A Performance Enhancement for 60 GHz Wireless Indoor Applications

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Abstract-- **This paper studies the throughput and range of the OFDM based IEEE 802.11ad millimeter-wave WPANs. The cross layer results show that the MIMO and beamforming schemes with frame aggregation and block acknowledgement enhance the throughput and operation range compared to the case of single antenna with reasonable hardware complexity.**

I. INTRODUCTION

In recent years, the demands for multi gigabit per second (Gbps) wireless multimedia services such as uncompressed high definition video streaming and data transferring have increased dramatically. In particular, the 60 GHz wireless technology is expected to provide very high data throughput for indoor applications, because it is unlicensed and with a large amount of spectrum available worldwide. The IEEE 802.11ad published a 60 GHz standard in May 2010 [1], and it is built on the existing successful wireless local area network. The proposed data rates range from about 1.4 Gbps to 6.7 Gbps. However, in this paper it is shown that very high SNR is required for high data rate transmission. It is also shown that the maximum operating range is limited, especially in non-light-of-sight (NLOS) scenario.

In order to enhance the system performance, this paper employs space-time block coding (STBC), spatial multiplexing (SM), and three types of beamforming (BF) schemes in the physical layer (PHY). In addition, the medium access control layer (MAC) throughput is calculated for different bit error rates (BERs), packet sizes and acknowledgements (ACKs). The link throughput and operating range results show that a performance enhancement can be achieved for 60 GHz indoor applications.

II. SYSTEM MODELS

We consider a 1-D uniform linear array consisting of M_t and M_r antenna elements at the transmitter and the receiver respectively. In [2] Alamouti proposed a simple transmit diversity scheme to form STBC. The transmit diversity can be easily applied to OFDM in order to achieve a diversity gain over frequency selective fading channels. For a 2×2 STBC architecture, the scheme uses a transmission matrix $[x_1, -x_2^*; x_2, x_1^*]$, where x_1 and x_2 are two consecutive OFDM symbols.

Typically, SM scheme is used to increase the peak data rate by transmitting separate data streams from each antenna [3]. A 2×2 SM system can double the peak data rate. In 60 GHz WPANs, since the highest modulation and coding scheme (MCS) has already reached to about 6.7 Gbps, the data rate is no longer the major concern. We employ multiple antennas to increase the reliability and throughput of lower MCS modes.

In OFDM systems, BF can be carried out by three generic types, namely, subcarrier-wise BF, symbol-wise BF, and hybrid BF [4]. The first type performs BF in the frequency domain and the second type in the time domain. The hybrid BF (Fig. 1), which employs symbol-wise BF at the transmitter and subcarrier-wise BF at the receiver, is a trade off between complexity and performance.

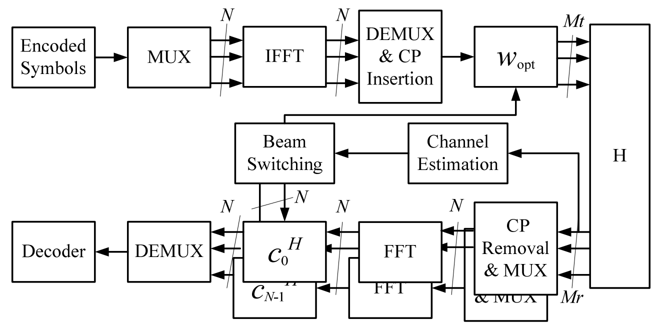

Fig. 1. Block diagram of the hybrid beamforming

III. MAC ENHANCEMENT

In high data rate 60 GHz communication systems, the required packet transmission time decreases dramatically, so that the overheads by a protocol could consume more bandwidth than the payload data frame. Sources of overhead include preamble, header, gap time and ACK frames. The basic immediate ACK scheme (Imm-ACK), which acknowledges each individual frame may introduce too much overhead. In order to achieve high MAC efficiency, frame aggregation and block ACK (Blk-ACK) are considered in this paper. The Blk-ACK groups the ACKs of each subframe in the aggregated frame, and the Blk-NAK [5] only acknowledges the error subframe in the aggregated frame.

