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Enhancement of K-Best Sphere Detection algorithm Performance in MIMO Systems

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Abstract. Due to the rapid development of our life toward a life with high-quality communication systems, which require large data rates for transfer such as Long Term Evolution (LTE), Worldwide Interoperability for Microwave Access(WiMAX), and Wireless Fidelity (WiFi) which use Multiple Input - Multiple Output (MIMO) systems. Therefore, become necessary to interest in MIMO system parts especially the MIMO detector (MIMOD). A good detector system must have two important goals, low Computational Complexity (CC) and good Symbol Error Rate (SER) performance). To achieve that two important goals, our work divided into two parts. The first part, by using an unequal power transmission (UEPT) scheme in instead of equal power transmission (EPT) scheme to get a good SER. The second part, how to reduced CC, this achieved by changing the Euclidean Distance (ED) by using Manhattan Distance (MD). The simulation results show us a slight improvement in the SER performance of about 1.1 dB as average gain and a good reduction in CC about 24% as average reduction in visited nodes when using the UEPT with MD against using EPT with ED.

1. Introduction:

In the last few years, as a result of rapid development in our life many researchers and communication system designers appeared more interested in MIMO detector techniques (MIMODTs), due to increasing demand for higher capacities of information in newfangled communications systems [1]. MIMO techniques (MIMOTs) are becoming an important element in the rapid development of communication systems, due to the fulfilling of higher transmit data rates and a good performance of systems. MIMO improved the performance of many wireless standards such as 3GPP, LTE [2], and WiMAX [3], and also the researchers predicted an outstanding role for MIMOTs to implement the upcoming 5th generation (5G) standard, which is anticipated to transfer high data rates reaching to tens of Gigabits/sec [4].

In this days, the communication system designers consider MIMODT is a defy topic, and there are many research efforts appear the birth of detector techniques (DTs) was done in the last years and show also the difference in a strategy of adapted between different types of DTs. The designers of MIMODTs concentrated on sub-optimal DTs to disband the detection issue in MIMO systems by design an efficient detector in terms of SER performance and CC, and suitable in term of implementation issues [5]. In all wireless communication systems, the efficient MIMODTs must have important features like low CC, near-ideal performance, and robust schema [6].

The story of MIMODTs starts with the Maximum Likelihood detector Technique (MLDT) [7], MLDT has outstanding performance (optimal performance) with worse practical implementation (high CC) especially in MIMO systems that have a high number of transmit antennas to fulfill a high transmission capacity. Many works suggest near-ideal MIMODTs like zero-forcing (ZF) [8], minimum mean square error (MMSE) [8], successive interference cancellation (SIC) [9], parallel

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interference cancellation (PIC) [10], and ordered SIC (OSIC) [11]. Regrettably, all this MIMODTs cannot fulfill the good performance of an MLDT. Sphere decoder technique (SDT) [12, 13] was suggest to fulfill the near-ideal performance of MLDT by using a credible radius. The idea of SD was presented in [14]. The K-best sphere decoder Technique (KSDT) [15] appeared in the area of MIMODTs, it has appeared good features such as fixed throughput and the parallel implementation. The KSDT requires a high amount of K to get a good performance like MLDT performance, this stipulation (high amount of K) leads to a larger CC than that who in the SDT. None the less, due to features of KSDT several variants have been suggested to get better the SER performance and/or decreasing the CC in many works such as [16, 17, 18].

In [19] the authors suggest a MIMO system have multiple transmit antennas with a different energy. The methodology of this work is an analytic method and it is efficient to receive and transmit an arbitrary number of antennas ($N_R \geq N_T$) with a very fast estimation of MIMO system performance. The simulation results showed that the suggested scheme of unequal transmit power is earning around 3-4 dB over a traditional case of equal transmit power. In [6] the author suggested a method for boosting the performance of IKSD scheme, he used the channel ordering and MD together to get a good SER performance with lower CC. The simulation results of this work showed a good SER performance and reduction in CC. Therefore, this work became more suitable for practical implementation. In [20] the authors went on to develop standardized approximations to reduce the complication of ED calculations. In [21] the authors suggested a new scheme to enhance the performance of the K-best algorithm depends on serial sorting strategy for the algorithm. The result showed a good reduction in CC than other algorithms.

