Mobile Transmit Diversity

Overview

The paper provides highlights regarding the basics of Mobile Transmit antenna Diversity (**MTD**), calculation method for diversity gain, impact on network capacity and on data rate. The impact of unequal antennas is reviewed in conjunction with the parameters described above

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Preliminary discussion: Base Station antenna diversity

At base stations, the signal from the mobile is usually confined to a small angular sector, thus the major multipath travel throughout similar terrain thus subjected to spatial differentiation of somewhat limited nature. “Looking” at the combined multipath from different antennas yields slightly different phase interaction that contributes to diversity, and the more the antennas are separated, the differentiation increases. The trouble is that when the base station antennas have full or partial uninterrupted Fresnel zone, the practical distance between the antennas is usually insufficient. Dr. William C.Y. Lee, former VP of Air-touch Communications in his mobile Communications Engineering test book from 1982 and 1988, has quantified the problem as the following:

In order to achieve Correlation factor of 0.7 or less, the separation between a base station diversity antennas should be at least HAAT/11, when HAAT being height-above-average-terrain (meaning surrounding roof level). The majority of the base stations have to settle for insufficient antenna separation and usually pick a 10λ spread rule-of-thumb, thus exposed to relatively high correlation factors. Under such cases, signal level experienced by the pair of antennas will therefore vary within relatively small range of few dB. Practical experience derived form Base stations antenna diversity is applicable only partially to mobile unit antenna diversity, where the correlation factor between the antennas is much lower

Mobile unit antenna diversity

Unlike the base station, the mobile unit is exposed to a very wide angle spread of multipath, practically coming form all 360^0. This gives rise to a very significant swing in the relative power levels each antenna experiences, sometimes as much as 10 and even 15 dB apart. It is therefore easy to achieve in this case the required correlation factor of 0.7 or less
In their 2001 article “Smart antenna for handsets” Biedka and colleagues from Virginia Tech Antenna group and the Mobile Portable Radio Research Group, have outline the results of their study about Mobile Transmit Diversity and concluded that as little as 0.13 λ of separation between the mobile antenna will reach the target of correlation factor = 0.7

