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THE PERFORMANCE OF POLARIZATION DIVERSITY SCHEMES IN OUTDOOR MICRO CELLS

T.-C. Tu, C.-M. Li, and C.-C. Chiu

Electrical Engineering Department
Tamkang University
Tamsui, Taipei, R.O.C.

Abstract—The application of polarization diversity reception at the mobile terminal in micro cells at 2 GHz is presented in this paper. Ray-tracing tool is used to study effects of electric field polarization on the received power in outdoor environments. The performance of diversity schemes with vertical/ horizontal polarization and $+45^\circ/-45^\circ$ slanted polarization are compared in different line-of-sight (LOS) and nonline-of-sight (NLOS) environments.

Based on the evaluation of cross polarization discrimination (XPD) parameters, it is clarified that different environments will affect XPD values in micro cells. Then, the vertical/horizontal polarization diversity and $+45^\circ/-45^\circ$ slanted polarization diversity are chosen to compare with space diversity. Several different combining techniques of polarization and space diversity schemes are also compared in different environments. It is found that dual-polarized antennas for mobile terminal are a promising alternative for two spaced antennas.

1. INTRODUCTION

Multipath propagation resulted in Rayleigh fading in nonline-of-sight (NLOS) and Rician fading in line-of-sight (LOS) paths in a radio propagation channel [1]. Space diversity is traditionally used to reduce fading problems at the base-station (BS) end in mobile networks. However, two separate receiving antennas are required when this scheme is applied and antenna implementation is spatially large. Unfortunately, large antenna spacing increases both size and cost of BS and renders the use of multiple antennas in handsets very difficult. The use of dual-polarized antennas for the mobile terminal is promising cost and space-effective alternative, where two spatially separated uni-polarized antennas are replaced by a single antenna structure employing two orthogonal polarizations [2].

Polarization diversity is one of the most promising techniques to reduce fading with a compact antenna configuration requiring only one antenna location for the mobile terminal. The applicability of polarization diversity can partly be evaluated to analyze signal cross correlation and cross polarization discrimination (XPD) values. Further, the effectiveness of a diversity system is measured by a quantity known as diversity gain.

The first aim of this paper is to clarify the influence of an environment on polarization diversity scheme in micro cells. This is based on the evaluation of XPD parameter. The second target is to study the system performance of the polarization diversity scheme and compare it with horizontal space diversity schemes for different environments.

2. SIMULATION DESCRIPTION

The characteristics of the micro-cellular channel in outdoor environments are at 2 GHz. Multiple reflections, transmissions, diffractions are taken into account. We simulate two different environments as shown in Figure 1 (urban) and Figure 2 (semi-urban).

Figure 1 shows a propagation environment consisting of 12 buildings with different heights between 20 m∼50 m. The main street is 30 m wide. The testing routes are labeled as R1 (LOS) and R2 (NLOS), respectively.

Figure 2 shows a propagation environment consisting of 6 buildings with different heights between 20 m∼45 m. The main street is 30 m wide.

Above the two routes in different environments, the transmitting antenna is located at Tx on the main street near the crossroad.

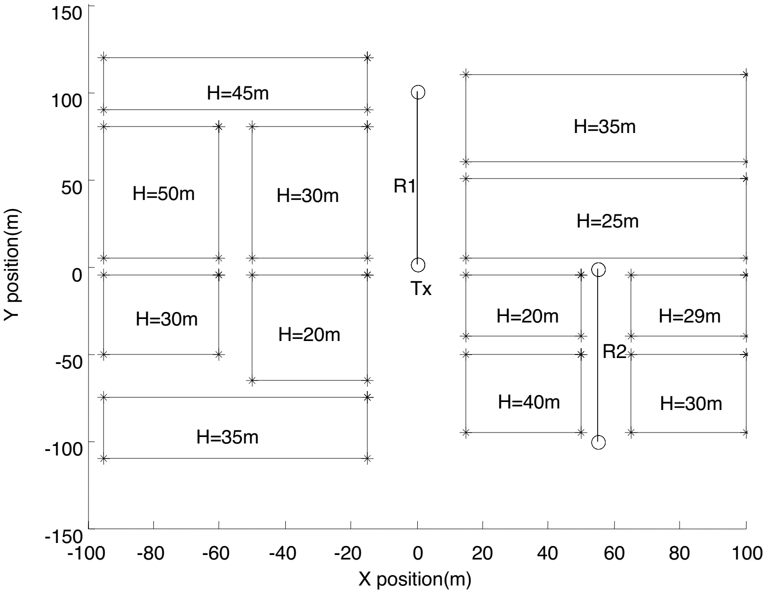

Figure 1. Layout of urban.

