System Level Performance Comparison of MIMO and SISO Hiperlan/2 Networks

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ABSTRACT

In this paper the system level performance of a Hiperlan/2 network enhanced through MIMO techniques is investigated and compared to the performance of the conventional Single-Input- Single-Output (SISO) network. The MIMO scheme applied is closed loop power allocation based on Singular Value Decomposition (SVD). The work has been partly performed within the frame of IST-FITNESS project [1]. The above investigations are carried out by means of a software based simulation platform and for a number of test cases taking into account specific space-time algorithms, antenna configurations, propagation environment, traffic load, mobility and user requirements.

The performance evaluation is achieved by monitoring the system throughput and the percentage of satisfied users. Extensive simulations have been carried out that prove the superiority of MIMO techniques especially for heavy traffic load conditions.

1. INTRODUCTION

In the forth coming years, Wireless Local Area Networks are expected to grow their use in hot-spots (i.e. airports, conference rooms etc.) where high capacity is necessary to serve a large number of demanding data users. On the other hand, space-time processing incorporating Multiple-Input-Multiple-Output (MIMO) techniques have become a hot topic of research as they have been proved to offer extremely high amounts of capacity at the link level. Nevertheless, the application of these techniques at the link level may not translate to equivalent gains at the system level where multiple base stations communicate with multiple users. Hence, system level evaluation is crucial for the realistic validation of the benefits brought by such techniques.

At this point it is emphasized that the evaluation of MIMO techniques through system level simulations introduces a number of challenges, such as the requirement for suitable spatio-temporal channel modeling, the development of a suitable link-to-system level interface and the optimization of the trade-off between simulation complexity and accuracy.

The structure of the paper is as follows: First, the system level assumptions are described in Section 2. Then, in Section 3 the closed loop power allocation MIMO techniques based on SVD performed at the link level are briefly explained. The link-to-system interface is presented in Section 4. In section 5 the simulation process is described. In Section 6 simulation results and the validation of the benefits of the MIMO techniques versus the single antenna ones are illustrated.

2. SYSTEM LEVEL ASSUMPTIONS

The basic assumptions for the implementation of the Hiperlan/2 system level simulator [2] are as follows:

Cell deployment: Two deployments are considered to capture indoor and outdoor propagation characteristics. Specifically, the following two deployments have been implemented:

- An indoor deployment that represents an airport as a hotspot.
- An outdoor deployment that represents a city center as a hotspot.

Both deployments consist of 16 omni-directional Access Points placed in square cells. Figure 1, illustrates the case where four frequencies are employed and thus, each of them is re-used in 4 cells. For each AP (e.g. 11) three co-channel interferers exist (APs 1, 3 and 9).

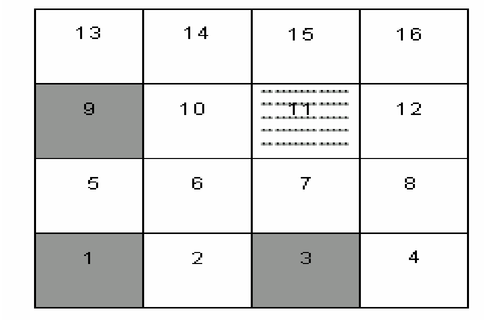

Figure 1: The HIPERLAN/2 deployment

Propagation issues: Suitable propagation models have been adopted according to the specified deployments and scenarios. The following two propagation models have been implemented for the indoor and outdoor deployments respectively:

- Indoor (airport) deployment:

The one-slop model for LOS propagation in closed large space areas is implemented. Lognormal fading with standard deviation of 8dB is added to the path loss (PL) to account for shadowing (S) effects:

$$PL=46.7+24\log10 (d) +S \qquad (1)$$

where the distance *d* is measured in meters and the Path Loss (PL) is expressed in dB.

- Outdoor (city center) deployment:

The linear attenuation model is implemented. Lognormal fading (S) with standard deviation of 10dB is included:

$$PL=46.7+20\log10 (d) + a d + S \qquad (2)$$

where the distance *d* is measured in meters and *a* is the attenuation factor, which is found equal to 0.3dB/m in dense urban environments [3]. Path Loss (PL) is expressed in dB.