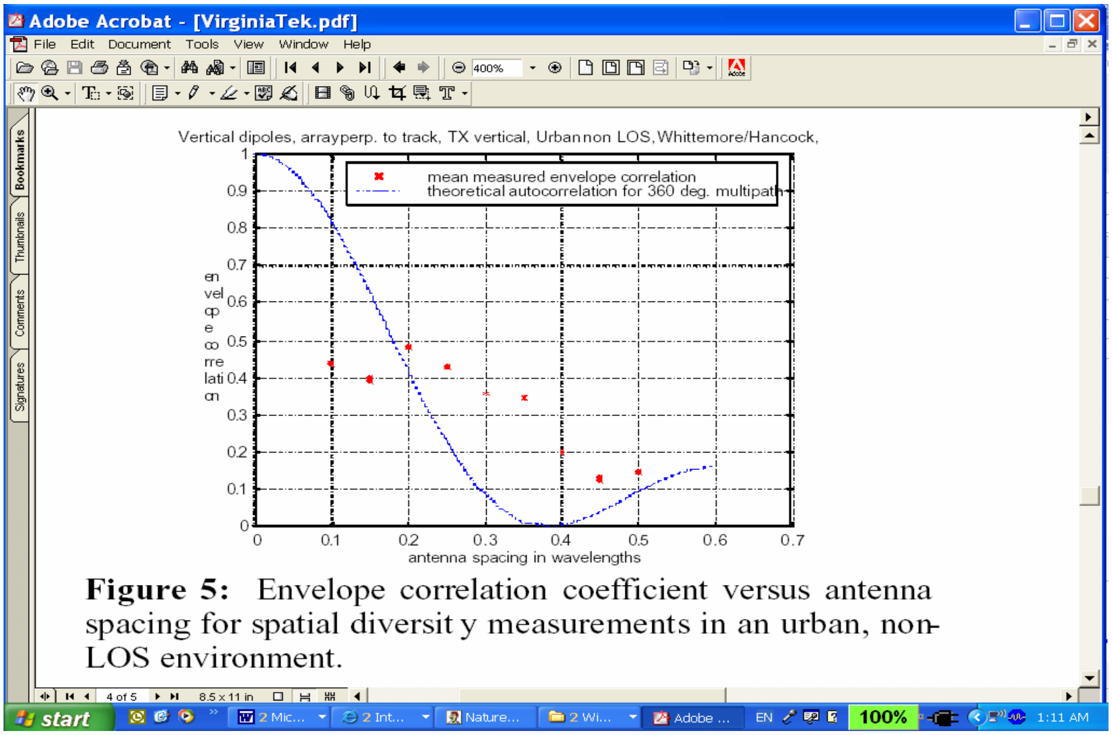


Figure 5: Envelope correlation coefficient versus antenna spacing for spatial diversit y measurements in an urban, non-LOS environment.

Therefore, the mobile experiences a much wider range of fading differences between the two antennas, allowing for diversity gains higher than ones available for Base stations

MPRG measurements show MTD gains of 4-5 dB with antenna spacing of 0.2-0.3 λ under static Conditions

