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Performance Enhancement of Cellular OFDM Based Wireless LANs by Exploiting Spatial Diversity Techniques

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***Abstract*—**This paper represents an investigation on how exploiting multiple transmit antennas by OFDM based wireless LAN subscribers can mitigate physical layer error rate. Then by comparing the Wireless LANs that utilize spatial diversity techniques with the conventional ones it will reveal how PHY and TCP throughputs behaviors are ameliorated. In the next step it will assess the same issues based on a cellular context operation which is mainly introduced as an innovated solution that beside a multi cell operation scenario benefits spatio-temporal signaling schemes as well. Presented simulations will shed light on the improved performance of the wide range and high quality wireless LAN services provided by the proposed approach.

***Keywords*—**Multiple Input Multiple Output (MIMO), Orthogonal Frequency Division Multiplexing (OFDM), and Wireless Local Area Network (WLAN).

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I. Introduction

DURING recent years increasing research has been made on modern wireless communication technologies for more efficient utilization of the available frequency spectrum and combating the performance degrading effects of fading channels. Achieved advances are much indebted to promising promotions that spatial diversity techniques assure. The initial studies by Telatar [1] and Foschini [2] , has ignited a variety of works on different aspects of multiple input – multiple output (MIMO) channels which has become one of the most progressive research frontiers. MIMO channels are popularly investigated in the literature due to two noticeable features; increasing the channel capacity linearly with the number of antenna pairs and decreasing the fading effects by providing alternative paths between transmitter and receiver. Among all MIMO channel realizations, its contribution to the OFDM systems performance has received a great deal of attention [3]. This is mainly due to the reality that high data rate achieving characteristic of MIMO systems is the same as the designated orientation of OFDM systems; high data rate broadband communication.

In this paper our studies are based on IEEE 802.11a standard [4] operation which is used to a large extent and its performance is widely known. In IEEE 802.11a Standard all the operation rates are predefined. Therefore we are not concerning about the channel capacity increasing feature of MIMO channels. Instead we are going to deal with IEEE 802.11a throughput issues by taking the advantage of fading combating characteristic of MIMO channels [5].

Contribution - The goal of this paper is to represent a multi-cell operation environment as an extension to the previous works on evaluating the impact of space time block codes on 802.11 network throughput [6]. As the antenna array structure, 2 transmit antennas and 1 receive antenna are recruited and as the signaling scheme, the diversity technique introduced by Alamouti [7] is implemented. To reach the final results on multi cell operation, we will track the following steps:

1. First we simulate the physical layer data transmission and receipt of a single link communication in both conventional and space time coded systems.
2. Then we evaluate and compare the TCP throughput performance of both models.
3. And in the final step we analyze the same concepts in steps 1 and 2 in a cellular context.

II. IEEE 802.11a ARCHITECTURE

The basic component of IEEE 802.11 WLAN is the station which consists of PHY, MAC and the module that connects to the wireless medium. The IEEE 802.11a standard is designed to operate under the IEEE 802.2 Logical Link Control (LLC). The purpose of LLC is to make the layers above independent of the layers below. Thereby, the higher levels are not to be concerned about what type of media is used for the actual data transmission. But it does not mean that the higher levels performance is not affected by lower levels performance. For instance, if the PHY layer bit error rate decreases, it is more likely to have a data packet sent with less retransmissions tries, consequently the time interval that the channel is idle will be increased and there would be less collisions. Decreased number of retransmissions and collisions results in an improved throughput.

III. Introduction To IEEE 802.11n

In the recently released proposals for IEEE 802.11n standard [11,12] which is an improved version of IEEE 802.11a, the throughput gains are expected basically due to applying multiple transmit and receive antennas and extending signaling bandwidth. Some of optional techniques which contribute to throughput enhancement are beamforming and unequal power distribution across the transmit antennas, advanced channel coding with higher rates, 256-QAM modulation scheme, aggregation of multiple MPDUs in one PPDU, new frame exchange rules and receiver assisted channel training.

IV. Models And Assumptions

A. Physical Layer

The model of the physical layer includes measurements of SNIRs and decisions about the possibility of receiving frames. When a new transmission starts the SNIR of the frame is compared to the SNIR threshold in each receiving unit. The highest received field strength is taken as carrier and the sum of the others as interference. A constant noise level is added to the interference.

