal

Signal Strength Dynamic Sampling

Z_i

A. Fading Parameters Dynamic Estimating

B. Statistical Intervals

C. Sampling Numbers

$N = f_N(\nu)$

$\Delta d/\lambda = f_{\Delta d}(\nu,\sigma)$

Figure 4: On-line and Dynamic Estimation of Rician Fading Channels

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Local Power Estimation

1. EM algorithm for Rician estimation[6]

$$\nu_{k+1} = \frac{1}{N}\sum_{i=1}^{N} \frac{I_1\left(\frac{\nu_k z_i}{\sigma_k^2}\right)}{I_0\left(\frac{\nu_k z_i}{\sigma_k^2}\right)} z_i \tag{3}$$

$$\sigma_{k+1}^2 = \max\left[\frac{1}{2N}\sum_{i=1}^{N} z_i^2 - \frac{\nu_k^2}{2}, 0\right] \tag{4}$$

where N is the number of samples. The initial values are:

$$\nu_0 = \left(2\left(\frac{1}{N}\sum_{i=1}^{N} z_i^2\right)^2 - \frac{1}{N}\sum_{i=1}^{N} z_i^4\right)^{1/4} \tag{5}$$

$$\sigma_0^2 = \frac{1}{2}\left(\frac{1}{N}\sum_{i=1}^{N} z_i^2 - \nu_0\right) \tag{6}$$

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[6] T.L. Marzetta. "EM algorithm for estimating the parameters of a multivariate complex Rician density for polarimetric SAR". In: International Conference on Acoustics, Speech, and Signal Processing, 1995. IEEE. 1995, pp. 3651–3654.

Local Power Estimation

2. Length of Statistical Intervals

The local mean power can be estimated by the integral spatial average of $p_r^2(x)$:

$$\hat{s} = \frac{1}{2L} \int\limits_{y-L}^{y+L} p_r^2(x)dx = \frac{s}{2L} \int\limits_{y-L}^{y+L} h(x)dx \tag{7}$$

$$\sigma_{\hat{s}}^2 = \frac{2(n-1)}{n^2(1+K)^2} \int\limits_0^n g(K;\rho)d\rho \tag{8}$$

Local Power Estimation

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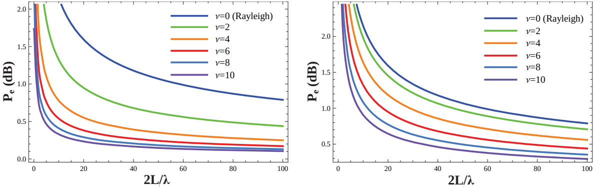
$$\sigma_{\hat{s}}^2 = \frac{2(n-1)}{n^2(1+K)^2}\int\limits_0^n g(K;\rho)d\rho \qquad (8)$$

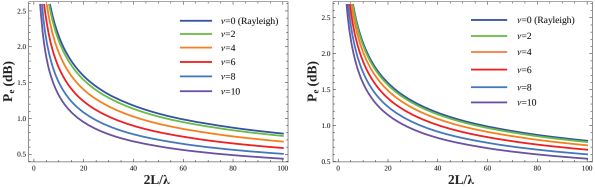
$$\Downarrow$$

$$P_e = 10\log_{10}\left(\frac{\hat{s}+\sigma_{\hat{s}}}{\hat{s}-\sigma_{\hat{s}}}\right) = 10\log_{10}\left(\frac{\frac{2\sigma^2+\nu^2}{2\sigma^2}n + \sqrt{2(1+n)\int\limits_0^n g\left(\frac{\nu^2}{2\sigma^2};\rho\right)d\rho}}{\frac{2\sigma^2+\nu^2}{2\sigma^2}n - \sqrt{2(1+n)\int\limits_0^n g\left(\frac{\nu^2}{2\sigma^2};\rho\right)d\rho}}\right) \qquad (9)$$

Local Power Estimation



(a) $\sigma = 1$ (b) $\sigma = 3$



(c) $\sigma = 5$ (d) $\sigma = 7$

Figure 5: Proper Length of Statistical Intervals

$$P_e = 1dB$$
$$\Downarrow$$
$$2L = f_{2L}(\lambda; \nu, \sigma)$$

Local Power Estimation

3. Number of Averaging Samples

The received power $r^2 = 2\sigma^2 + \nu^2 \approx \frac{1}{N}\sum_{i=1}^{N} z_i^2$ can be calculated by (3) and (4), then the expectation and variance of r^2 can be calculated:

$$\bar{r^2} = E\left[r^2\right] = \frac{1}{N}E\left[\sum_{i=1}^{N} z_i^2\right] = \frac{\sigma^2}{N}\left(2N+\nu^2\right) \tag{10}$$

$$\sigma_{\bar{r^2}} = D\left[r^2\right] = \frac{1}{N^2}D\left[\sum_{i=1}^{N} z_i^2\right] = \frac{\sigma^4}{N^2}\left(4N+4\nu^2\right) \tag{11}$$

