

# Performance of a UMTS Uplink MIMO Scheme

Esa Tirola and Juha Ylitalo

Nokia Networks  
P.O. Box 319, FIN-90651  
Oulu, FINLAND  
esa.tirola@nokia.com

**Abstract**— In this study uplink (UL) performance was studied in the 3<sup>rd</sup> generation UMTS (Universal Mobile Telecommunications System) system assuming different SIMO/MIMO (Single/Multiple Input Multiple Output) approaches. Link simulations and theoretical analysis were used to investigate the uplink capacity and coverage of the considered antenna configurations. Link simulations assumed that the user equipment (UE) has a maximum of two transmit antennas while the base station can employ up to four antennas. The considered MIMO scheme can be classified as diversity MIMO, which means that the UE transmits the same data symbols via two antennas. Results of the performance evaluation demonstrate that receive diversity is a dominant factor in improving uplink capacity and coverage. For example, in terms of isolated cell capacity, a MIMO technique with 2 transmit (Tx) and 2 receive (Rx) antennas performed approximately 50% worse than a traditional approach with 1 Tx and 4 Rx antennas. Results show also that MIMO transmission will provide some benefit (up to 2 dB) for UL coverage and UE battery consumption. However, doubling the number of receiving antennas is still much more efficient than introducing the 2<sup>nd</sup> transmit antenna at the UE. Based on this study the MIMO concept does not seem feasible for improving UMTS uplink performance.

## I. INTRODUCTION

Multimedia messaging is expected to dominate wireless communications in near future, which demands enhanced data throughput for both uplink and downlink directions. It is well acknowledged that improved data rates with good spectral efficiency can be achieved by increasing the number of transmit and receive antennas [1]. This MIMO approach is still in a starting phase in different standardization bodies for radio communications.

As videophones become more and more popular, it is extremely important to reach high spectral efficiency also for the uplink direction. The goal is to achieve reasonably high data rates with limited transmission power of the user equipment. Enhanced uplink performance is crucial for reducing the UE transmission power requirements, especially for high data rate applications. In addition to reduced UE battery consumption, an improved UL performance translates into better coverage area for the high data rate services [2, 3, 4, 5]. On the other hand increasing the uplink capacity and coverage reduces the number of base station sites and the overall cost of the network. Thus the performance

improvement obtained using advanced antenna techniques including MIMO can bring benefit for both the network operator and the end user of a mobile terminal.

High spectral efficiency in uplink can be obtained via multiple antennas combined with link adaptation techniques. In FDD (Frequency-Division Duplex) systems this requires a reference channel in the uplink and a feedback channel in the downlink. Since the feedback rate is limited by the downlink traffic requirements only open loop methods were chosen for the current study. Typically, in code division multiple access systems uplink data transmission can be characterized by the following key factors: limited pilot power, no strict code limitation, and diversity reception at base station.

The paper is organized as follows. Section II introduces the considered transmission/reception schemes and describes the main assumptions for the performance evaluation. Section III illustrates the simulated link performance results for single user scenario. In Section IV the UL capacity results for isolated cell are presented. Section V presents and discusses the UL coverage results and finally, concluding remarks will be given in Section VI.

## II. PERFORMANCE EVALUATION

Fig. 1 illustrates block diagram of the considered SIMO [6] and MIMO transmission schemes. In the MIMO scheme under study the UE transmits the same data streams (both the Dedicated Physical Data Channel, DPDCH and the Dedicated Physical Control Channel, DPCCH) simultaneously via two antennas. In order to separate the two chip streams at the Node B the two transmit antennas use different channelization codes. Thus, the considered MIMO scheme doubles the utilization of the UL channelization codes when compared to the single antenna transmission or STTD [7] (Space Time Transmit Diversity, used in 3GPP downlink) but without the need for STTD encoder/decoder. The link performance of the current MIMO scheme is the same as with the UL STTD since both schemes represent two-way transmit diversity.

The considered base station receiver performs MRC (Maximal Ratio Combining) over signal multipath components, antennas, and Tx-diversity branches (standard Rake receiver). Doubling the number of transmit/receive antennas will double the base band complexity of the considered base station receiver.