B. Propagation and Fading

The propagation model used in our simulations is a quietly

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modified Keenan-Motley model [8]. Free space propagation is used as the first 60 meters from the transmitter.

$$L_{KM} = L_{free} + \alpha \max(0, d - d_0) \quad (1)$$

Where $\alpha = 0.3dB/m$ and $d_0 = 60m$ and L_{free} is the free space propagation modeled with path loss

$$L_{free} = 32.4 + 20(\log(f) + \log(d)) \quad (2)$$

Where f is the frequency in GHz, d is is the distance between transmitter and receiver in meters. To this distance dependent propagation model the fading component R is added. R is a fast fading component which is Rayleigh distributed and constant during a frame.

$$L_{Tot} = L_{KM} + R \quad (3)$$

C. MAC Layer

The detailed model of the IEEE 802.11 MAC includes random backoff duration procedure, virtual carrier sense, ACK and ideal link adaptation. RTS/CTS and fragmentation are not considered here. Each station can be in either one of the states; idle, busy, receiving or transmitting. As IEEE 802.11 uses the CSMA/CA protocol, the main task is to decide whether a station hears another. The carrier sense state is updated at each event that changes the interferences profile. For stations that stop sensing a carrier a defer event is scheduled.

D. Cell Planning

As mentioned, the main purpose of this paper is to evaluate IEEE 802.11a in a cellular environment. The major problem in such a case is that if two access points placed too closes to each other utilize the same frequency band will interfere. For resolving this problem such APs should be placed far enough which in turn limits the number of APs in a certain area. As IEEE 802.11a offers 12 different channels, there is possibility to use different frequencies in different APs. Smart frequency reuse enables more APs on a certain area while the distance between the APs which use the same channel is still large enough. More APs give a decreased cell radius which enables higher capacity on each channel due to a better SNIR. On the other hand, the number of channels per AP is reduced. A 12 reuse will only give one channel in each AP while a 3 reuse will give 4 channels each.

In order to minimize interference, the distance between two co channel APs must be maximized. It can be shown that for a hexagonal symmetric cell plan with radius R and distance D between the centers of two identical cells, we have [9]

$$\frac{D}{R} = \sqrt{3K} \quad (4)$$

Where K is an integer of the form: $K = (i + j)^2 - ij$ where i and j are non-negative integers.

An essential part of the CSMA/CA protocol is that all stations in a cell shall be able to hear all other stations in that cell. Therefore a mobile on the edge of the cell must be able to detect transmission on the other side of the cell at a distance of 2R in the other direction which means a neighboring cell. So the cells using the same channel should be placed at least 2R apart to get a complete isolation so:

$$D \geq 4R \Rightarrow K \geq 6 \quad (5)$$

Therefore the allowed values for K to get a completed isolation are 7, 9 and 12.

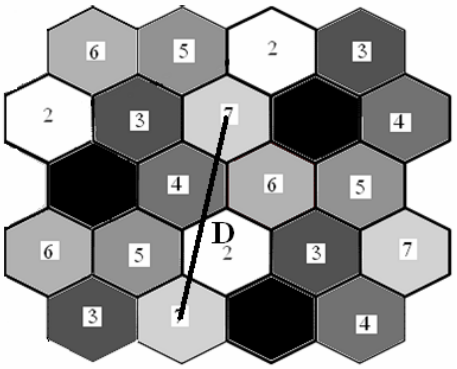


Fig 1. Cell Planning with 7 Reuse Factor. Co-channel cells are of the same color.

E. Simulation Scenario

IEEE 802.11a provides twelve non overlapping channels, which makes a number of reuse patterns possible. In this case, 7 and 12 reuse factors are chosen since 7 reuse factor is the smallest possible to provide isolation and 12 reuse factor is the largest possible.

F. Space Time Coded OFDM System

According to the diversity scheme proposed by Alamouti, two consequent symbols s_1 and s_2 and their complex conjugates are transmitted via two transmit antennas in two progressive time slots as below:

$$\begin{pmatrix} s_1 \\ s_2 \end{pmatrix} \Rightarrow \begin{pmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{pmatrix} \quad (6)$$

where in the first time slot symbols s_1 and s_2 and in the second time slot symbols $-s_2^*$ and s_1^* are transmitted through the first and second antenna consequently. Once we are going to apply Alamouti STBC in OFDM systems, two consequent OFDM symbols are used to construct to desired coded signal [10].