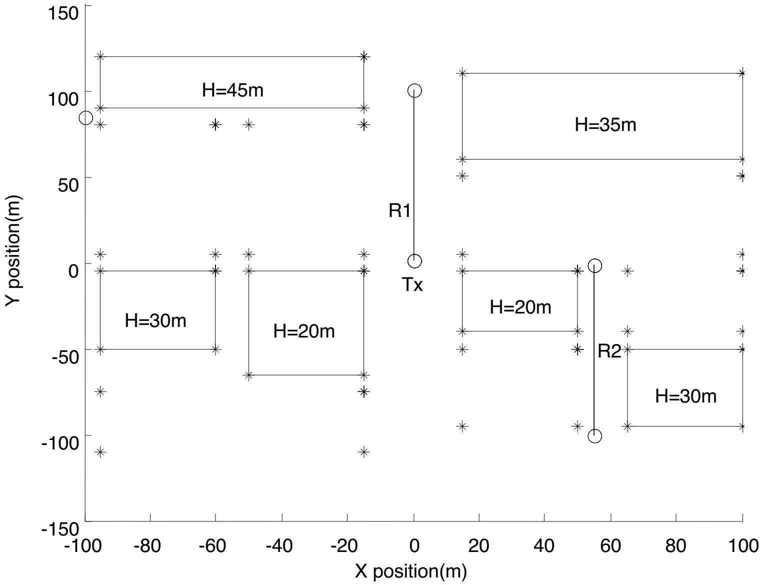

Figure 2. Layout of semi-urban.

Transmitting and receiving antennas are both half-wavelength dipole. The heights of the transmitting and receiving antennas are 20 m and 2 m, respectively. Transmitting power is 3.6 W, and the operating frequency is 2 GHz. In Figures 3 and 4, we show the comparisons of propagation loss in the different routes in the urban area. Figures 5 and 6, show the comparison of propagation loss in the different routes in the semi-urban area. Each of Tx/Rx antennas uses four different polarization types:

1) Tx: vertical polarization/Rx: vertical polarization.
2) Tx: vertical polarization/Rx: horizontal polarization.
3) Tx: $+45^\circ$ slanted polarization/Rx: $+45^\circ$ slanted polarization.
4) Tx: $+45^\circ$ slanted polarization/Rx: -45° slanted polarization.

3. SIMULATION RESULTS AND DISCUSSIONS

3.1. Cross Polarization Discriminations (XPD)

Two methods are considered in the following. In the first method, the primary polarization is set to be vertical. Therefore, co-polarization for this case means Vertical/Vertical, and cross polarization means Vertical/Horizontal [4]. We assume vertical and horizontal components of the receiving field to have uncorrelated small-scale fading because of different propagation paths. The value of XPD in this method can be determined as:

$$XPD_{v/h}=\frac{P_{vv}}{P_{vh}}=\frac{|1/P_{vv(loss)}|}{|1/P_{vh(loss)}|}=\frac{|P_{vh(loss)}|}{|P_{vv(loss)}|} \tag{1}$$

The primary polarization is set to be 45° in the second method where primary polarization is $+45^\circ$. Therefore, co-polarization for this case means $+45^\circ/+45^\circ$, and cross polarization means $+45^\circ/-45^\circ$. We assume $+45^\circ$ and -45° component of the receiving filed to have uncorrelated small-scale fading because of different propagation paths. The value of XPD in this method can be determined as:

$$XPD_{+45^\circ/-45^\circ}=\frac{P_{+45^\circ+45^\circ}}{P_{+45^\circ-45^\circ}}=\frac{|1/P_{+45^\circ+45^\circ(loss)}|}{|1/P_{+45^\circ-45^\circ(loss)}|}=\frac{|P_{+45^\circ-45^\circ(loss)}|}{|P_{+45^\circ+45^\circ(loss)}|} \tag{2}$$

We used two methods to compare XPD in different environments (urban & semi-urban areas). In Figures 7 and 8, we illustrate the comparison of XPD in the different routes.