MIMO Channel modelling: The MIMO channel model incorporated in the Hiperlan/2 simulator is a correlation-based stochastic channel model [4]. According to this model the channel **H** in the case of *M* transmit and *N* receive antennas can be written as follows:

$$\mathbf{H}=\mathbf{H}_W \mathbf{R}_T^{1/2} \qquad (3)$$

where $\mathbf{H}_W$ is an *N*x*M* i.i.d. complex matrix and $\mathbf{R}_T$ is the *M*x*M* transmit antenna correlation matrix.

User mobility: The following mobility model has been applied [5]: At the beginning of a simulation run a user is assigned an initial position, a final position and speed. The starting and end points coordinates are chosen independently and randomly according to a Uniform distribution over the whole simulation area. Thus the direction of the user is uniquely determined by the start and end points. It is considered that users speed is kept constant during a simulation run. Moreover, the velocity is fixed at 1 m/s in the case of outdoor deployment (walking speed mobility) and 0.5 m/s in the case of indoor deployment (limited mobility).

Services: Two types of data services are simulated in the downlink only:

- Web browsing with minimum average transmission rate 64Kbps
- FTP with transmission rate 384Kbps

The Service Activity Factor is set to 0.2 for the Web users and 0.8 for the FTP users.

Packet Scheduler: Packet scheduling is performed by every access point. The users are rank ordered according to their instantaneous capacity C-metric. (This is the metric used to interface the link to system performance and is further described in Section 4). Every user has one source queue where data are generated according to the user service rate. The scheduling is performed on a frame-by-frame basis and the user with top C-metric is served first. Before the scheduling process, the portion of the MAC frame during which data will be transferred to users, is generated for each user, depending on the service bit rate, the physical bit rate and the frame error rate. The scheduler continues to transfer data for all the reserved users, following the highest C-metric priority scheme, until the MAC frame downlink time resources are exhausted.

3. CLOSED LOOP POWER ALLOCATION ALGORITHMS BASED ON SVD

Let us consider a MIMO system with *M* transmitting and *N* receiving antennas, as illustrated in Figure 2. The closed-loop scheme processes the information symbols before sending them across the MIMO channel. As the transmitter has information on the CSI (Channel State Information), an optimal linear transformation, denoted with matrix **F**, can be applied in order to match the signal to the propagation channel. The transformation can be understood as an encoder that maps *n* symbols onto the *M* transmitting antennas. Similarly, at the output of the MIMO channel, the received symbols are processed by a second linear transformation, designed as **G** matrix, which has been jointly designed with the transmitter in accordance with specific criteria.

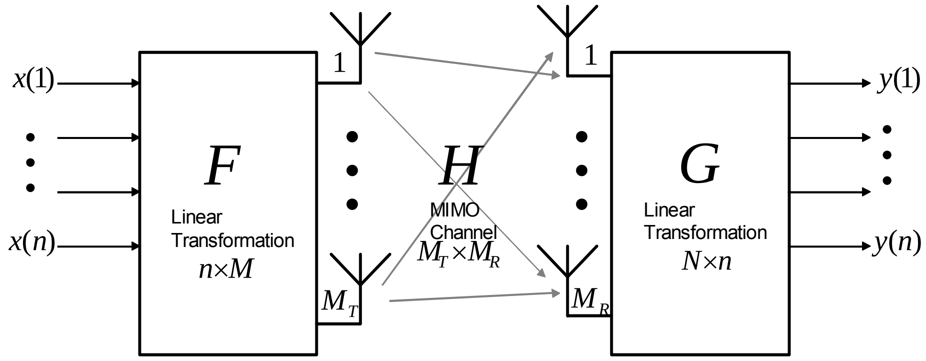

Figure 2: Closed loop scheme for MIMO Channels

Let $x^T = [x(1)^T \quad x(2)^T \quad \cdots \quad x(n)^T]$ be the nx1 vector that simultaneously stacks and transmits n information symbols. The information symbols are assumed to be i.i.d, with zero mean and unit variance. If the fading channel is not frequency selective, the MIMO propagation channel can be modelled as a MxN matrix **H** and the system model can be written as:

$$\mathbf{y} = \mathbf{GHFx} + \mathbf{Gn} \qquad (4)$$

The elements in channel matrix **H** are the complex path gains between transmitter and receiver, and can be modelled as i.i.d. complex Gaussian variables with zero mean and variance σ^2. Matrix **F** is a linear coding matrix that maps the symbols to be transmitted onto the different antennas achieving power allocation strategies. Similarly, matrix **G** is a linear decoding matrix that combines the signal received at the antennas to accurately recover transmitted vector. Finally **n** is the noise vector modelled as a zero mean complex Gaussian variable.