V. Simulation Results

A. Physical Layer Bit Error Rate Improvement

The channel and propagation model described by relation (3) is used throughout our simulations. In this part physical layer bit error rate behavior in conventional systems and space time coded ones are compared. The simulations are performed based on 6 and 12 Mbps data rate modes operation. Figures 2 and 3 compare the performance of a non-cellular operation with two cellular operation schemes; cellular environments with 7 and 12 reuse factors. As simulations show, the non cellular environment has the best performance since there is no interference; the performance of operation environment with 12 reuse factor diverges from that of non-cellular environment only in high SNRs where the effect of interference power is more than the noise power and the operation environment with 7 reuse factor has the worst performance which is due to the existence of strong interference. The simulations are performed for a large

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number of independent channel realizations and their average is shown in the figures below.

B. Physical Layer Throughput

By tracking the transmission and reception of PHY data packets and calculating the ratio of correctly received to the total transmitted packets, the PHY throughput is estimated. The packets are generated randomly and independently with 100 bytes length each which would be reasonable. Here in analyzing the PHY throughput we are not concerning about any kind of FEC[1] or ARQ[2].

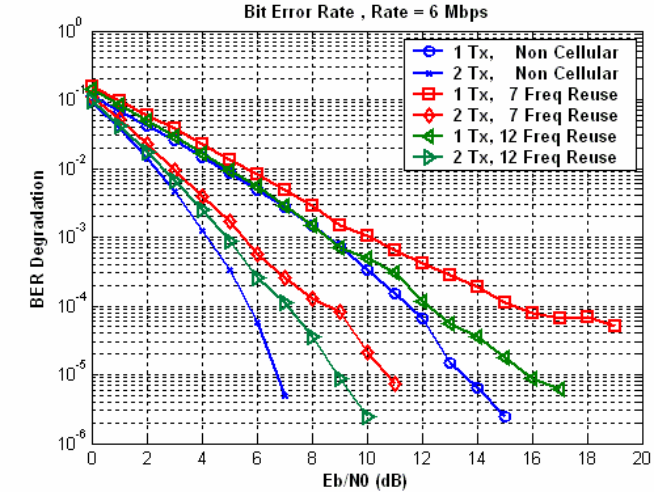


Fig 2. BER Comparison of Conventional and Space Time Coded Systems (Rate = 6 Mbps)

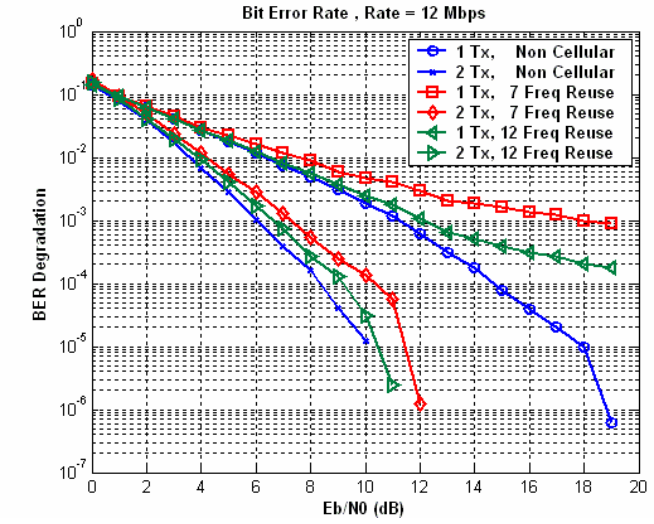


Fig 3. BER Comparison of Conventional and Space Time Coded Systems (Rate = 12 Mbps)

Theoretically we know that the PHY throughput is

$$Throughput = R(1-p_b)^{L_P} \qquad (7)$$

Where R is the data rate, p_b is bit error probability and L_P is packet length. By reviewing figures 4 and 5 it is concluded that in low and high SNIRs STC exhibits low improvements, but in the range of 5dB to 15dB there is a prominent gain which means that if designated for the same throughput, space time coded systems can operate in much more harsh channel conditions than conventional systems. In other words if both systems work in the same environment, space time coded systems will have a much better performance.