It is shown that the simulated XPD value of the vertical/horizontal polarization diversity scheme was larger than $+45^\circ/-45^\circ$

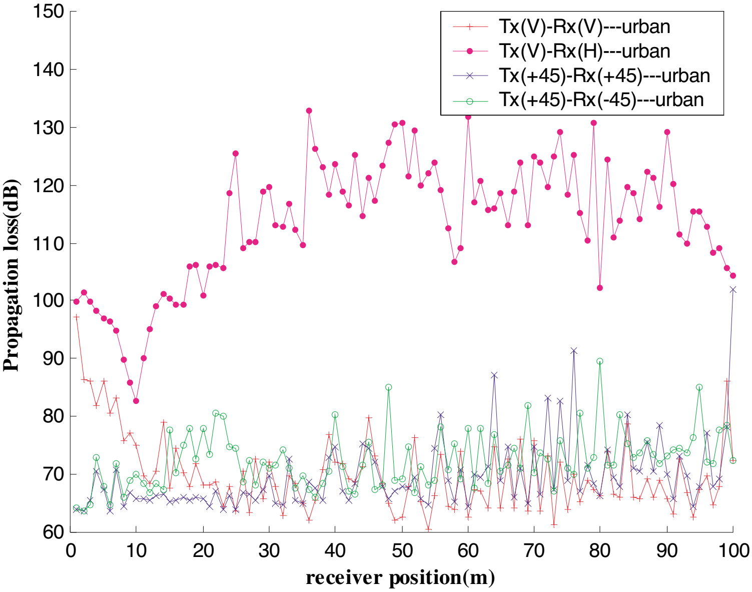

Figure 3. Propagation losses in route $R1$ (urban).

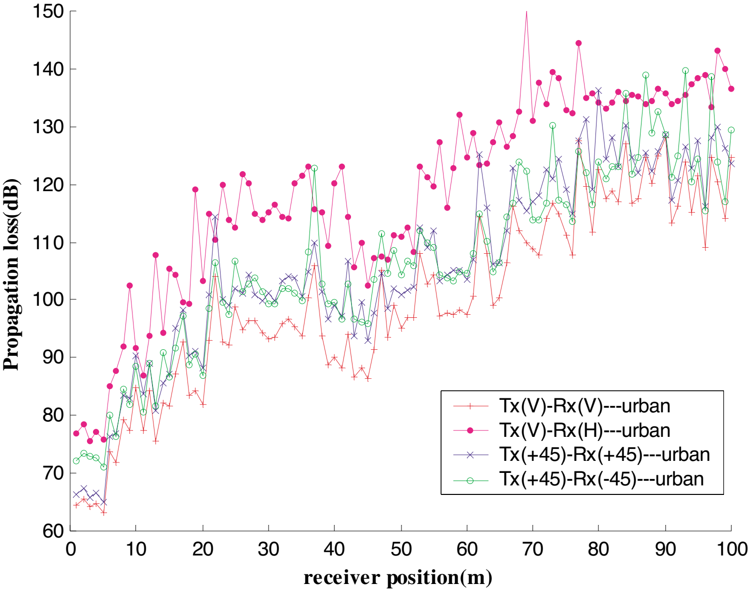

Figure 4. Propagation losses in route $R2$ (urban).