Optimal values for **F** and **G** matrices are derived under the hypothesis of i.i.d transmitted symbols, constrained transmitted power and perfect CSI knowledge at the transmitter and receiver sides by means of the singular value decomposition (SVD) of the channel matrix **H,** $\mathbf{H} = \mathbf{U\Lambda V}^H$. Those optimal expressions are [6]:

$$\mathbf{F}_{opt} = \mathbf{V\Phi}$$
$$\mathbf{G}_{opt} = \mathbf{\Gamma\Lambda}^{-1}\mathbf{U}^H \qquad (5)$$

where $\mathbf{\Phi}$ and $\mathbf{\Gamma}$ are diagonal matrices allowing different design rules. Different criteria can be found in literature to design those matrices [7].

4. LINK-TO-SYSTEM INTERFACE

Assume a multi-carrier transmission system with K sub-carriers is used that converts the frequency selective fading channel into a set of K flat fading channels. Let $\mathbf{F}_k$ stands for the linear transformation applied at the transmitter to allocate power over the different channel modes of the k-th OFDM sub-carrier. Let also $\mathbf{H}_k$, $\mathbf{R}_k$ stand for the MIMO channel response at the k-th sub-carrier and the correlation matrix of the Gaussian coloured noise at the receiver, so the received signal at the k-th sub-carrier is written as:

$$\boldsymbol{y_k} = \boldsymbol{H_k}\,\boldsymbol{F_k}\boldsymbol{c_k} + \boldsymbol{v_k} \qquad k=1,\ldots,K$$
$$\mathbf{R}_k = \mathrm{E}\{\boldsymbol{v_k}\,\boldsymbol{v_k}^{\boldsymbol{H}}\} \qquad k=1,\ldots,K \qquad (6)$$

Then, the channel capacity to the multi-carrier transmission is given by

$$C = \frac{1}{K}\sum_{k=1}^{K}\log\left(\det\left(\mathbf{I} + \left(\mathbf{F}_k^H\mathbf{H}_k^H\mathbf{R}_k^{-1}\mathbf{H}_k\mathbf{F}_k\right)\right)\right) \quad (7)$$

Substituting in the above formula K = 52, an appropriate C-metric for HIPERLAN/2 is obtained. Suitable link-level pre-computed curves have been generated, via which the MIMO channel capacity is uniquely mapped into a FER value. An optimal second degree polynomial curve that fits in the link level data has been generated for each data rate. Analytic tables that provide the coefficients of the interpolation polynomials are presented in [8].

5. SIMULATION PROCESS

In this section, the simulation loop for the stand-alone simulations is presented. The simulation process is depicted in Figure 3. At the initialisation phase, all parameters that are needed for the whole simulation process are initialised or calculated, such as the cell deployment, the traffic model, the user mobility and the channel model. Some important parameters remain constant within the simulation and are not modified during one trial such as the simulation time, and constant parameters related to the specific simulated networks. The load per AP is one of the most important input parameters. This load is converted into an equivalent number of users for the considered system, in accordance to the service bit rate and the activity factor of this service. Users are uniformly dropped within the system deployment and their assignment in cells is performed according to their average C/I ratio.

In the main simulation loop it is checked whether the position of every user should be updated. In this case the average signal strengths between all considered transmitters and receivers are calculated. Thus, C/I is evaluated for each link and link adaptation mechanisms are activated. Handover algorithms are also executed in this phase.