Five different antenna configurations are considered in the link simulations: 1x1 (one transmit antenna, one receive antenna), 1x2, 2x2, 1x4 and 2x4, respectively. In all the cases both transmit and receive antennas are assumed to be uncorrelated. Furthermore, the Branch Power Ratio (BPR) of the multi element array was assumed to be zero dB [8]. Table I illustrates the temporal properties of the considered radio channel models.

The link performance of different antenna configurations is evaluated by means of Monte-Carlo simulations. The main simulation parameters and assumptions are shown in Table II. Full 3GPP (3rd Generation Partnership Project) link level modeling was used with inner and outer loop power control and realistic channel and interference estimation algorithms. Circuit-switched 64 kb/s data service specified in 3GPP conformance tests [9] was used in the link simulations. The service related parameters are summarized in Table III.

When studying the UL performance of different transmission schemes, the UL load factor, denoted as  $\eta$  plays an important role. The UL load factor is calculated as [2]

$$\eta = (1 + i) \cdot \sum_{j=1}^J \frac{1}{1 + \frac{1}{(E_c / N_0)_j}}, \quad (1)$$

where  $i$  is the ratio of other cell to own cell interference,  $J$  is the number of users and  $E_c / N_0$  is the chip energy per total noise power density.  $E_c / N_0$  is calculated from the simulated Rx  $E_b / N_0$  as

$$(E_c / N_0)_j = \frac{\text{user bit rate}}{\text{chip rate}} \cdot (R_x E_b / N_0). \quad (2)$$

Setting  $i = 0$  in (1) gives the load factor in an isolated cell, in which case the amount of other cell interference is zero. Noise rise is used as a final performance criterion for different transmission schemes. It is calculated from the UL load factor as

$$\text{Noise\_rise} = 10 * \log_{10} \left( \frac{1}{1 - \eta} \right). \quad (3)$$

Equations (1) and (2) can be used to calculate the noise rise based on the simulated single user Rx  $E_b / N_0$  values. In the performance evaluation we use another approach. As mentioned, we are doing multi user simulations, which give us Rx  $E_b / N_0$  results in case of multiple simultaneous users. We calculate the noise rise in case of  $j$  users as

$$\text{Noise\_rise}(j) = R_x \frac{E_b}{N_0}(j) - R_x \frac{E_b}{N_0}(1) + \text{Noise\_rise}(1), \quad (4)$$

where  $R_x E_b / N_0(j)$  (dB) is the simulated average Rx  $E_b / N_0$  value (dB) obtained from the multi-user simulation having  $j$  simultaneous users and  $\text{Noise\_rise}(1)$  (dB) corresponds the noise rise caused by a single user and it is calculated using (3) and (4).

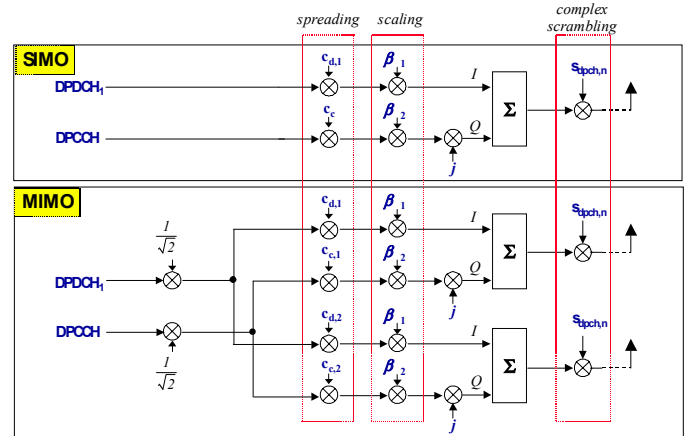


Figure 1. Block diagram of the considered transmission schemes.