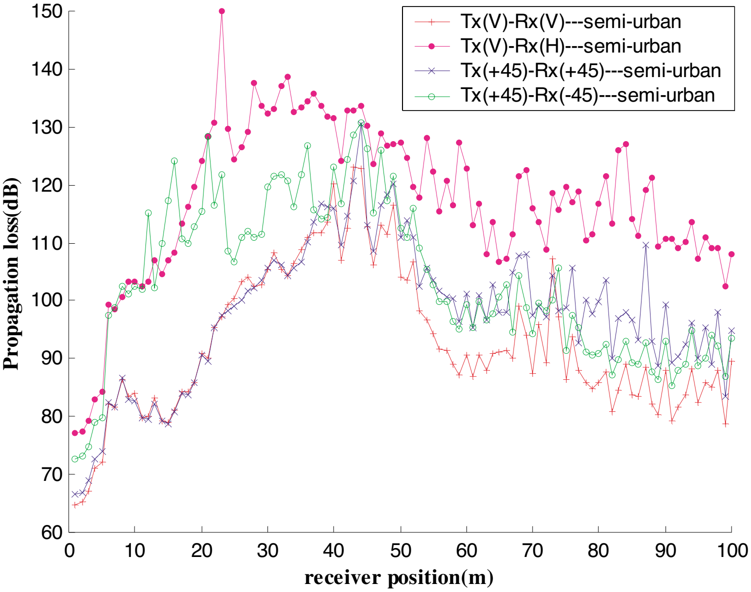

Figure 5. Propagation losses in route $R1$ (semi-urban).

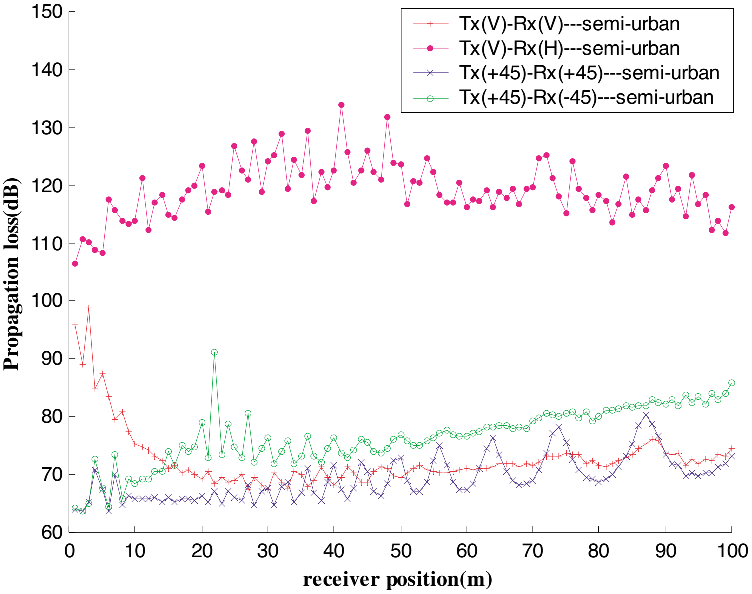

Figure 6. Propagation losses in route $R2$ (semi-urban).

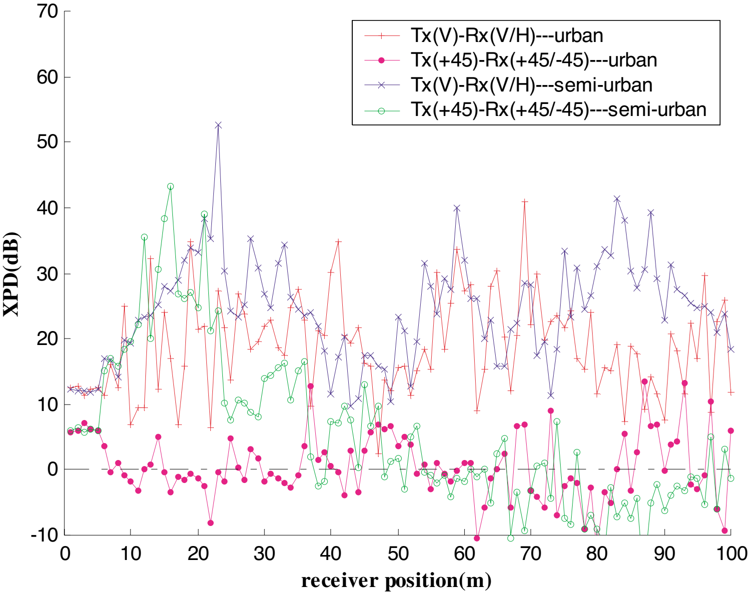

Figure 7. XPD in route $R1$.