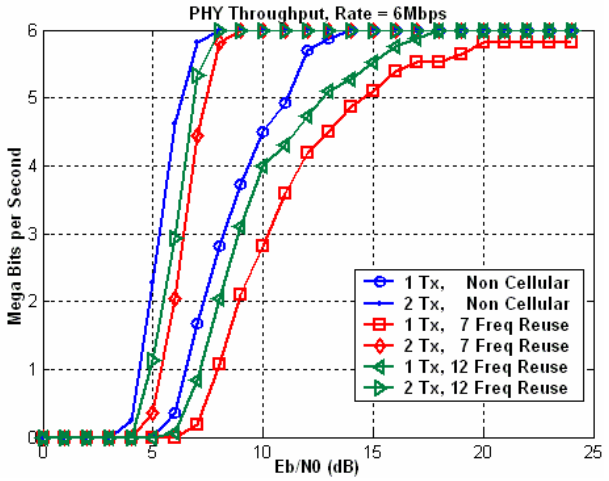


Fig 4. PHY Throughput Comparison, Rate = 6 Mbps

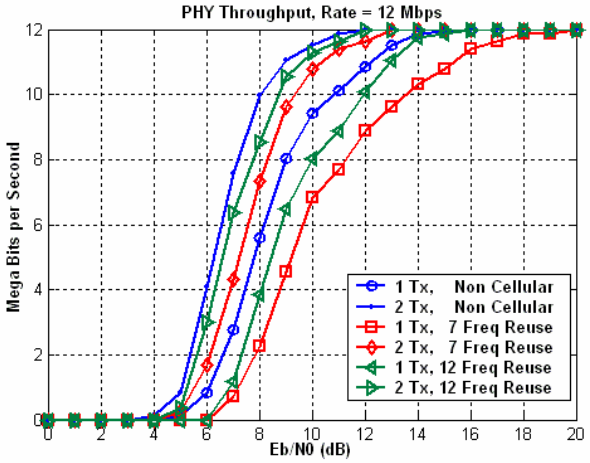


Fig 5. PHY Throughput Comparison, Rate = 12 Mbps

As formerly stated, there are 12 different channels available. So in the plan with 12 reuse factor, each cell is allocated one channel meanwhile in the plan with 7 reuse factor, in average each cell is equipped with 12/7 channel. Considering that the throughputs shown in above figures are per channel, for a fair comparison between two cellular schemes, 12/7 times of 7 reuse factor throughput should be compared with the 12 reused factor plan throughput.

C. Improvement in the Number of MAC ARQs

As the consequent of improvements attained in the physical layer, it is expected to have some gains in the MAC layer throughput as well.

The TCP throughput of such systems directly is dependent to the number of acknowledged packet transmission, number of retransmissions when errors in the reception of packets take place, number of collisions occurrence and the amount of time that the channel is idle. As a determinant parameter in the TCP throughput, having

2 Forward Error Correction
3 Automatic Repeat Request

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the physical layer performance improved, the number of retransmissions and ARQs reduce which leads to a better TCP throughput as indicated in figure 6.

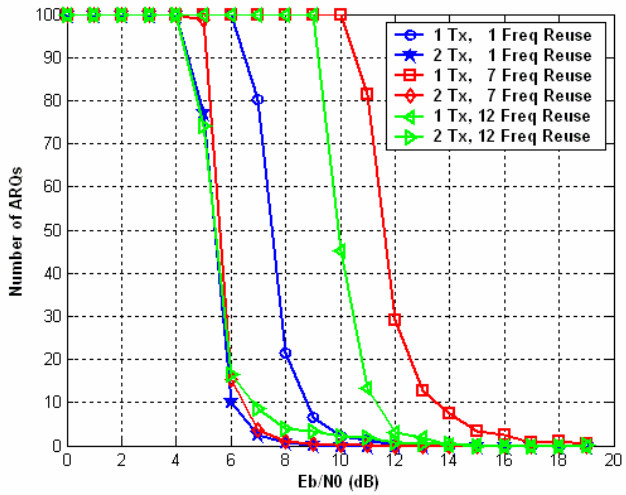


Fig 6. Number of ARQs (Rate = 6 Mbps)

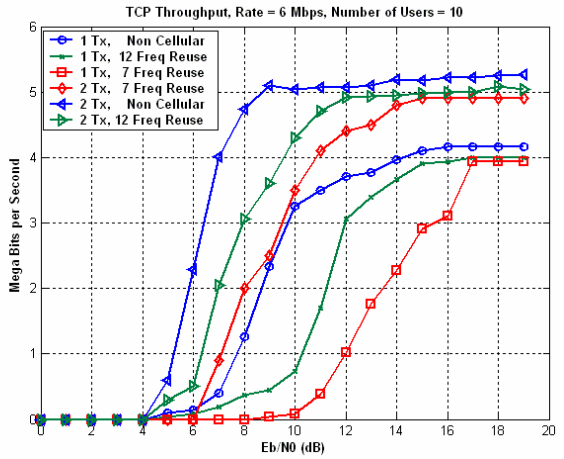


Fig 7. TCP Throughput Comparison.