TABLE I.  
CHANNEL MODELS USED IN PERFORMANCE SIMULATIONS

| Channel model                       | Relative path powers [dB]     | UE velocity [km/h] |
|-------------------------------------|-------------------------------|--------------------|
| Flat fading (1-path)                | 0                             | 3, 50              |
| modified ITU Pedestrian A (2-paths) | 0 -12.7                       | 3                  |
| modified ITU Vehicular A (6-paths)  | 0 -1.9 -7.3 -10.4 -10.9 -17.3 | 50                 |

TABLE II.  
SIMULATION PARAMETERS

|                                          |                                                                |
|------------------------------------------|----------------------------------------------------------------|
| Carrier frequency                        | 1940 MHz                                                       |
| Chip rate                                | 3.840 Mcps                                                     |
| Sampling rate                            | 1 sample/chip                                                  |
| Power control                            | ON, both inner and outer loops                                 |
| BLER target                              | 10%                                                            |
| Rake finger allocation                   | Known delays                                                   |
| Maximum number of allocated Rake fingers | 2 Rx ant.: 4·2·(# of Tx ant.)<br>4 Rx ant.: 2·4·(# of Tx ant.) |
| Channel estimation                       | Estimated from DPCCCH                                          |
| Signal-to-interference est.              | Estimated from DPCCCH                                          |

TABLE III.  
SERVICE RELATED PARAMETERS

|                                                                                                  |                                       |
|--------------------------------------------------------------------------------------------------|---------------------------------------|
| Data rate DTCH/DCCH (Dedicated Traffic Channel / Dedicated Control channel)                      | 64 / 2.4 kb/s (circuit switched data) |
| Rate matching (DTCH)                                                                             | 16% repetition                        |
| Channel coding                                                                                   | Turbo 1/3                             |
| Interleaving                                                                                     | 10 ms                                 |
| Number of DPDCHs                                                                                 | 1                                     |
| Spreading factor DPCCCH/DPDCH                                                                    | 256 / 16                              |
| Number of dedicated pilot / power control / transport format combination indicator (bits / slot) | 6 / 2 / 2                             |
| Power ratio of DPCCCH/DPDCH                                                                      | -5.46 dB                              |

### III. LINK PERFORMANCE

This section presents the link performance of different antenna configurations in a single user scenario in which the intra-cell interference is modeled as AWGN (Additive White Gaussian Noise). The measure for comparison is the average receive/transmit (Rx/Tx)  $E_b/N_0$  (bit energy / total noise power density) that is required to obtain the desired Quality of Service (QoS) (10% block error rate). Average Rx  $E_b/N_0$  per receiving antenna reflects to the amount of intra-cell interference that the other users experience from the given UE. Thus it is a measure of uplink capacity, i.e., the maximum number of users that can be supported by a single cell. Required Tx  $E_b/N_0$  illustrates the average transmit power of the given UE and it corresponds to the amount of interference that the given UE generates to the other cells. Tx  $E_b/N_0$  can be used as a performance measure also when comparing the UL coverage of different antenna configurations.

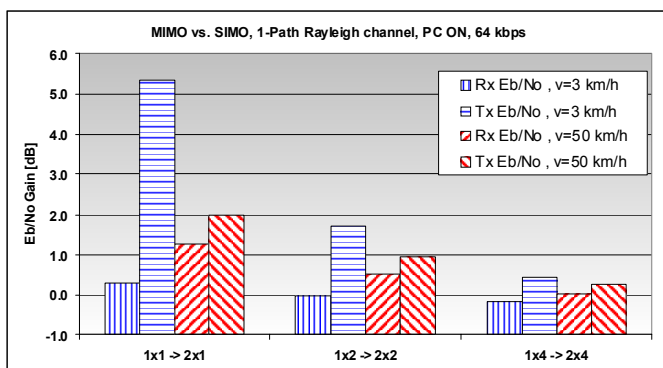


Figure 2. Transmit diversity gain with different number of receive antennas, flat fading channel. ( $v=3, 50$  km/h).