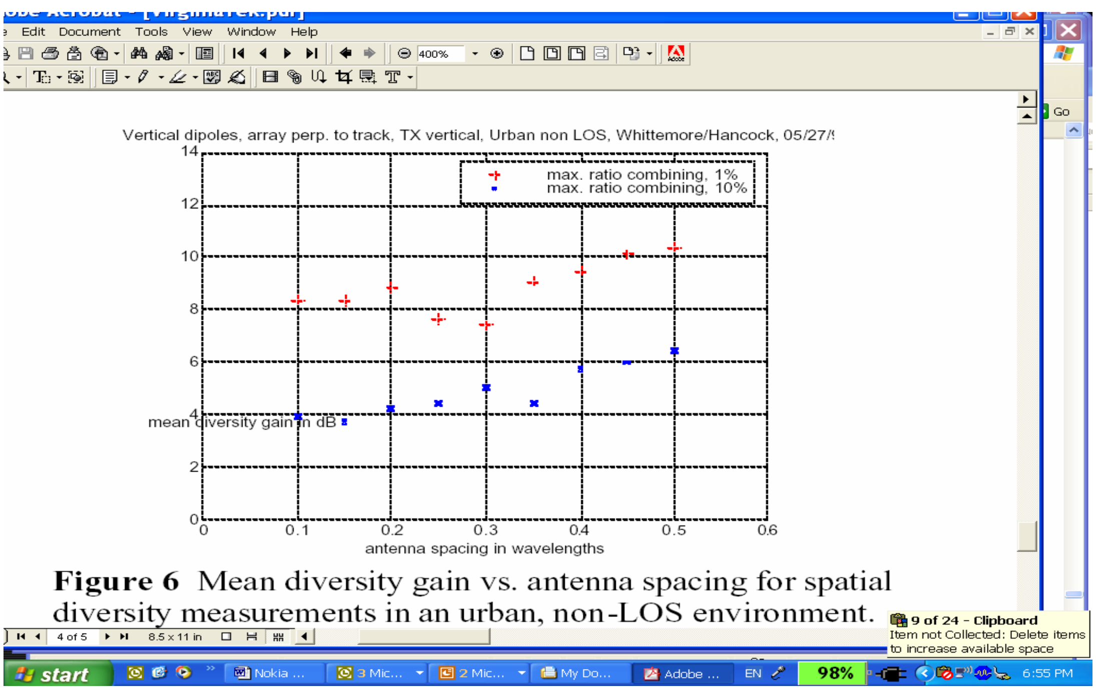


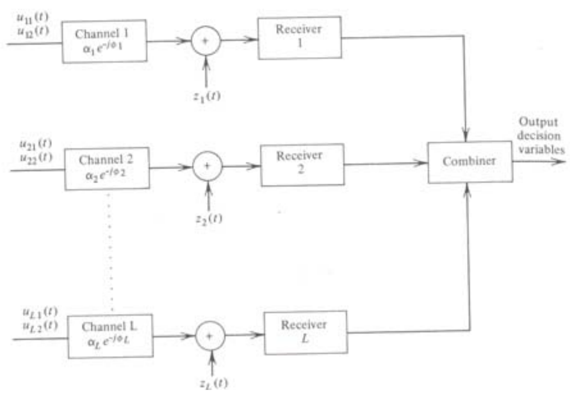
Figure 6 Mean diversity gain vs. antenna spacing for spatial diversity measurements in an urban, non-LOS environment.

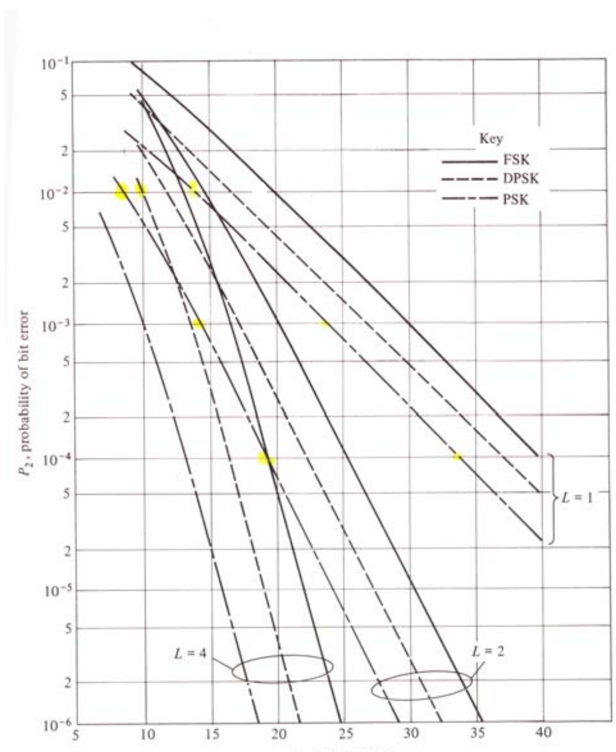
<u>Diversity gain in text books</u>

Dr. John G. Proakis **Digital Communications, McGraw-Hill, 1989**

In Chapter 7.4 Diversity techniques for fading channels, pp722 & pp727 we see figure 7.4.1 & figure 7.4.2 which a□ shown below

The first figure shows the schematics under discussion, depicting L to be the number of antennas
In the second figure, picking PSK modulation, and comparing the L=1 to L=2 along a constant BER line, we get 8-9 dB gain for BER=10^ -3, some 5 dB gain for BER= 10^ -2





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Dr. Yingxue Li   Wireless communications system design with transmit diversity
Texas A&M University, 2001

A coding-based system is analyzed in the article estimating performance of transmit diversity