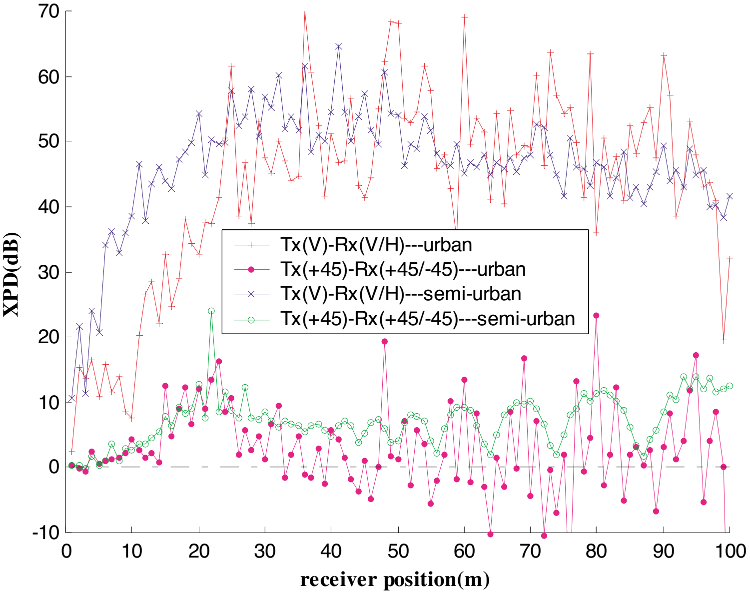

Figure 8. XPD in route $R2$.

slanted polarization diversity scheme in each route and environment. It was found the simulated XPD value is usually greater in LOS than NLOS paths, because the direct ray is a great influence for the reception, dominating over the other multipath contributions. It was also found that XPD value were higher in the semi-urban than urban environment, this may be due to the fact that semi-urban is a more open scenario and there is fewer obstacles near the antennas and thus the signal received with horizontal (−45°) polarization is not sufficiently depolarized to be an important coupling of energy in the vertical (+45°) polarization.

3.2. Diversity Gain

Diversity gain is defined as the ratio of output SNR after combining (γ_{out}) to the input SNR on the strongest branch (γ_{in}), and is calculated based on cumulative probabilities. For given cumulative of X, the diversity gain is [5]:

$$G_{div}(X) = \frac{\gamma_{out}(X)}{\gamma_{in}(X)} \tag{3}$$

For a cumulative probability X, the SNR after combining is:

$$\gamma_{out}(X) = \frac{S_{out}^2(X)}{2\sigma_{N_{out}}^2} \tag{4}$$

where $\sigma_{N_{out}}^2$ is the noise power in the combined signal and $S_{out}(X)$ is the envelope in the combined signal. The input SNR is:

$$\gamma_{in}(X) = \frac{S_{in}^2(X)}{2\sigma_{N_{in}}^2} \tag{5}$$

where $\sigma_{N_{in}}^2$ is the noise power of the branch that has the highest average signal and $S_{in}(X)$ is the envelope of the branch that has the highest average signal.

For selection diversity, the output SNR is given by

$$\gamma_{out}(X) = \gamma_{sel}(X) = \frac{S_{sel}^2(X)}{2\sigma_{N_{out}}^2} \tag{6}$$

If $S_{out}^2(X) \gg 2\sigma_{N_{out}}^2$ and $S_{in}^2(X) \gg 2\sigma_{N_{in}}^2$, the approximate selection diversity gain is:

$$G_{sel}(X) = \frac{\gamma_{out}(X)}{\gamma_{in}(X)} \approx \frac{S_{out}^2(X)}{S_{in}^2(X)} \tag{7}$$

The largest diversity gain is achieved when the mean levels of the signals from the two branches are equal and fading is independent in the two branches [6]. The vertical/horizontal diversity signals are always unequal, so we choice +45°/ − 45° slanted polarization to compete space diversity. We use formula (7) for selective combining techniques to calculate diversity gain of horizontal space diversity and +45°/−45° slanted polarization diversity in two different environments (urban & semi-urban). In Figures 9 and 10, we illustrate the comparison of cumulative diversity gain in the different routes.

It is seem that the diversity gain with polarization diversity in NLOS routes is sometimes superior to space diversity. So we can use +45°/ − 45° slanted polarization for mobile terminal to obtain good diversity gain in NLOS routes. It was also found the diversity gain is greater in urban than semi-urban area, and this might be caused by more multiple reflections, transmissions, and diffractions in urban environments.