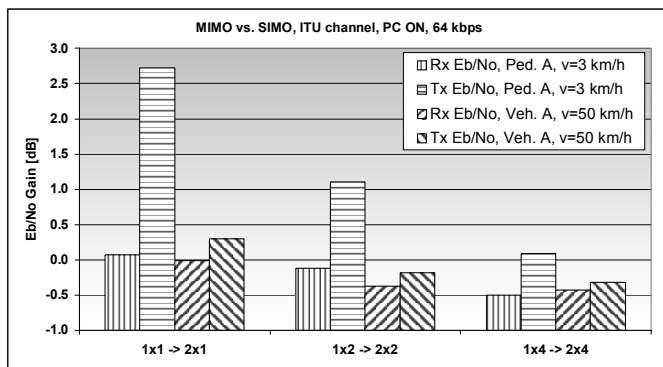


Figure 3. Transmit diversity gain with different number of receive antennas, mod. ITU Ped. A ( $v=3$  km/h) and mod. ITU Veh A ( $v=50$  km/h) channels.

Fig. 2 shows the uplink performance gain of the chosen MIMO scheme in a flat fading channel with 1, 2 and 4 receive antennas. In power controlled UL the gain is seen as reduced average transmit power of the mobile terminal rather than in the received Rx  $E_b/N_0$  level. Results show that in all cases the gain of the 2<sup>nd</sup> transmit antenna decreases quite rapidly as the number of receiving antennas increases. Increasing the speed of mobile from 3 km/h to 50 km/h has the same effect: high degree of diversity is already available in the system (through the channel coding and interleaving). Thus, the additional antenna diversity gain is smaller. Fig. 3 illustrates the same results in modified ITU Pedestrian A and Vehicular A radio

channels. It can be seen from Fig. 3 that the additional antenna diversity gain is getting smaller when the amount of multipath diversity is increased. In a typical uplink case with Rx diversity the gain at the transmitter side is about 1 dB (mod ITU Ped. A channel,  $v=3$  km/h). Introducing MIMO in multipath channels leads to some loss in Rx  $E_b/N_0$  performance ( $1x2 \Rightarrow 2x2$ ). 2x4 MIMO performs about 0.5 dB worse than receive diversity with 4 antennas (1x4 case). Main reason for the above results is that errors in channel estimation increase with increased number of diversity branches. Since the uplink capacity is directly proportional to the required Rx  $E_b/N_0$  per antenna, it is evident that receive diversity with 4 antennas is a good choice for optimizing user data throughput in uplink.

### IV. ISOLATED CELL CAPACITY

Isolated cell capacity was studied by means of a multi-user simulation in which the intra-cell interference is being modeled as actual multiple-access interference. In the simulations each user meets the defined QoS target (10% BLER) by having both inner and outer loop power control loops running. It should be noted that capacity evaluation is valid only in the isolated cell environment since the system level issues such as soft handover and inter-cell interference are not taken into account.

Fig. 4 presents the simulated noise rise curves for the considered SIMO and MIMO transmission schemes. The presented noise rise is given as a function of number of 64 kb/s users in an isolated cell. The noise rise of 3.0 dB corresponds to a 50% load factor, and the noise rise of 6.0 dB to a 75% load factor. We can notice from Fig. 4a) that the usage of the 2<sup>nd</sup> transmit antenna does not increase the isolated cell capacity in a one path Rayleigh channel ( $v=3$  km/h). UL power control (PC) translates into an additional diversity gain provided by the MIMO transmission. However, this gain is visible only at the transmit (UE) side. For that reason the Rx  $E_b/N_0$  requirement is not improved using MIMO and thereby the isolated cell capacity is approximately the same as in the SIMO case. Doubling the number of receiving antennas will double the isolated cell capacity in both SIMO and MIMO cases.

Fig. 4b) illustrates again one-path Rayleigh channel, but now the speed of mobile is 50 km/h. This is the only simulated case in which the usage of the 2<sup>nd</sup> transmit antenna provides some capacity gain in an isolated cell (about 10% with 2 receive antennas). The explanation for that is the non-ideal behavior of the power control. UE speed of 50 km/h is relatively high velocity from the PC point of view and it cannot fully compensate the fast fading. Since the MIMO has smaller variance in the received power than SIMO (due to the higher number of diversity branches) the “slowness” of the PC loop does not impact as much in the MIMO case.