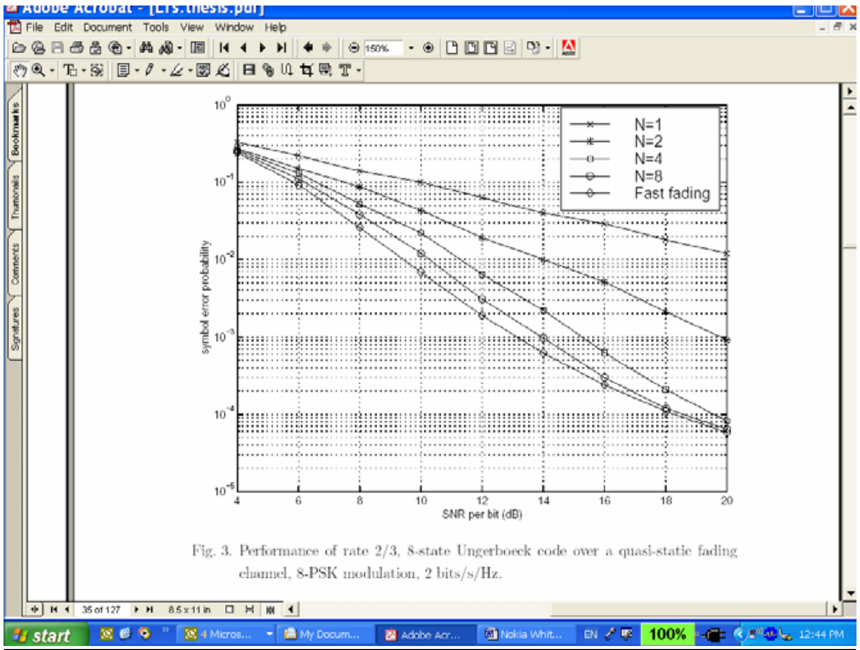


Fig. 3. Performance of rate 2/3, 8-state Ungerboeck code over a quasi-static fading channel, 8-PSK modulation, 2 bits/s/Hz.

This chart shows some 6 dB diversity gain for BER=10^ -2

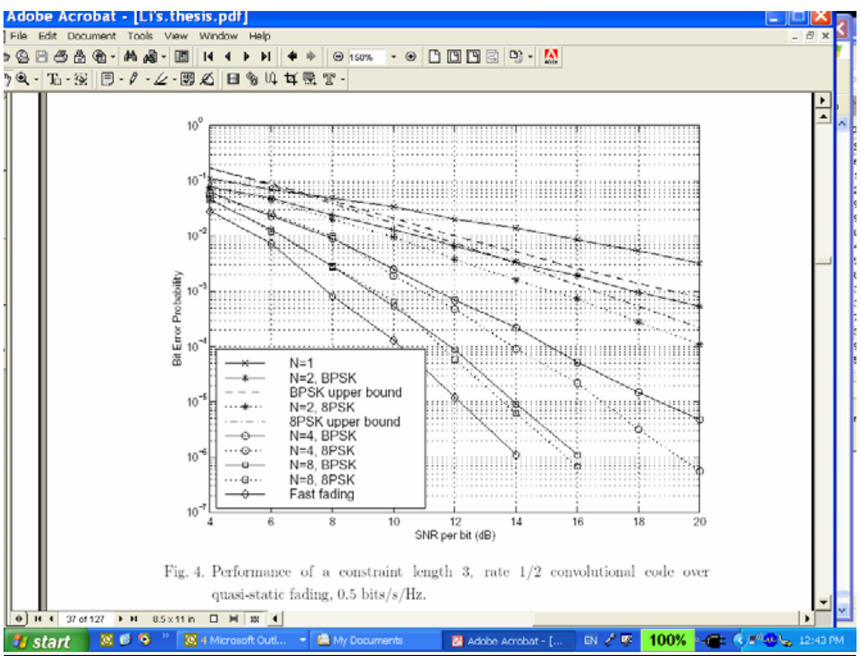


Fig. 4. Performance of a constraint length 3, rate 1/2 convolutional code over quasi-static fading, 0.5 bits/s/Hz.

This chart shows for BPSK some 6 dB diversity gain for BER=10^ -2

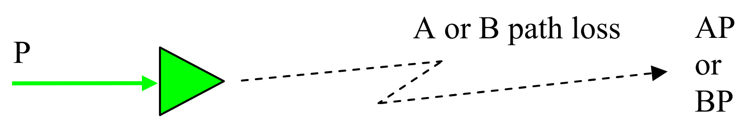
Although Magnolia's transmit diversity implementation is different, the article is brought here to demonstrate how 2 antennas can bring much more than 3 dB of gain

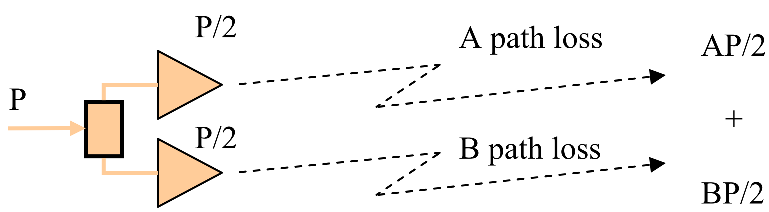
MTD Gain calculation

When 2 equal gain antennas are fed with equal transmit power, and if these antennas happened to have equal pathloss towards the receiver on the other end, then the diversity gain will be bounded by 3 dB, yielding typically around 2 dB on the average