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$$\Downarrow$$

$$\begin{aligned} Q_e = 10\log_{10}\left(\frac{\bar{r}^2 + \sigma_{\bar{r}^2}}{\bar{r}^2}\right) &= 10\log_{10}\left(\frac{\frac{\sigma^2}{N}\left(2N+\nu^2\right) + \frac{2\sigma^2}{N}\sqrt{N+\nu^2}}{\frac{\sigma^2}{N}\left(2N+\nu^2\right)}\right) \\ &= 10\log_{10}\left(\frac{2N+\nu^2+2\sqrt{N+\nu^2}}{2N+\nu^2}\right) \end{aligned} \tag{12}$$

Local Power Estimation

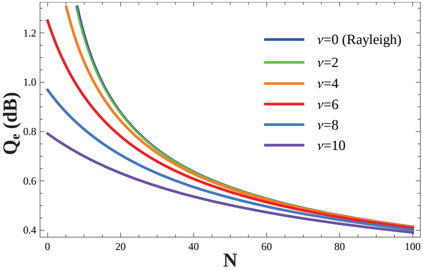
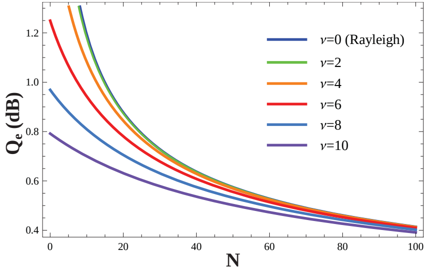


Figure 6: Required Number of Averaging Samples

Number of Samples

$$Q_e = 1dB$$
$$\Downarrow$$
$$N = f_N(\lambda; \nu, \sigma)$$

Local Power Estimation



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Sampling Intervals

$$\Delta d = 2L/N$$

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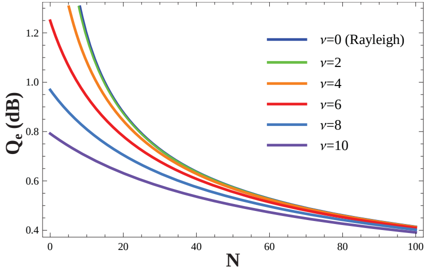

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$$\Delta d = 2L/N = f_{2L}(\lambda; \nu, \sigma)/f_N(\lambda; \nu, \sigma) = f_d(\lambda; \nu, \sigma)$$

- $\Delta d \Leftarrow$ statistical interval $2L$ and number of averaging samples N;
- $\Delta d \Rightarrow$ measurement accuracy and overhead of on-line estimation.

Local Power Estimation

Distance Driven: Δd

1. SDU: the radars and speed sensors are required
2. GPS: the accuracy is limited with additional overhead of communication

Time Driven: Δt

1. Accuracy: the speed and wave length are steady
2. Overhead: the system only needs vocality information from speed sensor

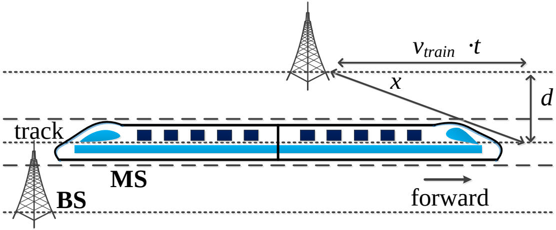

Figure 7: The distance between MS and BS.

Relative Distance

Since BSs are settled so close to the railway track, the relative distance of MS and BS can be deemed as $\Delta x = v_{train} \cdot \Delta t$.

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Implementation

1. Platform of On-line Monitoring System

- Hardware: The CPU is RTD's CME137686LX-W, and the GSM-R module is COM16155RER-1 using Triorail's engine TRM:3a.
- Software: The software is developed by Microsoft .NET Compact Framework in C#, and it can run on Windows XP/CE/Mobile.

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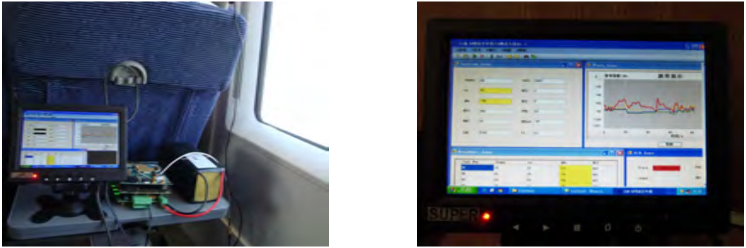

(a) Hardware Design (b) Software Development

Figure 8: Um Interface Monitoring System for GSM-R Networks

Implementation

2. Algorithm Implementation and System Design

- The raw data is processed by the on-line estimation algorithm to provide current network status and conduct next signal sampling.
- The algorithm can also provide received signal strength prediction, and it will give the warning information when it is necessary.