3.3. Diversity Combining

Diversity combining techniques include selection, equal-gain combining, and maximum-ratio combining. More detailed background information will be described as follows: contains more detailed background information will be listed on diversity combining.

1) Selection diversity: In selection diversity, two or more receivers are used, with each connected to a different antenna. For selection diversity, the output SNR is give by

$$\gamma_{sel}(t) = \max\left[\frac{S_m^2(t)}{2\sigma_{N_m}^2}\right] = \frac{1}{2\sigma_N^2}\max\left(S_m^2(t)\right) = \frac{S_{sel}^2(t)}{2\sigma_N^2} \tag{8}$$

where $\sigma_{N_m}^2$ is the noise power on the mth diversity branch and $S_m(t)$ is the envelope of the signal on the mth branch.

The approximate diversity gain is found by substituting (7) and (8).

$$G_{sel}(X) \approx \frac{S_{sel}^2(X)}{S_{m_{\max}}^2(X)} \tag{9}$$

where

$$m_{\max} = \max\left(\left\langle S_1^2\right\rangle, \cdots \left\langle S_M^2\right\rangle\right) \tag{10}$$

2) Equal gain combining: Equal gain combining is achieved by co-phasing and summing signals from two or more receiver branches. For equal gain combining, the instantaneous SNR of the combined signal

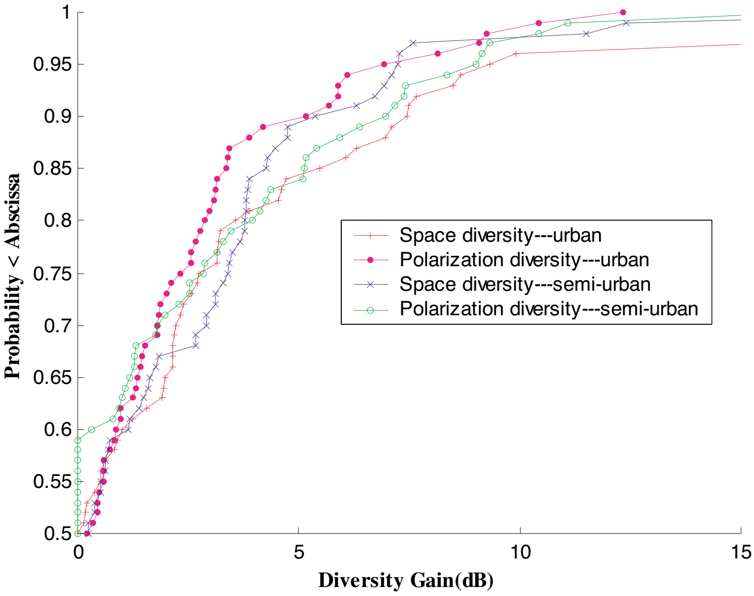

Figure 9. Cumulative diversity gain in route $R1$.

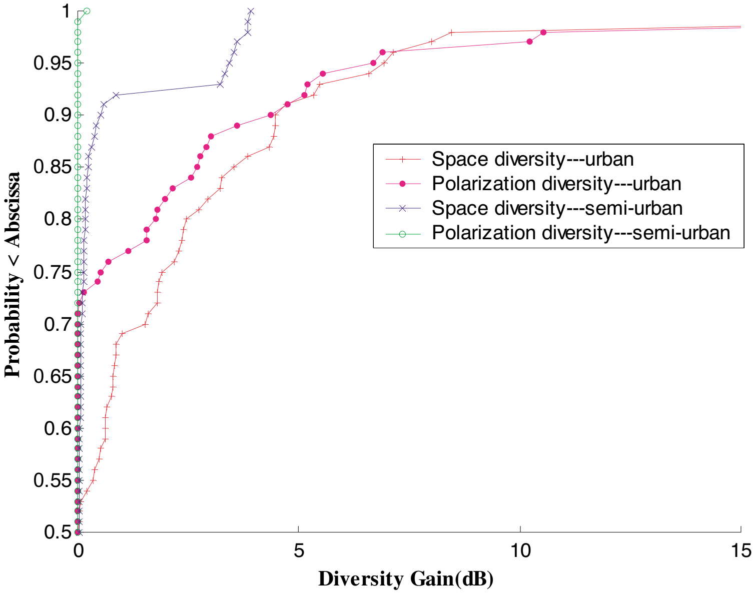

Figure 10. Cumulative diversity gain in route $R2$.