However, the Mobile antennas are having significantly different pathloss, caused by fading differentiation, as explained above, and the following calculation will demonstrate how this occurrence pushes Mobile Transmit Diversity gains above 3 dB and sometimes much more than that

In order to explain the concept, we assume a fast and accurate implementation phase combination, that while does not exist in real life, can be used as a benchmark for the calculation process





The above figure compares two cases: The first is a non-diversity case (Green) where the available transmit power is fed into a single antenna, the second is a diversity case (Pink) where the available transmit power is split into two equal parts, fed into 2 antennas, each of the same gain as the original one

We also assume that the 2 antennas in the diversity case, exhibit different pathloss A & B, and will compare the performance to the single antenna case, exposed to either the A pathloss or the B pathloss with equal probability

If we note that phase combining is essentially coherent addition, than the diversity scheme will enjoy “voltage combination” rather than “power combination”; therefore the combined received power in the Base station will be

$$R_{Div} = [(A*P/2)^{1/2} + (B*P/2)^{1/2}]^2$$

For the non-diversity scheme we assume that the mobile is using a single antenna exposed to either A or B pathloss so

$$R_{Non\text{-}Div} = AP \text{ or } BP$$

For simplicity purposes, lets assume that A=1 and B represents the ration between the 2 paths, to be either smaller or larger than 1 (so that the A pathloss can be either better or worse than the B one):

$$R_{Div} = [(P/2)^{1/2} + (B*P/2)^{1/2}]^2 = (P/2)\,[1+ (B)^{1/2}]^2$$

For the non-diversity scheme we assume that the mobile is using a single antenna exposed to either A or B path loss so

$$R_{Non\text{-}Div} = P \text{ or } BP \quad \text{(depending on whether we assume A or B pathloss)}$$

Note that the transmit regime of CDMA & UMTS protocols maintains closed loop constant received SNR, so the system will award a better-than–required link with instruction to reduce Mobile transmit power, as well as penalize a underperforming link by instructing it to increase transmit power

The required Mobile’s transmit power will be as follows:

-For non diversity case, with pathloss A, the required mobile transmit power is P
-For non diversity case, with pathloss B, the required mobile transmit power is P/B

Example: If B pathloss is worse by a factor of 2 versus A, then the mobile will have to transmit twice as much to meet requirements

-For the diversity case, with one antennas exposed to pathloss A, the other to B, the required mobile transmit power will be

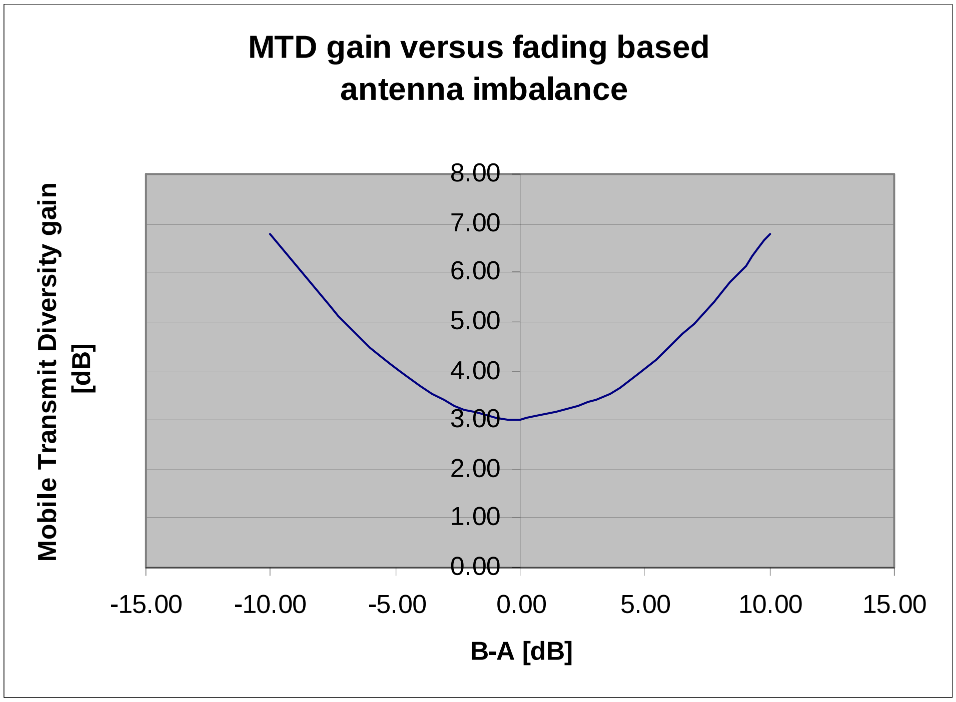
$$RQT_D = \text{Required transmit power for diversity} = 2P*/\ [1+ (B)^{1/2}]^2$$