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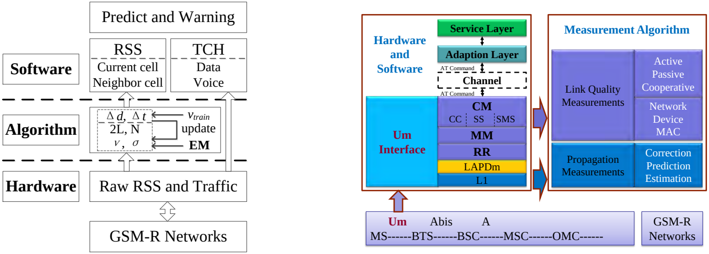

(a) (b)

Figure 9: Measurement framework and algorithm implementation

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Evaluation

1. Experiments

- The experiment is carried out by the on-line monitoring system.
- The data was collected on Beijing-Shanghai high-speed railway.
- The collected data is also analyzed and evaluated by simulation.

1	ID	chann	rs	dBm	[illegible]	[illegible]	[illegible]	C1	C2	chann2	rs3	dBm4	[illegible]	[illegible]	[illegible]	C18	C19	chann10	rs11	dBm12
2	2011-9-25 14:35:06	2	11	-99	460	0	2	0	0	3	8	-102	460	0	2	-3	-3	23	7	-103
3	2011-9-25 14:35:07	2	9	-101	460	0	2	-2	-2	3	8	-102	460	0	2	-3	-3	23	7	-103
4	2011-9-25 14:35:08	2	9	-101	460	0	2	-2	-2	3	8	-102	460	0	2	-3	-3	23	8	-102
5	2011-9-25 14:35:09	2	8	-102	460	0	2	-3	-3	3	8	-102	460	0	2	-3	-3	23	8	-102
6	2011-9-25 14:35:10	3	9	-101	460	0	2	-2	-2	23	8	-102	460	0	0	-1	-1	2	7	-103
7	2011-9-25 14:35:11	23	9	-101	460	0	0	0	0	3	9	-101	460	0	2	-2	-2	2	6	-104
8	2011-9-25 14:35:12	23	10	-100	460	0	0	1	1	3	7	-103	460	0	2	-4	-4	2	7	-105
9	2011-9-25 14:35:30	23	10	-100	460	0	0	1	1	29	8	-102	460	0	0	-7	-7	2	8	-102
10	2011-9-25 14:35:31	23	11	-99	460	0	0	2	2	3	9	-101	460	0	2	-2	-2	29	8	-102
11	2011-9-25 14:35:32	23	11	-99	460	0	0	2	2	2	9	-101	460	0	2	-2	-2	29	8	-102
12	2011-9-25 14:35:33	23	10	-100	460	0	0	1	1	2	8	-102	460	0	2	-3	-3	548	8	-102
13	2011-9-25 14:35:34	23	10	-100	460	0	0	1	1	2	8	-102	460	0	2	-3	-3	548	8	-102
14	2011-9-25 14:35:35	2	10	-100	460	0	2	-1	-1	23	10	-100	460	0	0	1	1	29	7	-103
15	2011-9-25 14:35:43	29	8	-102	460	0	0	-7	-7	23	6	-104	460	0	0	-3	-3	548	5	-105
16	2011-9-25 14:35:44	548	7	-103	460	0	5	-4	2	29	6	-104	460	0	0	-9	-9	23	5	-105
17	2011-9-25 14:36:03	2	8	-102	460	0	2	-3	-3	23	7	-103	460	0	0	-2	-2	29	7	-103
18	2011-9-25 14:36:04	2	10	-100	460	0	2	-1	-1	23	7	-103	460	0	0	-2	-2	29	7	-103
19	2011-9-25 14:36:05	2	12	-98	460	0	2	1	1	29	8	-102	460	0	0	-7	-7	23	7	-103
20	2011-9-25 14:36:07	2	14	-96	460	0	2	3	3	23	9	-101	460	0	0	0	0	29	8	-102
21	2011-9-25 14:36:08	2	15	-95	460	0	2	4	4	23	10	-100	460	0	0	1	1	29	9	-101
22	2011-9-25 14:36:09	2	15	-95	460	0	2	4	4	29	11	-99	460	0	0	-4	-4	23	10	-100
23	2011-9-25 14:36:10	2	16	-94	460	0	2	5	5	23	12	-98	460	0	0	3	3	29	12	-98
24	2011-9-25 14:36:11	2	17	-93	460	0	2	6	6	23	13	-97	460	0	0	4	4	29	12	-98
25	2011-9-25 14:36:12	2	17	-93	460	0	2	6	6	29	15	-95	460	0	0	0	0	23	13	-97
26	2011-9-25 14:36:13	2	17	-93	460	0	2	6	6	29	15	-95	460	0	0	0	0	23	12	-98
27	2011-9-25 14:36:14	2	17	-93	460	0	2	6	6	29	15	-95	460	0	0	0	0	23	12	-98
28	2011-9-25 14:36:15	2	17	-93	460	0	2	6	6	29	15	-95	460	0	0	0	0	23	12	-98
29	2011-9-25 14:36:16	2	17	-93	460	0	2	6	6	29	15	-95	460	0	0	0	0	23	12	-98
30	2011-9-25 14:36:17	2	17	-93	460	0	2	6	6	29	16	-94	460	0	0	1	1	23	12	-98
31	2011-9-25 14:36:18	2	17	-93	460	0	2	6	6	29	16	-94	460	0	0	1	1	23	11	-99
32	2011-9-25 14:36:19	2	17	-93	460	0	2	6	6	29	16	-94	460	0	0	1	1	23	11	-99