Fig. 4c) represents the simulated noise rise in the modified ITU Pedestrian A channels ( $v=3$  km/h). We can notice that the usage of the 2<sup>nd</sup> transmit antenna will actually degrade the isolated cell capacity especially in case of 4 receiving antennas. The reason for that is that the estimation errors (combining losses) are larger in the MIMO case since the DPCH must be transmitted via both antennas (pilot power per antenna is 3 dB smaller than in SIMO case). Performance degradation caused by the 2<sup>nd</sup> transmit antenna increases as, number of multipath

components in the radio channel increases. The degradation is due to the fact that the SNR (signal-to-noise ratio) per Rake finger decreases as the number of multi-path components increases. This is seen in Fig. 4d) which represents noise rise curves in the modified Vehicular A channel ( $v=50$  km/h). We can notice that the isolated cell capacity of the SIMO case is almost 10% better than that of the MIMO case. Estimation errors increase also as the number of Tx/Rx antennas and/or the speed of mobile increase. In addition, the considered service has also an impact on the estimation errors: for the high data rate the power of the dedicated pilot channel can be increased without significant increase of the pilot overhead and the estimation errors will be accordingly smaller.

As a summary, it can be said that the doubling of the number of receiving antennas will almost double the isolated cell capacity, whereas the increase of the number of transmit antennas will mostly have negative impact on the isolated cell capacity. Moreover, the capacity gain from doubling the Rx antenna count from two to four may be even slightly pessimistic in the Vehicular A channel (Fig. 4d) since eight Rake fingers per transmit antenna were allocated in all cases. Accordingly, the 4-antenna receivers exploit only a half of the multipath components employed by the 2-antenna receivers (see Table II). Thus the 4-antenna receiver does not exploit all the signal energy that could be used.

## V. UPLINK COVERAGE

Coverage calculation is based on the average transmitted  $E_b/N_0$  (dB) values. Fig. 5a) presents the relative coverage gain of three different antenna configurations (2x2, 1x4 and 2x4) in a single user scenario. The reference case is the 1x2 case. We can notice in Fig. 5a) that the 2x2 MIMO case can support up to 2 dB higher path loss than the SIMO scheme with 2 receiving antennas. The coverage gain of MIMO decreases as the degree of time, multipath and/or Rx diversity in the radio channel increases. The gain can be also negative (mod. ITU Vehicular A channel,  $v=50$  km/h) when the additional estimation errors are larger than the additional diversity gain provided by the 2<sup>nd</sup> transmit antenna. One finding is also the fact that for the same degree of diversity the 1x4 antenna constellation is 3 dB better than the 2x2 constellation.

Figs. 5b) and 5c) illustrate examples of coverage evaluation in the modified Pedestrian A channel with the UE speed of 3 km/h. Fig. 5b) compares the 2x2 configuration to the 1x2 case and Fig. 5c) the 1x4 constellation to the 1x2 case. We can notice that in the 1x4 case the coverage gain increases with the increasing UL load. The total coverage gain is obtained by taking both reduced Tx  $E_b/N_0$  and reduced noise rise into account. This means that e.g., having 30 simultaneous 64 kb/s users in the sector of interest the 2x2 case provides 1.3 dB better coverage compared to 1x2 case whereas the 1x4 case can provide as large gain as 6.6 dB (2.3 dB + 4.3 dB). Table IV gives the total coverage gain figures for the considered SIMO and MIMO approaches in the mod. ITU Pedestrian A channel ( $v=3$  km/h).

As a conclusion from the uplink coverage studies it can be stated that increasing the number of receive antennas is more

feasible than employing the MIMO concept. The coverage improvement of 4 Rx antennas over 2 Rx antennas is significant. Those operators, which do not have existing base station infrastructure can exploit this gain effectively since fewer base station sites are needed for the initial network roll-out. Moreover, as the data services get more popular this gain can be also realized as improved coverage for medium or high data rates.