is

$$\gamma_{egc} = \frac{\left(\sum\limits_{m=1}^{M} S_m\right)^2}{2\sum\limits_{m=1}^{M} \sigma_{N_m}^2} = \frac{S_{egc}^2}{2M\sigma_N^2} \tag{11}$$

The approximate diversity gain is

$$G_{egc}(X) \approx \frac{S_{egc}^2(X)}{MS_{m_{\max}}^2(X)} \tag{12}$$

where

$$S_{egc} = \sum_{m=1}^{M} S_m \tag{13}$$

3) Maximal-ratio combining: In maximal ratio combining, the signals from all receiver branches are co-phased, weighted, and summed. The amplitude weighting of each branch is proportional to the SNR on that branch. For maximal ratio combining, the instantaneous SNR of the combined signal is given by the sum of the SNR on the M branches.

$$\gamma_{mrc} = \sum_{m=1}^{M} \gamma_m = \frac{\sum\limits_{m=1}^{M} S_m^2}{2\sigma_N^2} = \frac{S_{mrc}^2}{2\sigma_N^2} \tag{14}$$

The approximate diversity gain is

$$G_{mrc} \approx \frac{S_{mrc}^2(X)}{S_{m_{\max}}^2(X)} \tag{15}$$

where

$$S_{mrc} = \sqrt{\sum_{m=1}^{M} (S_m^2)} \tag{16}$$

We use formula (9), (12) and (15) to calculate different diversity gain. Selection, equal gains and maximum ratio combining of polarization diversity scheme and space diversity are compared in Figures 11 and 12, respectively.

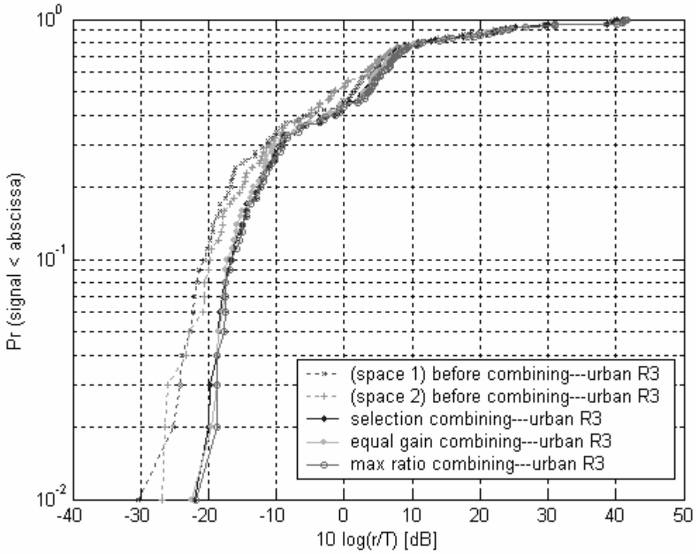

Figure 11. Comparison of combining methods of polarization diversity scheme.

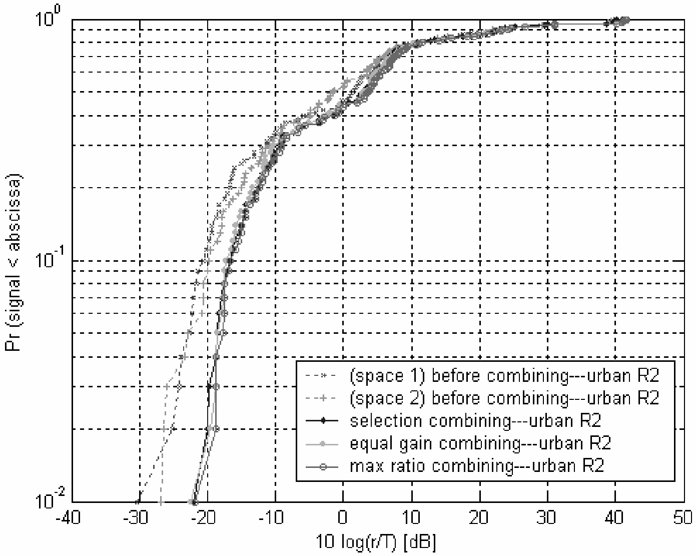

Figure 12. Comparison of combining methods of polarization and space diversity schemes.