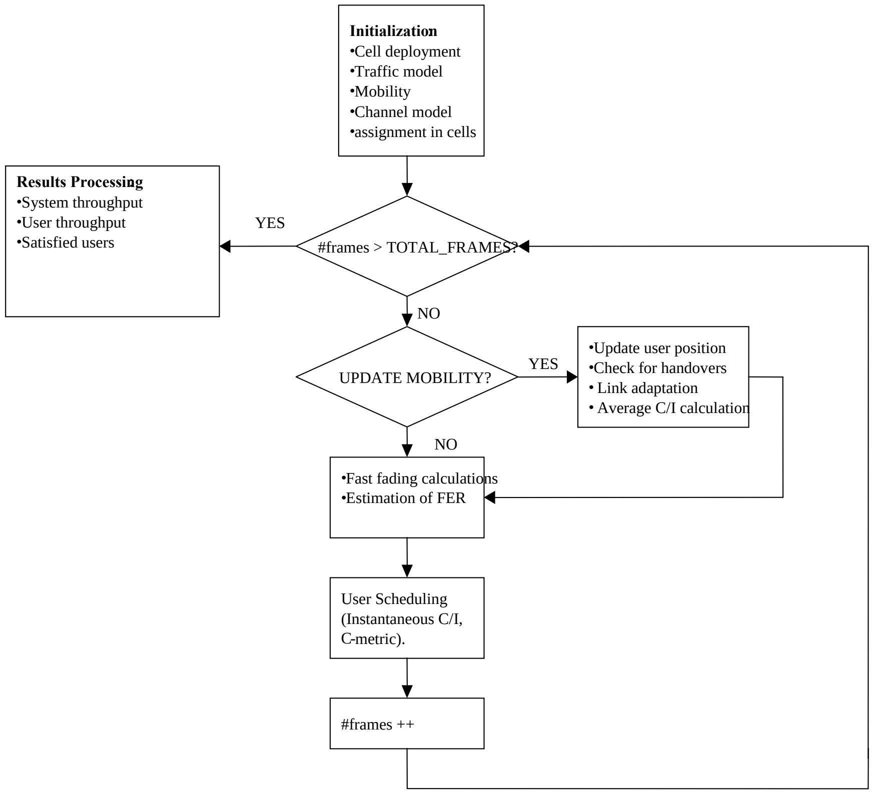

Figure 3: Simulation loop

For every frame, channel matrices are generated for the wanted signals, using the channel models described in previous sections. The appropriate C metric is evaluated and mapped into a FER value, which is also used for scheduling purposes. A C-metric user priority queue is formed and packet scheduling takes place at the end of each frame. At the end of the simulation time, statistical results from the simulated network are gathered and processed.

6. SIMULATION RESULTS

System level simulation results are presented for the SISO and MIMO Hiperlan/2 cases. The system is simulated for 180secs. The performance metrics of interest are the system throughput and the number of satisfied users that is the users with allocated data rate at least 95% of their requested data rate.

The simulation results for SISO HIPERLAN/2 are summarized in Table 1 in terms of the mean throughput and the percentage of satisfied users. Additionally, the percentage of web and FTP users that were allocated rates greater than 40 kbps and 140 kbps respectively, are given to gain a better insight. As expected, the performance of the system is gradually decreasing as the traffic load increases.

Specifically, for 6Mbps the performance of the system is very high for both outdoor and indoor environments achieving a very high percentage of the nominal traffic load and satisfying approximately 79% of the users.

The performance is significantly reduced for 12 and 18 Mbps traffic loads. Nevertheless, more than 50% of the users achieve rates greater than 40 kbps or 140 kbps depending on their service. In these test-cases, it can be seen that the system performs better in an outdoor than in an indoor environment.

Further degradation is observed for 27 Mbps traffic load. Besides the low number of satisfied users, less than 50% of the users achieve rates greater than 40 kbps or 140 kbps depending on their service. The system performance is similar for indoor and outdoor environments and it seems that it reaches its limits in terms of the traffic load that can be served.

In Table 2 we summarize the main system performance metrics for all indoor and outdoor MIMO 2x2 test-cases. Apart from the Mean Throughput we present the Percentage of Satisfied Users. Moreover, apart from the strict 95% criterion we also provide the percentages of FTP and Web users that were allocated more than 140Kbps and 40 Kbps respectively. In the case of 12 and 18 Mbps the mean throughput is higher in the indoor than in the outdoor test cases. For 27 and 36 Mbps the mean throughput is comparable in the indoor and outdoor test cases. As expected, the throughput is near the nominal system load for 12 and 18 Mbps while it is significantly reduced for 27 and 36 Mbps. The percentage of satisfied users is less than 50% for the 36 Mbps test cases, indicating that the system reaches its limits. However, even in this case, nearly 80% of FTP users receive more than 140 Kbps while nearly 70% of Web users receive more than 40 Kbps.