In our work, we propose improving the work of the KSD algorithm, this can be achieved by using an effective power allocation scheme such as unequal power of transmission antennas to get a good SER performance, and to reduce the CC by using the MD to decrease the visited nodes in the KSD algorithm. In [19] the work based on using the UEPT to get a good SER performance without reduction of CC. Also in [20], this work goes to develop standardized approximations to reduce the complication of ED calculations to reduce the CC in the detection algorithms without addressing the enhancing of SER performance for these algorithms, while in our work we used UEPT with MD to make SER performance better and reduce the CC of KSD algorithm to make this algorithm more suitable for FPGA implementation. The use of UEPT to enhance the SER performance of detection algorithms is not a new idea but, to the author's knowledge, there is no work suggest using UEPT with MD to enhance the SER performance and reduction CC of KSD algorithms in same work.

The rest of this work is organized as follows: Section 2 (System Model) exhibit the description of the MIMO system for EPT, UEPT, and UEPT with MD. Section 3 shows the simulation results of SER performance and average of visited nodes with SNR. The conclusion was presented in section 4.

2. System Model:

In this work, the flat Rayleigh fading MIMO channel is considered. Assume the transmitter is M antennas and the receiver is N antennas ($M \leq N$). In the transmitter part, the information torrent is distributed for M sub-flows in a parallel manner, and transmit each sub-flow onto one of the transmit antennas. Suppose the receiver had ideal knowledge of the channel state information (CSI).

In this system, the constellation $A^L \in \mathbb{C}^M$equip the symbols that transmit through the transmitter, the symbols are defined by the QAM modulation $(L - QAM)$. The received vector $y = [y_1, y_2, \dots . y_N]^T$ defined as a discrete-time complex baseband signal for EPT can be written as

$$\bar{y} = Hx + n \tag{1}$$

And for UEPT as

$$y = PHx + n \tag{2}$$

H is represent $(M \times N)$ channel matrix of $(i, j)th$ component denoted by $h_{i,j}$, the channel has two fading coefficients one of them is jth transmit antenna and the other is ith receive antenna, the channel was modeled as an independent and identically-distributed (i.i.d.) complex Gaussian variable with zero mean and unit variance, $P = diag(P_1^{\frac{1}{2}}, P_2^{\frac{1}{2}}, \dots P_M^{\frac{1}{2}})$ is the diagonal transmit power matrix with total power constraint $\sum_{k=1}^{M} P_k = 1$, x is represent the $M \times 1$ a vector of transmit signal as a covariance matrix $E[x^H x] = 1$, and n is assumed to be the $N \times 1$ a vector noisy and complex, the elements of this vector are modeled as specimens of Gaussian random, independent, and complex with zero mean and variance σ_n^2. The signal/noise ratio (SNR) is calculated via $1/\sigma_n^2$. Since the work of this consecutive detection schemes relies on the sequence of symbols that detected, such as the sequence $x^i = (x_{M-i+1}, \dots, x_M, x_1, \dots, x_{M-i})$, $i = 0, 1, \dots, M-1$. By shifting the columns of both matrices H & P, the vector of received symbol can written as

$$y = P^i H^i x^i + n^i \tag{3}$$

where

$$H^i = \begin{pmatrix} h_{1,M-i+1} & \cdots & h_{1,M} & h_{1,1} & \cdots & h_{1,M-i} \\ h_{2,M-i+1} & \cdots & h_{2,M} & h_{2,1} & \cdots & h_{2,M-i} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ h_{N,M-i+1} & \cdots & h_{N,M} & h_{N,1} & \cdots & h_{N,M-i} \end{pmatrix} \tag{4}$$

$$P^i = \begin{pmatrix} \sqrt{P_{M-i+1}} & \cdots & 0 & \cdots & \cdots & 0 \\ \vdots & \ddots & \vdots & \vdots & \vdots & \vdots \\ 0 & \cdots & \sqrt{P_M} & \cdots & \cdots & 0 \\ 0 & \cdots & \cdots & \sqrt{P_1} & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & \cdots & \sqrt{P_{M-i}} \end{pmatrix} \tag{5}$$