IV. SIMULATION RESULTS

In this section, MATLAB simulation results are presented to illustrate the performance of the different MIMO and BF schemes. The key parameters used for the simulation are shown in Table I. The conference room scenario is considered, and the channel model is generated at a carrier frequency of 60 GHz with 2.16 GHz bandwidth. We assume that the average channel correlation across all channel realizations are 0.1 (low), 0.5 (medium) or 0.9 (high) respectively for the NLOS scenario. Fig. 2 shows the PER performance for the single antenna and all MIMO 2×2 schemes for the NLOS case.

The MAC layer throughput for 1KB payload is illustrated in Table II. It can be seen that the MAC throughput with Imm-

ACK is only 6.9%-26% of the maximum data rate, while Blk-ACK improve the efficiency to about 54%-85%.

In order to enable the system to adapt the transmission mode to the link quality, the PHY modes with different MCSs are selected by a link adaptation scheme described by: *Throughput* = *DataRate*×(1-*PER*). Fig. 3 shows the MAC throughput for 1KB packet considering the MAC efficiency. The throughput envelop is the ideal adaptive MCS based on the optimum switching point. By computing the link budget, the operating range can be obtained as shown in Fig. 4.

V. CONCLUSIONS

The paper has presented a performance evaluation of three types of MIMO techniques over the OFDM based 60 GHz WPANs. The results show that the STBC produces the best performance due to its robustness in all channel conditions. The 2×2 SM does not significantly improve the operation range but doubles the peak error-free data rate for the NLOS scenario. All three BF schemes increase the system performance significantly. Hybrid BF shows considerable improvements while maintaining reasonable hardware complexity in NLOS. It is also shown that the enhanced methods with frame aggregation and Blk-ACK increased the MAC throughput 3-8 times compared to Imm-ACK. The cross layer results show that our approach significantly improved the throughput and coverage of the IEEE 802.11ad system. Consequently, the schemes can be widely used to enhance the performance of consumer devices in 60 GHz WPAN systems.

TABLE I.
PARAMETERS FOR OFDM SYSTEMS IN IEEE 802.11AD

Parameter	Value
N_{Sub}: Number of subcarriers	512
N_{SD}: Number of data subcarriers	336
N_{SP}: Number of pilot subcarriers	16
Δ_F: Subcarrier frequency spacing (MHz)	5.156
T_S: Sample duration (ns)	0.38
T_{DFT}: IFFT and FFT period (ns)	194
T_{SYM}: OFDM symbol duration (ns)	242

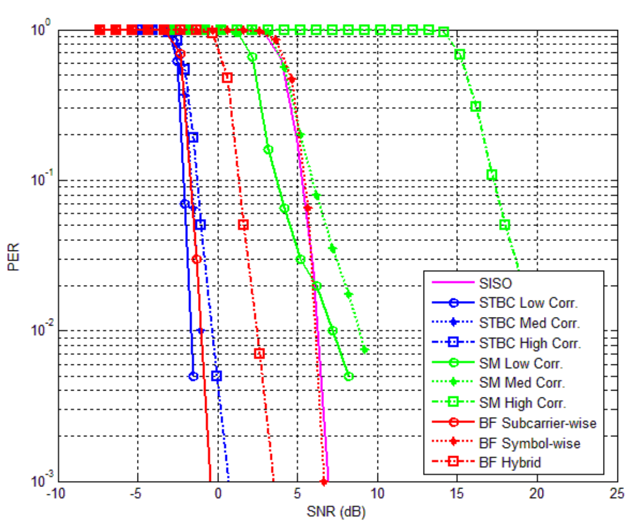

Fig. 2. PER performance comparison of MIMO schemes with NLOS, QPSK 1/2 coding rate