In Figures 4 and 5 the percentage of the satisfied users and the system throughput for traffic loads equal to 12 and 18Mbps are depicted for both SISO and MIMO cases. The superiority of the MIMO techniques compared to the conventional single antenna ones is clearly demonstrated.

Table 1: Mean Throughput and Percentage of Satisfied Users for SISO Test Cases

Test Case	Mean Throughput (Mbps)	Percentage of Satisfied Users	Percentage of FTP Users achieving > 140 Kbps	Percentage of Web Users achieving > 40 Kbps
6 Mbps Indoor	5.74	78.8	100.0	97.0
6 Mbps Outdoor	5.58	78.9	98.0	92.0
12 Mbps Indoor	8.65	44.0	75.0	69.0
12 Mbps Outdoor	9.51	63.4	80.3	75.8
18 Mbps Indoor	10.72	33.5	63.1	54.6
18 Mbps Outdoor	12.05	41.8	72.3	61.5
27 Mbps Indoor	12.40	23.3	48.8	42.7
27 Mbps Outdoor	13.23	24.5	52.3	44.2

Table 2: Mean Throughput and Percentage of Satisfied Users for MIMO 2x2 Test Cases

Test Case	Mean Throughput (Mbps)	Percentage of Satisfied Users	Percentage of FTP Users achieving > 140 Kbps	Percentage of Web Users achieving > 40 Kbps
12 Mbps Indoor	11.99	99.7	100.0	100.0
12 Mbps Outdoor	10.58	73.3	94.3	89.0
18 Mbps Indoor	17.69	90.9	100.0	99.7
18 Mbps Outdoor	15.31	67.2	90.7	80.2
27 Mbps Indoor	23.15	62.8	94.4	88.2
27 Mbps Outdoor	22.75	65.9	88.3	81.4
36 Mbps Indoor	26.12	43.3	78.1	68.2
36 Mbps Outdoor	26.11	47.8	78.1	66.9