By performing decomposition of the standard QR matrix, the H^i can be expressed as

$$H^i = Q^i R^i \tag{6}$$

where Q^i is represent an unity matrix with dimension $N \times M$ and R^i is represent an upper triangular matrix with dimension $M \times M$. By pre-multiplying both sides of (3) of ${Q^i}^H$ and defining $z = {Q^i}^H y$, now we can write (3) as

$$z^i = P^i H^i x^i + n^i = \tilde{R}^i x^i + n^i \tag{7}$$

where $z^i = {Q^i}^H y$, $n^i = {Q^i}^H n$ and it can be easily seen that $\tilde{R}^i$ is also an upper triangular matrix.
With a fixed value of i like $i = 0$, we can change the brute-vigor of MLDT to a full tree construction search as

$$x_{MLD} = \arg\min_{\tilde{x}\in A^L} \left\| z^i - \tilde{R}^i x^i \right\| = \arg\min_{\tilde{x}\in A^L} \sum_{p=1}^{M} \left| z_p^i - \sum_{q=p}^{M} \tilde{R}_{p,q}^i \tilde{x}_q^i \right|^2 = \arg\min_{\tilde{x}\in A^L} \sum_{p=1}^{M} T_p \tag{8}$$

where $T_p = \left| z_p^i - \sum_{q=p}^{M} \tilde{R}_{p,q}^i \tilde{x}_q^i \right|^2$ is the branch distance for the $p-th$ data layer and $(p = 1, 2, \dots, M)$. The partial Euclidean distance (PED), i.e., the cumulative branch distance is $\sum T_p$. The path with the minimum PED represent the final detection result, which gets it from the last level when all the path solution candidates reach it. As we know that the complexity of MLD is unacceptable, The CC of MLDT is inadmissible, so uses of successive detection algorithm like K-best [22] or IKSD [23] repetitively from $i = 0$ to $i = M-1$ and the detected vector is considered the vector with the fewer number of iterations.

To explain the effect of MD on the detection process. From (8) the MLDT (x_{MLD}) searches a candidate x^i that minimizes the squared ED between $z^i and\ \tilde{R}^i x^i$. So it's clear that the performing of ED needs for two operations (summation and multiplication) due to square term. For 16-QAM and 4×4 antennas, the compute of ED needs for $4N16^M = 1{,}048{,}576$ from multiplication operations. So the implementation becomes very hard or not possible in term of logic circuits. For this reason, and in term of practical implementation, the implement of the detection algorithm becomes impossible in MIMO schemes especially with high order modulation (64-QAM, 128-QAM). Due to that, we suggested using MD as a practical metric to eliminate the arithmetic multiplication processes to reduce the CC. As in (9), the MD is computed by absolute value of $z^i - \tilde{R}^i x^i$. The difference between (8) and (9), is apparent in the difference between the existences of the arithmetic square in ED that leads to complex the process of hardware implementation, on the other side, in MD the absolute value has appeared, which need to summation process only and thereby reducing CC.

IOP Conf. Series: Materials Science and Engineering **518** (2019) 052007 doi:10.1088/1757-899X/518/5/052007

$$x_{MLD}(MM) = \arg\min_{\tilde{x}\in A^L}\left|z^i - \tilde{R}^i x^i\right| = \arg\min_{\tilde{x}\in A^L}\sum_{p=1}^{M}\left|z_p^i - \sum_{q=p}^{M}\tilde{R}_{p,q}^i\tilde{x}_q^i\right| \quad (9)$$

3. Simulation Results

In this work, the uncoded MIMO scheme (4×4 antennas) and type modulation 16-Quadrature amplitude modulation were considered, this scheme simulated over a flat Rayleigh fading channel. In this section we discuss the simulation results for KSD algorithm by comparing the curve of performance (SER) between EPT with ED and the UEPT with MD, then comparing the curve of CC (visited nodes) between EPT with ED and the UEPT with MD. To do a good comparison for all statuses, consider the premier radius for all statuses is the same. KSD algorithm with EPT {1 1 1 1} have K=1, Δ=0.2 [15], KSD algorithm with UEPT {1.2 1.1 0.9 0.8} have K=1, Δ=0.2, by employing the parameters $p_{T_i} = P_{T_i}/\sum_{j=1}^{M} P_{T_j}$ can get the rate between the various transmitted powers/symbol for each substream [19].