Figure 10: Experimental Results along Beijing-Shanghai High-speed Railway

1. Experiments

- The experiment is carried out by the on-line monitoring system.
- The data was collected on Beijing-Shanghai high-speed railway.
- The collected data is also analyzed and evaluated by simulation.

Figure 11: Experimental Results along Beijing-Shanghai High-speed Railway

Evaluation

2. Results

- Δd is more larger compared to Lee's method when $K = 0$, which means the multi-path fading is Rayleigh distributed.
- Δd may be not so small although $2L$ decreases, for $n < 5$ when the terrains gradually become flat until $\nu > 10$.

Table 1: Summary of Experiment Results

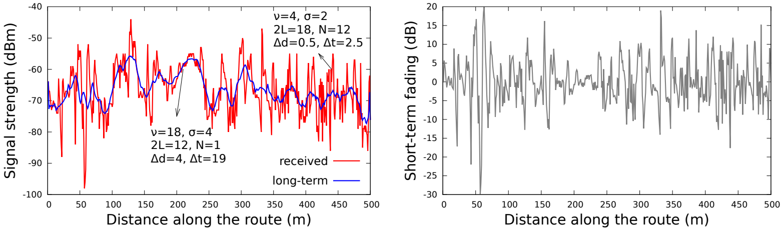
Terrain	K(dB)	ν	σ	$2L(\lambda)$	N	$\Delta d(\lambda)$	Δd(m)	v_{train}(km/h)		
								200	250	300
								Δt(ms)		
NLOS[*]	0	-	-	40	36	1.1	0.367	2.20	1.76	1.47
Intensive	0	0	1	55	15	3.7	1.222	7.33	5.86	4.89
	2	4	2	18	12	1.5	0.500	3.00	2.40	2.00
	4	5.6	2	9	9	1.0	0.333	2.00	1.60	1.33
	6	6	3	20	7	2.9	0.967	5.80	4.64	3.87
	8	12	3	8	1	8.0	2.667	16.00	12.80	10.67
Open	10	18	4	12	1	12.0	4.000	24.00	19.20	16.00

[*] Caculated by Lee's method in the case of Rayleigh fading

Evaluation

The long-term and short-term fading are differentiated separately.

1. Long-term: propagation prediction by ML or MMSE estimator.[7]
2. Short-term: hysteresis selection in handoff algorithms.[8]



(a) Signal Strength (b) Short-term Fading

Figure 12: Measurement Results

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[7] L. Gopal et al. "Power Estimation in Mobile Communication Systems". In: Comp. and Info. Science (2009), P88.

[8] K.I. Itoh et al. "Performance of handoff algorithm based on distance and RSSI measurements". In: IEEE Trans. on Vehicular Technology (2002), pp. 1460–1468.

Evaluation

3. Conclusions

1. The on-line and dynamic estimation algorithm and Um monitoring system is designed, and be tested by experiments&simulations.
2. EM algorithm is employed to reduce the estimation overhead: only the most recent samples instead of all routes of the database;
3. The measurement accuracy is guaranteed without unnecessarily frequent sampling: 12λ compared to Lee's 1.1λ for LOS signal.

The estimation algorithm can be used in upper layer applications:

- network planning with lower overhead, e.g., coverage assessment;
- real-time operating with dynamic adjustment to the time and space changes, e.g., channel allocation, power control and handoff;[1]
- Since Rician fading is the generalized model of multi-path fading channels, the algorithm can also be introduced to other networks.

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[1] G. Baldini et al. "An early warning system for detecting GSM-R wireless interference in the high-speed railway infrastructure". In: International Journal of Critical Infrastructure Protection (2010).

On-line Estimation of Rician Channels

THANKS!

http://yongsen.github.com