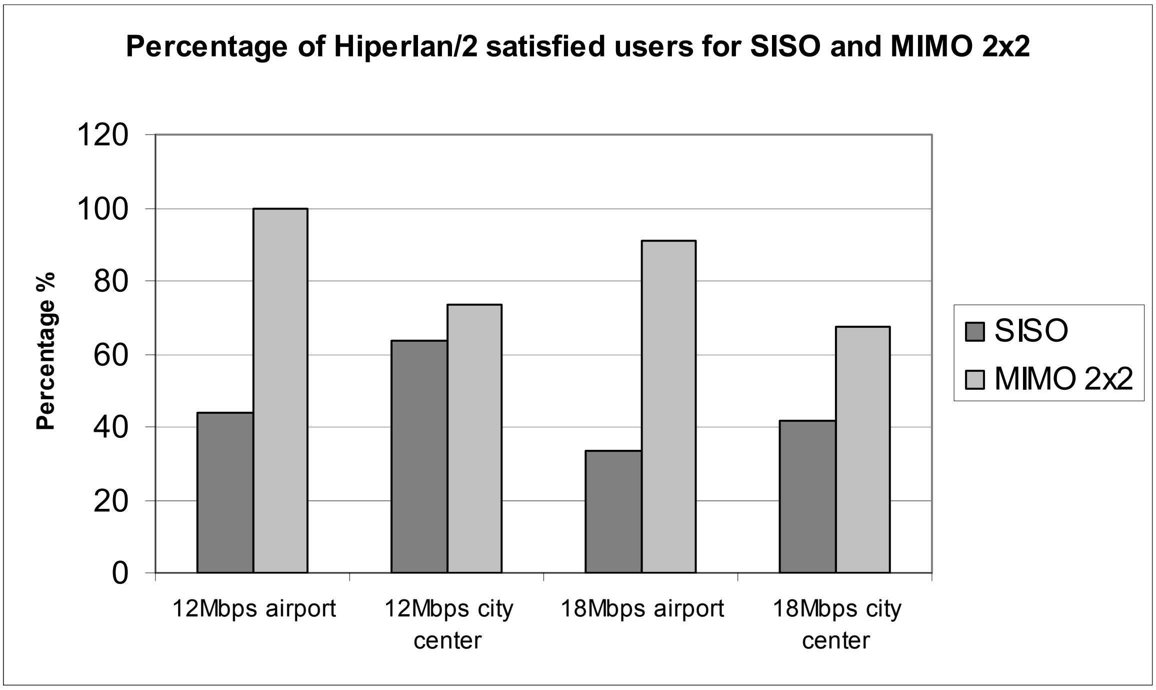

Figure 4: Percentage of Hiperlan/2 satisfied users for SISO and MIMO 2x2

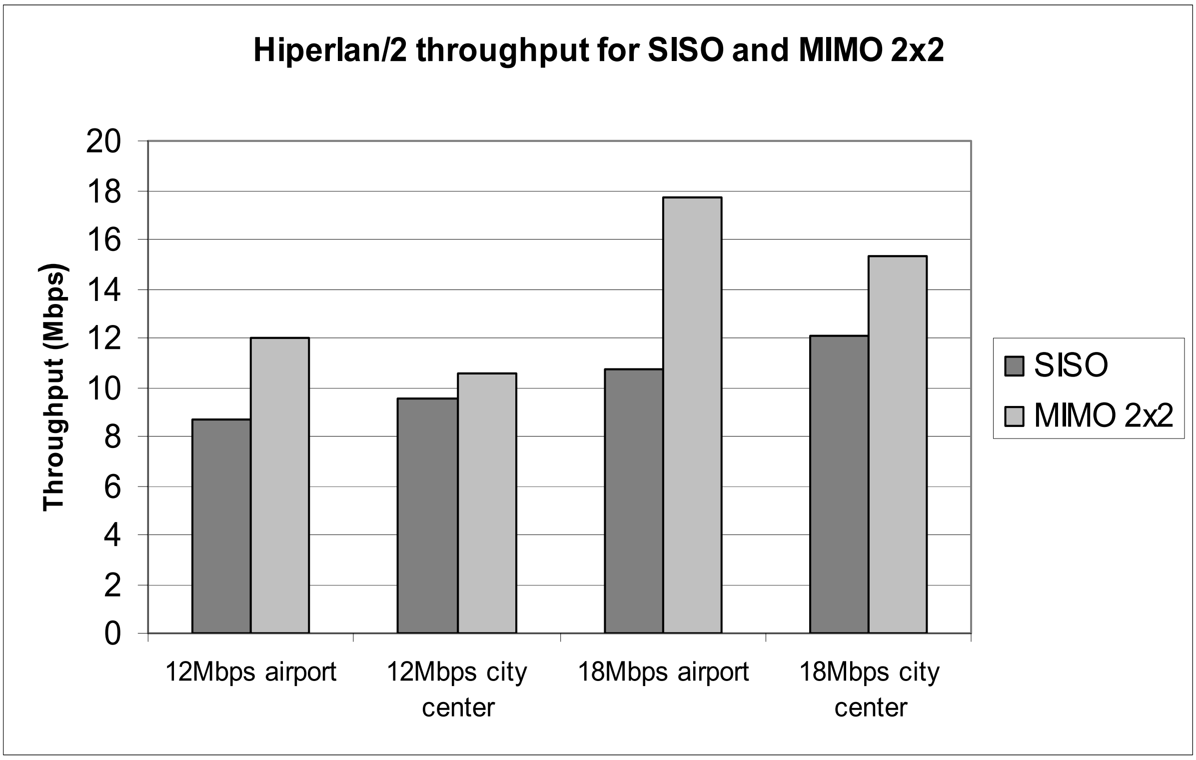

Figure 5: System throughput for SISO and MIMO 2x2

7. CONCLUSIONS

In this paper the system level performance of a Hiperlan/2 network, enhanced with MIMO closed loop power allocation techniques based on SVD has been investigated in comparison to the single antenna network. A suitable link to system interface was applied and the system level performance was measured in terms of average system throughput and number of satisfied users. Web browsing and FTP services were considered in the simulations. Extensive simulations have been carried out that proved the superiority of the MIMO techniques to the conventional single antenna ones.

ACKNOWLEDGEMENT

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