Figure 1 shows the enhancement in performance, especially for SNR after value 12 dB, for example, the gain in SER between the curve of EPT with ED and UEPT with MD about 1.2 dB at SNR=18 and 2.5 dB at SNR=24. The little enhancement in performance comes from the consideration that the reception side doesn't have ordering phase, so if we say that the first detected substream comes from the first transmit antenna, and so on. Therefore, the model based on an assumption of neglect the error propagation and transmit the substreams with the same power. On the other hand, in the case of no order and unequal transmit power, this case gives a performance degradation due to a symbol error probability for the first detected substream. To fix this case, use a high transmission power on the first substream that will be detected, this gives a good performance refinement. Therefore, we consider the UEPT = {1.2 1.1 0.9 0.8}.

Figure 2, appear the enhancement in CC when compare the KSD of EPT with ED and KSD of UEPT with MD. A good reduction in CC seems in the curve of KSD of UEPT with MD which start the performance (SNR=0) at 61 visited node while the curve of KSD of EPT with ED starts at 166 visited node. In the middle of the two curves of CC (at SNR=12), the KSD of EPT with ED visited 934 nodes, while KSD of UEPT with MD 26 nodes. At the end of the two curves (SNR=24), the visited nodes are 111 and 14 for KSD of EPT with ED and KSD of UEPT with MD respectively.

4. Conclusions

As we mentioned earlier this work goes into two directions, one of them aim to enhance the performance of the KSD algorithm and we did that when getting about 1.1 as average gain in the curve of SER for UEPT against the SER of EPT. The second direction aim to reduce the CC of the KSD algorithm, this aim achieved when getting a good reduction between the two curves of EPT with ED and UEPT with MD, the reduction between two curves is 63% in SNR=0 dB and 87% in SNR=24 dB. Therefore, according to this results, the KSD algorithm becomes more suitable in term of FPGA implementation. Many works used the MD to reduce the CC as a result they suffered from slight SER performance degradation on the other side, our work exceeded this problem when suggesting the use of UEPT with MD to reduce the CC and enhance the SER performance. At last, we suggest using the UEPT with correlation metric to get better performance and more reduction in CC, because the use of correlation metric gives more reduction in CC than MD use and without suffering from performance degradation.