Mobile Transmit Diversity gain is defined as the mobile transmit power reduction achieved. For non-diversity case we assume path A or B have equal probability so the required power for this case will be the average of these 2 requirements:

$$RQT_{ND} = \text{Required transmit power for non-diversity} = P*(1+1/B)/2$$

We therefore define the diversity gain:

$$\text{MTD Gain} = RQT_{ND}\,/\,RQT_D = (1+1/B)*[1+ (B)^{1/2}]^2/4$$



As can be seen, the possible MTD beamforming gain is minimum 3 dB and usually higher

Note that the above chart depicts the behavior of the gain that can be achieved in fast and accurate phase combining. In real life situations, the measured results indicate that performance is degraded by between 0.5 dB (at close to balanced situations) to 1 dB (at highly imbalanced ones)
Note also that the assumption used here is that both antennas have equal gains; the imbalance is created by fading and blocking differentiation

MTD Capacity Gain

1. Introduction

We analyzed the improvement of the reverse link capacity from the mobiles with the mobile transmit diversity antennae. The transmit diversity antennae of mobiles can improve the reverse link capacity on both the serving cell and the neighbor cells. If the signals from the two antennae received at base station are coherent, they produce beam forming effect. The beam forming can effectively reduce the interference to other cells. The noise floors in other cells can then be reduced and the capacity of other cells is improved. On the other hand, if the received signals are incoherent, two receive antennae at the base station can take advantage of the two diversity signals and reduce the fading margin required for the same signal quality (FER) at the base station receiver. Through the outer loop power control, the incoherent diversity signal can reduce the required Eb/No. This will then reduce the mobile transmit power, through the inner loop power control. Eventually the serving cell's total noise will be reduced and the capacity of the serving cell is improved.

This document also describes the test plan for the capacity improvement testing. We use several mobiles equipped with Magnolia Broadband's **DiversityPlus™** and dual antenna to test on the CDMA 2000 3G1X network.

2. Capacity of a CDMA sector

The reverse link capacity usage can be characterized by the loading factor μ,

$$\mu = \frac{N}{N_{\max}} \tag{1}$$

N and N_{max} are the numbers of active mobiles and the pole capacity of a cell (or sector), respectively. From ref [1], we can present the received signal to noise ratio

$$\frac{E_b}{I_o} = G \frac{S}{FN_{th}W + a(1+f)(N-1)S}$$

(2)

Where

E_b = bit energy,
I_o = power spectra density of thermal noise plus interference,
F = base station noise figure,
N_{th} = power spectra density of thermal noise,
S = received signal strength of a mobile at base station,
R = bit rate,
a = voice activity factor,
f = other cell interference factor,
W = system bandwidth,
and G = W/R , processing gain.