TABLE IV.  
COVERAGE GAIN IN MOD ITU PEDESTRIAN A CHANNEL ( $v=3$  km/h)

|     | Relative coverage gain vs. 1x2 configuration (dB) |          |          |          |
|-----|---------------------------------------------------|----------|----------|----------|
|     | 1 user                                            | 10 users | 20 users | 30 users |
| 2x2 | 1.3                                               | 1.3      | 1.3      | 1.3      |
| 1x4 | 4.3                                               | 4.8      | 5.5      | 6.6      |

## VI. CONCLUSIONS

The results showed that transmit diversity in UL does not increase the isolated cell capacity. The reason for that is that additional diversity does not decrease the average received  $E_b/N_0$  value in the power controlled system. MIMO transmission will provide some gain (up to 2 dB) for UL coverage and UE battery consumption. Doubling the number of receiving antennas is much more effective than introducing the 2<sup>nd</sup> transmit antenna. The 4-antenna receive diversity approach can almost double the isolated cell capacity compared to the 2-antenna receiver and provide 3-6 dB better coverage than the 2x2 MIMO case. The coverage gain depends strongly on the UL load.

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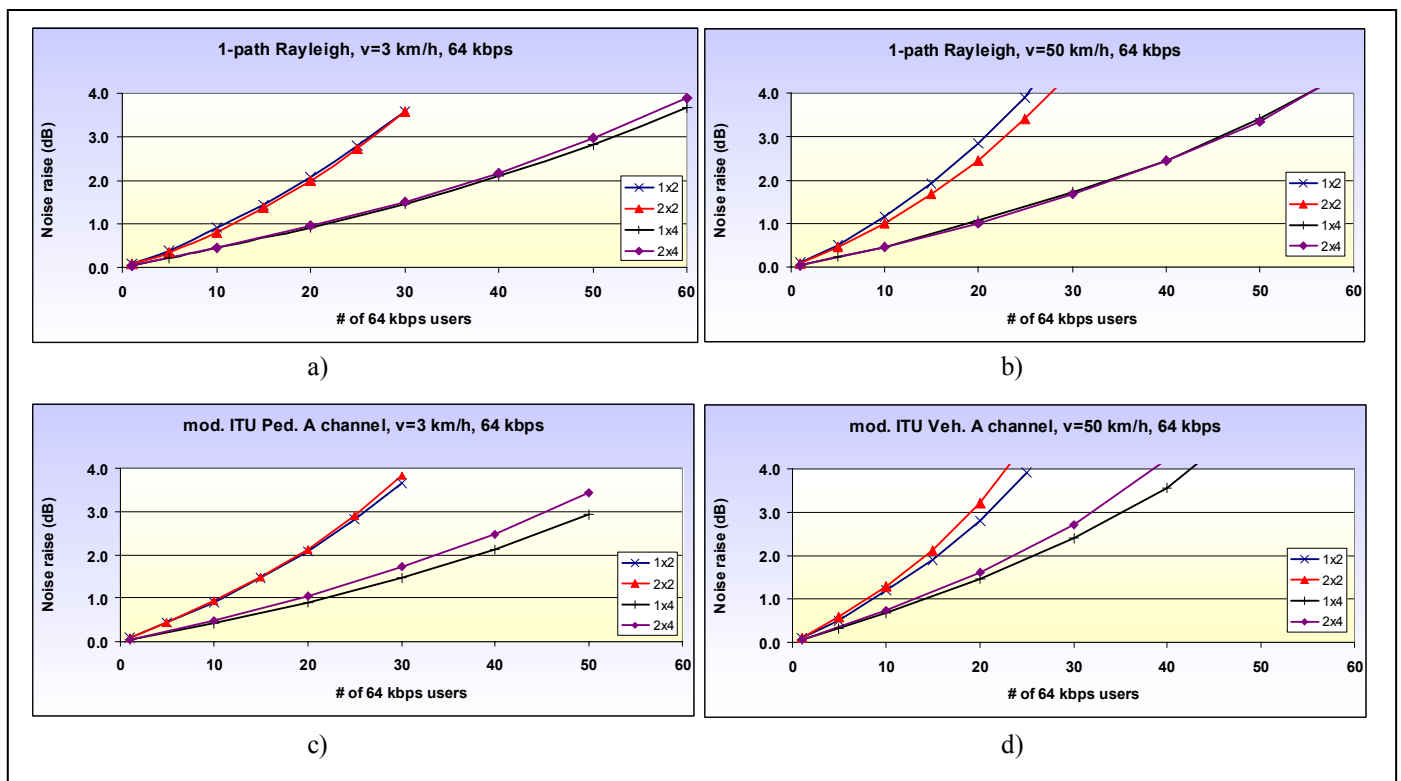


Figure 4. UL noise rise, SIMO and MIMO, 64 kb/s.