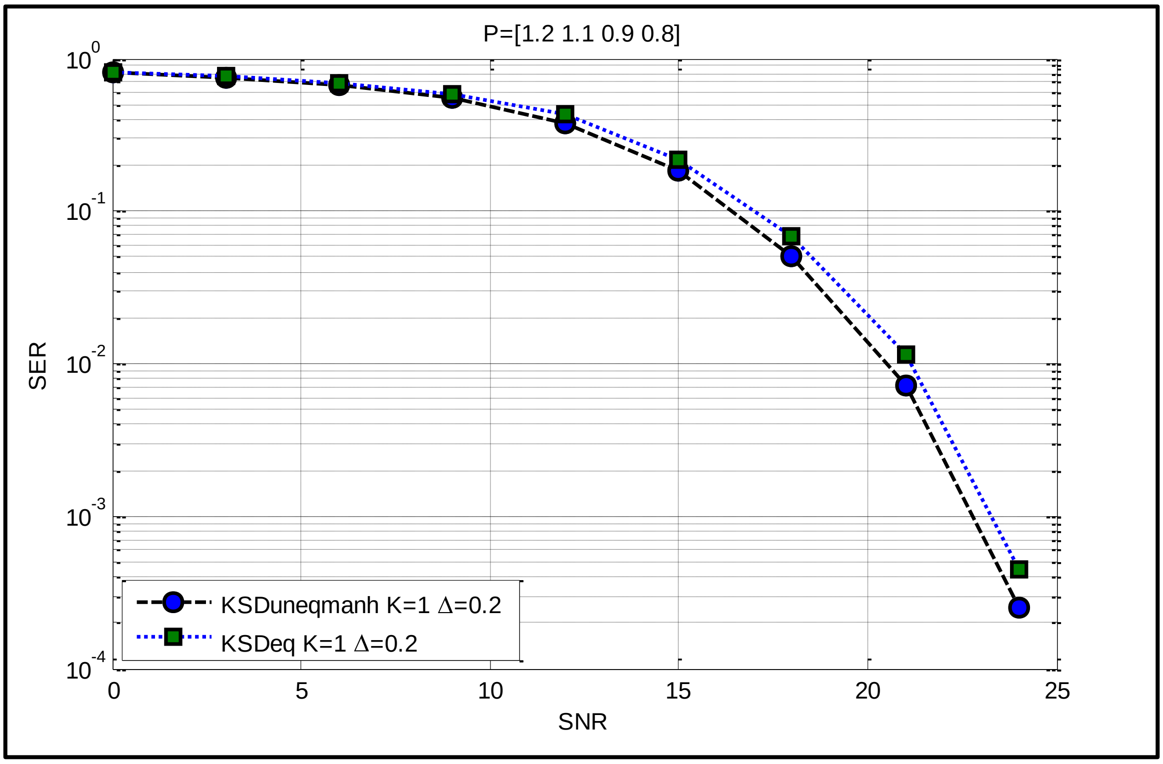

Figure 1. The performance of the KSD algorithm for EPT with ED and UEPT with MD for uncoded 4×4 MIMO 16-QAM system.

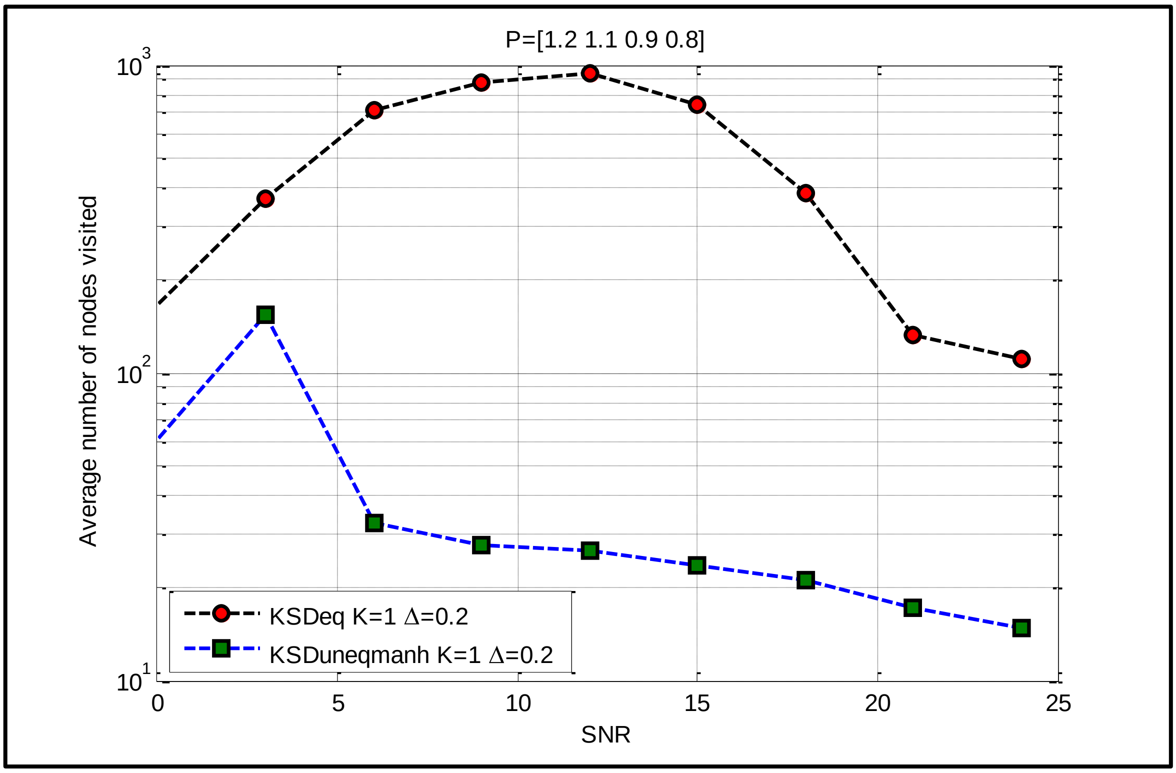

Figure 2. The CC of the KSD algorithm for EPT with ED and UEPT with MD for uncoded 4×4 MIMO 16-QAM system.

References

[1] Li P, De Lamare R C and Fa R 2011 Multiple feedback successive interference cancellation detection for multiuser MIMO systems *IEEE Transactions on Wireless Communications* **10** 2434-2439.

[2] Akyildiz I. F, Gutierrez-Estevez D M, Balakrishnan R and Chavarria-Reyes E 2014 LTE-Advanced and the evolution to Beyond 4G (B4G) systems *Physical Communication* **10** 31-60.