TABLE II. THROUGHPUT WITH 1 KB PACKETS

Mode	Imm-ACK (Mbps)	%	Blk-ACK (Mbps)	%
QPSK 1/2	336.16	26%	1172.31	85%
QPSK 5/8	386.76	22%	1413.51	82%
QPSK 3/4	401.83	19%	1638.21	79%
16-QAM 1/2	422.40	15%	2044.47	74%
16-QAM 5/8	435.79	13%	2401.84	69%
16-QAM 3/4	445.20	11%	2718.66	65%
16-QAM 13/16	448.92	10%	2863.96	64%
64-QAM 5/8	455.02	8.7%	3131.76	60%
64 QAM 3/4	461.81	7.4%	3484.76	56%
64-QAM 13/16	464.48	6.9%	3642.68	54%

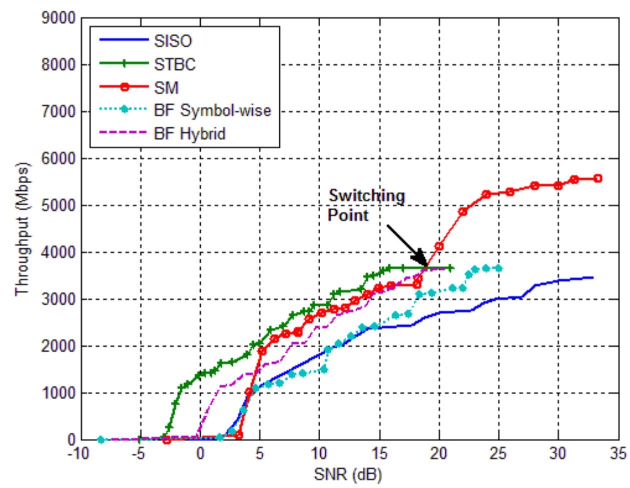

Fig. 3. MAC throughput for 1 KB packet with NLOS

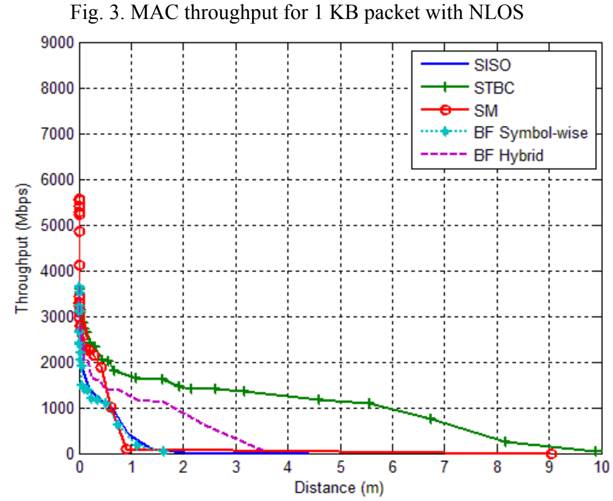

Fig. 4. MAC throughput versus distance for 1 KB packet with NLOS

REFERENCES

[1] IEEE 802.11 Task Group AD. "PHY/MAC complete proposal specification". IEEE 802.11-10/0433r2, May 2010.

[2] M. Alamouti, "A Simple transmit diversity technique for wireless communications". IEEE JSAC, Vol. 16, Issue. 8, pp. 1451-1458. Oct 1998.

[3] G. J. Foschini, and M. J. Gans, "On limits of wireless communications in a fading environment when using multiple antennas. Wireless Personal Communications". Vol. 6, pp. 311-335, 1998.

[4] S. Yoon, T. Jeon, and W. Lee, "Hybrid beam-forming and beam-switch for OFDM based wireless personal area network". IEEE JSAC, Vol. 27, No. 8, pp. 1425-1432, Oct 2009.

[5] C. W. Pyo, and H. Harada, "Throughput analysis and improvement of hybrid multiple access in IEEE 802.15.3c mm-Wave WPAN". IEEE JSAC, Vol. 27, No. 8, pp. 1414-1424, October 2009.