When the signal strength of a mobile is much larger than the thermal noise term, the system reaches the ***pole capacity***. From (2), we may obtain the capacity of a sector N_{max}
,

$$N_{\max} = \frac{G}{ad(1+f)} + 1 \tag{3}$$

Where d is the required E_b/I_o, as defined in (2).

3. Measurement of capacity improvement

We may associate the measurable noise rise (or Rise Over the Thermal noise ROT), τ, with the capacity improvement. ROT, τ,is defined as the ratio of the total received power plus thermal noise over the thermal noise, which can be derived from Equation (1), (2), and (3).

$$\tau = \frac{FN_{th}W + a(1+f)NS}{FN_{th}W} = \frac{1}{1-\mu} \tag{4}$$

Note that the pole capacity of the reverse link is N_{max} and loading $\mu = N/N_{max}$.
The new pole capacity $N_{\max\_div}$ has been improved by the diversity mobiles through the reduction of the noise rise τ_{div}. The reverse link capacity improvement by **these diversity mobiles** is then equal to**,**

$$\frac{N_{\max\_div} - N_{\max}}{N_{\max}} = \frac{\tau - \tau_{div}}{\tau(\tau_{div} - 1)} \tag{5}$$

Apparently, the noise reduction and hence the capacity improvement will be pronounced when all the mobiles are running diversity.

4. Test results

During the last 12 month period, 3 capacity tests have been conducted, 2 over Sprint PCS network and 1 over SKT network

- By April 2005, Sprint and Magnolia have conducted a network test in NJ, using <u>cdma2000 1x Data</u> transmission, yielding **35%** improvement in network capacity
- On July 2005, SKT and Magnolia have conducted a formal capacity test in Seoul 800MHZ system cdma2000 using <u>EVDO</u> data transmission, yielding **45%** capacity improvement
- By December 2005, Sprint has allowed Magnolia to conduct a <u>cdma20001x voice</u> test, yielding **38%** improvement in network capacity

MTD data-rate gain

CDMA network reverse link data rate is determined by Base station grants, and depends on overall loading (Interference generated by other served user in own and neighboring cells) as well as by individual handset estimated performance (Handset that has enough headroom to support higher data rate, will be preferred over one with a smaller one) MTD is helpful for both mechanisms: it reduces general noise level in the network, and it reduces the operating point power level of the handset

Measurement of EVDO data rate gain where done in Seoul with SKT, and following are examples:

- On July 13-15th a rehearsal done with 4 phones in an van going all over Seoul, we got an average of 21%, with headroom classification showing 27%, 40%, 90% respectively
- On June 29th a one day round trip over Seoul with 2 vans and 8 phones showed 19% overall improvement. Classifying the initial data rates to high, mid and low (<76.8kpbs, <56kpbs, <38.4kbps) 26%, 37%, 71% respectively

The case of unequal antenna gain

Some OEMs are still debating what kind of secondary antenna can they afford sticking into the handset's form factor
The following is an estimated impact on the MTD performance where the secondary antenna gain is reduced in the range of 0 – 4 dB below the gain of the primary one

Secondary ant. Gain vs. Primary dB	0	-1	-2	-3	-4
Diversity Gain Cell Band dB	4.2	3.6	3.1	2.6	2.2
Diversity Gain PCS dB	3.0	2.5	2.1	1.6	1.2

Secondary ant. Gain vs. Primary dB	0	-1	-2	-3	-4
Capacity Gain Cell Band %	45	41	37	33	29
Capacity Gain PCS %	36	32	28	22	17

Secondary ant. Gain vs. Primary dB	0	-1	-2	-3	-4
Data rate Gain Cell Band %	38	36	35	32	28
Data rate Gain CPCS %	35	31	27	19	15

Summary

Magnolia's Mobile Transmit Diversity provides operators with network improvements:

- Mobile power required is between 3-4 dB lower than a conventional handset
- Coverage is improved by a factor of some 40% in line of sight, and an equivalent increase in indoors availability
- Network capacity is enhanced by about 40%
- Data rates are doubled at the cell edge, and enhanced by 20% inside the cell
- User satisfaction is increased by reduced drop call rate