[3] Bacioccola A, Cicconetti C, Eklund C, Lenzini L, Li Z and Mingozzi, E 2010 IEEE 802.16: History, status and future trends *Computer Communications* **33** 113-123.

[4] Andrews J G, Buzzi S, Choi W, Hanly S V, Lozano A, Soong A C and Zhang J C 2014 What will 5G be? *IEEE Journal on selected areas in communications* **32**1065-1082.

[5] Saxena M and Patel H 2013 An efficient comparison of mimo-ofdm detection using spatial multiplexing techniques.

[6] Sulttan M Q 2016 Reducing Computational Complexity and Enhancing Performance of IKSD Algorithm for Encoded MIMO Systems *Indonesian Journal of Electrical Engineering and Computer Science* **2** 636-646.

[7] Choi J, Mo J and Heath R W 2016 Near maximum-likelihood detector and channel estimator for uplink multiuser massive MIMO systems with one-bit ADCs *IEEE Transactions on Communications* **64** 2005-2018.

[8] Vucetic B and Jinhong Y 2005 Space-Time Block Codes. Space-Time Coding 91-115.

[9] Elghariani A and Zoltowski M 2015, May Successive interference cancellation for large-scale MIMO OFDM. *In Electro/Information Technology (EIT), 2015 IEEE International Conference on* (pp. 657-661) IEEE.

[10] Chan, S C and Chu Y J 2015 Performance of NLMS-based Parallel Interference Cancellation (PIC) For Up-Link CDMA Systems *Journal of Signal Processing Systems* **78** 155-162.

[11] Shang Y and Xia X G 2009 On fast recursive algorithms for V-BLAST with optimal ordered SIC detection *IEEE Transactions on Wireless Communications* **8.**

[12] Chen T and Leib H. 2015, May GPU acceleration for fixed complexity sphere decoder in large MIMO uplink systems *In Electrical and Computer Engineering (CCECE), 2015 IEEE 28th Canadian Conference on* (pp. 771-777) IEEE.

[13] Chavali N K and Kumar B K 2015, February A reduced complexity MIMO decoder. *In Signal Processing, Informatics, Communication and Energy Systems (SPICES), 2015 IEEE International Conference on* (pp. 1-5) IEEE.

[14] Viterbo E and Boutros J 1999 A universal lattice code decoder for fading channels *IEEE Transactions on Information theory* **45** 1639-1642.

[15] Guo Z and Nilsson P 2006 Algorithm and implementation of the K-best sphere decoding for MIMO detection *IEEE Journal on selected areas in communications* **24** 491-503.

[16] Shen C A and Eltawil A M 2010 A radius adaptive K-best decoder with early termination: Algorithm and VLSI architecture *IEEE Transactions on Circuits and Systems I: regular papers* **57** 2476-2486.

[17] Kim T H and Park I C 2010, August Small-area and low-energy K-best MIMO detector using relaxed tree expansion and early forwarding *In Low-Power Electronics and Design (ISLPED), 2010 ACM/IEEE International Symposium on* (pp. 231-236) IEEE.

[18] Lai K C, Huang C C and Jia J J 2011 Variation of the fixed-complexity sphere decoder *IEEE Communications Letters* **15** 1001-1003.

[19] Zanella A, Chiani M and Win M Z 2003, December Analytical evaluation of MIMO systems with unequal power transmission in a Rayleigh fading environment *In Global Telecommunications Conference* 2003 GLOBECOM'03 IEEE (**Vol. 4**, pp. 1837-1841) IEEE.

[20] Burg A, Borgmann M, Wenk M, Zellweger M, Fichtner W and Bolcskei H 2005 VLSI implementation of MIMO detection using the sphere decoding algorithm *IEEE Journal of solid-state circuits* **40** 1566-1577.

[21] Shabany M and Gulak P G 2008, May Scalable VLSI architecture for K-best lattice decoders *In Circuits and Systems, 2008. ISCAS 2008. IEEE International Symposium on* (pp. 940-943). IEEE.
[22] Guo Z and Nilsson P 2006 Algorithm and implementation of the K-best sphere decoding for MIMO detection *IEEE Journal on selected areas in communications* **24** 491-503.
[23] Han S, Cui T and Tellambura C 2012 Improved K-best sphere detection for uncoded and coded MIMO systems *IEEE Wireless Communications Letters* **1** 472-475.