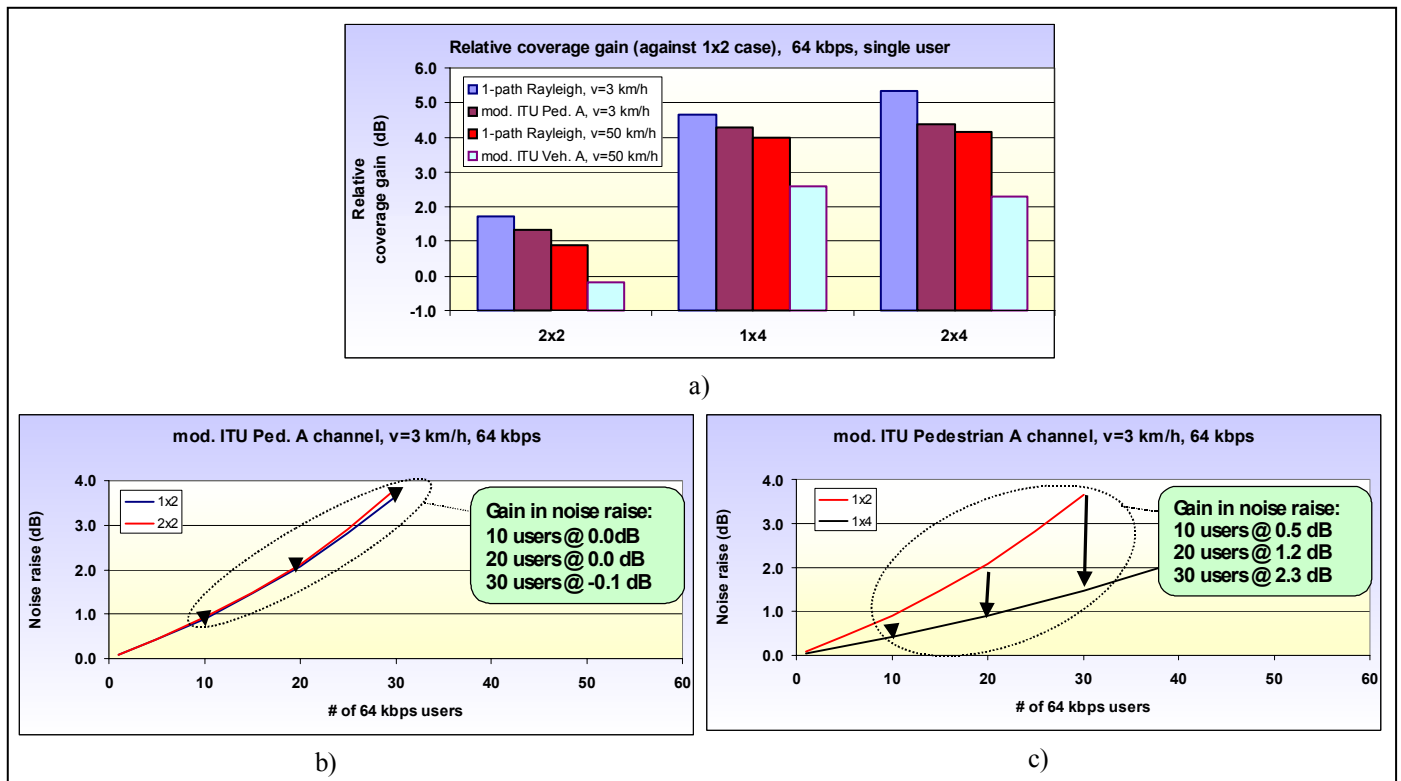


Figure 5. UL coverage, SIMO and MIMO, 64 kb/s.