D. TCP Throughput

In this part of simulations, using the MAC layer simulator we have developed, the transmission and repletion of packets are traced until a certain number of packets are received correctly. Then by taking into account the number of successful transmission, number of retransmission due to errors in the reception of the packet, number of collisions, the amount of time that the channel has been idle, the mount of time that the channel has been waiting for the acknowledges and other time interval considerations mentioned in the standard, we estimate the TCP throughput of the system. Like former sections, the simulations are developed for analyzing non cellular, and two different cellular environments. As described formerly, there are 12 non-overlapping available channels in 802.11a standard. So in the 12 reuse factor plan each cell will have access to one channel and in the 7 reuse factor one, in average each cell has 12/7 channels. Therefore it is beneficiary to use 12 reuse factor plan in the SNIRs that:

$$12\ \text{Throughput} \geq \frac{12}{7} \times (7\ \text{Throughput}) \quad (8)$$

and in other SNIRs 7 reuse factor plan exhibits a better throughput.

VI. Conclusion

In this paper we have assessed the contribution of spatial diversity technique to PHY bit error rate behavior, PHY throughput, number of retransmission conducted by the MAC layer and finally TCP throughput. The proposed cellular approach provides a wide area wireless coverage. As the smallest and largest reuse factors providing complete isolation we evaluated the performance of 7 and 12 reuse factors. For comparing purposes, we have performed all the simulations under 3 different scenarios; an isolated single cell and two cellular structures assuming that the cell containing the users is located in middle, so that for interference evaluation purposes these cells are symmetric in all directions. Throughputs estimated in simulations are per channel where for a fair judgment about the performance of different cellular schemes, we should consider the number of channels allocated to each cell as well. All the simulation results in the figures above show that in all mentioned scenarios, the space time coded systems have a much better performance.

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References

[1] I. E. Telatar " Capacity of Multi Antenna Gaussian Channels" E*uropean Trans. Telecommunicaion*, Vol 10, No. 6, Nov. pp. 585-595 1999.

[2] G. J. Foschini and M. J. Gans " On limits of Wireless Communication in a Fading Environment When Using Multiple Antennas", *Wireless Personal Communication,* Vol. 6, pp. 311-335 1998.

[3] H. Sampath, S. Talwar, J. Tellado, V. Erceg and A. Paulraj, "A Fourth-Generation MIMO-OFDM Broadband Wireless System: Design, Performance, and Field Trial Results" ,*IEEE Communication Magazine, September 2002.*

[4] Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications

[5] V. Tarokh, H. Jafarkhani, and A. R. Calderbank, "Space–time block codes from orthogonal designs," *IEEE Trans. Inform. Theory*, vol. 45, pp. 1456–1467, July 1999.

[6] A. Stamoulis and N. Al-Dhahir, "Impact of Space–Time Block Codes on 802.11 Network Throughput" *IEEE Transaction on Wireless Communications*, VOL. 2, NO. 5, SEPTEMBER 2003

[7] S. M. Alamouti, "A simple transmit diversity technique for Wireless communications," *IEEE J. Select. Areas Commun.*, vol. 16, pp. 1451–1458, Oct. 1998

[8] Keenan and Motley, Radio Coverage in Buildings, *Br. Telecom Techno,*8(1) 1999.

[9] Zander and Kim, Radio Resource Management for Wireless Networks, Artech House Publishers, 1st Edition, 2001

[10] A. Paulraj, R. Nabar and D. Gore, Introduction to Space-Time Wireless Communication, 1st Ed. Cambridge: Cambridge University Press 2003.

[11] TGn Sync Multi-Industry Group Proposal for 802.11n, http://www.tgnsync.org/techdocs.html

[12] WWiSE Technical Proposal for 802.11n, http://www.wwise.org/technicalproposal.htm