4. CONCLUSIONS

In this paper, the relationship between XPD and diversity gain of a polarization scheme at the mobile terminal in micro cells at 2 GHz was studied. The XPD value were calculated to use different polarization scheme in different routes and environments, and the results showed that the XPD value of the vertical/horizontal polarization diversity scheme was larger than $+45°/-45°$ slanted polarization diversity scheme in each routes and environments. It was found the simulated XPD value is usually greater in LOS paths than in NLOS paths, and greater in semi-urban than urban.

The largest diversity gain is achieved when the mean levels of the signals from the two branches are equal and fading is independent in the two branches. The horizontal space diversity was chosen to compare with $+45°/-45°$ slanted polarization, since vertical/horizontal diversity signals were always unequal. We used selective combining techniques to calculate diversity gain of this two diversity schemes in different environments. In the LOS routes, it was found the diversity gain with space diversity is usually greater than that with polarization diversity. However, in NLOS routes, the diversity gain with polarization diversity is sometime emerged as superior to space diversity. It was also found the diversity gain is greater in urban than semi-urban environment. We have also seen the maximal ratio combining gives the best performance with multipath fading. The performance of selection and equal gain systems depends on the signal distribution.

In conclusions, in the mobile terminal at 2 GHz, we can choose the $+45°/-45°$ slanted polarization diversity scheme in most of the NOLS paths and compact environments. The application of dual-polarized antennas for mobile terminal is a promising alternative for cost and space efficiency, where two spatially separated uni-polarized antennas are replaced by a single antenna structure employing two orthogonal $+45°/-45°$ slanted polarizations.

REFERENCES

1. Rappaport, T. S., *Wireless Communications*, Prentice-Hall, Upper Saddle River, NJ, 1996.
2. Nabar, R., H. Bölcskei, V. Erceg, D. Gesbert, and A. Paulraj, “Performance of multi-antenna signaling strategies in the presence of polarization diversity,” *IEEE Transactions on Signal Processing*, Vol. 50, No. 10, 2553–2562, October 2002.
3. Jan, S. C. and S. K. Jeng, “A novel propagation modeling

for microcellular communications in urban environments," *IEEE Transactions on Vehicular Technology*, Vol. 46, No. 4, 1021–1026, 1997.

4. Correia, L. M., *Wireless Flexible Personalised Communication*, John Wiley, 605 Third Avenue, NY, 2001.
5. Dietrich, Jr., C. B., "Adaptive arrays and diversity antenna configurations for handhead wireless communication terminals," Ph.D. Dissertation, Virginia, February 2000.
6. Eggers, P. C. F., I. Z. Kovács, and K. Olesen, "Penetration effects on XPD with GSM 1800 handset antennas, relevant for BS polarization diversity for indoor coverage," *IEEE VTC'98*, Ottawa Ont., Canada, May 18–21, 1998.

Ting-Chieh Tu was born in Tainan, Taiwan, Republic of China, on April 12, 1976. He received M.S.E.E. degree from Tamkang University in 2002. He is currently working toward Ph.D. degree at the Department of Electrical Engineering, Tamkang University.

Chao-Min Li was born in Taipei, Taiwan, Republic of China, on November 20, 1972. He received M.S.E.E. degree from Tamkang University in 2004. He is currently an Engineer in Chunghwa Telecom Co., Ltd. His current research interests include mobile computing and networks.

Chien-Ching Chiu was born in Taoyuan, Taiwan, Republic of China, on January 23, 1963. He received the B.S.C.E. degree from National Chiao Tung University, Hsinchu, Taiwan, in 1985 and M.S.E.E. and Ph.D. degrees from National Taiwan University, Taipei, Taiwan, in 1987 and 1991 respectively. From 1987 to 1989, he served in the ROC Army Force as a communication officer. In 1992 he joined the faculty of the Department of Electrical Engineering, Tamkang University, where he is now an Professor. He was a visiting scholar at MIT and University of Illinois, Urbana from 1998 to 1999. His current research interests include microwave imaging, numerical techniques in electromagnetics and indoor wireless communications.