Center for Multimedia Communication

FPGA Implementation of Dynamic Threshold Sphere Detection (DTSD)

Kia Amiri (kiaa@rice.edu)
Joseph Cavallaro (cavallar@rice.edu)
ECE Dept., Rice University
CMC Lab

Outline

- MIMO Systems
  - Challenges in MIMO Detection
- Proposed Scheme for MIMO Detection
- Hardware Implementation
- Conclusion & Future Work

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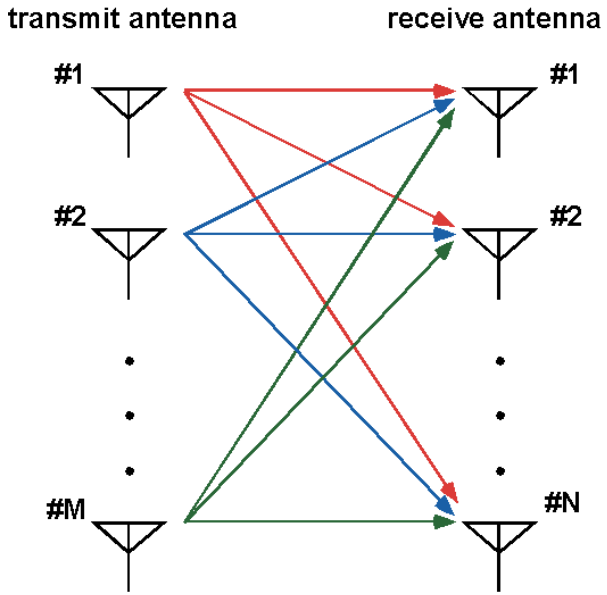
MIMO

- MIMO
  - High spectral efficiency
  - Increase in reliability and range
  - Application in 802.11n, Wi-Fi, WiMax, 3G Cellular,…

$$\mathbf{y} = \mathbf{Hs} + \mathbf{n}$$

- MIMO Receiver
  - Fast detector



MIMO Detection

- Maximum-Likelihood (ML) Detection
  - Optimum
  - Brute-force search
  - High Complexity
  - Slow

$$\hat{\mathbf{s}} = \arg\min_{\mathbf{s}\in\Omega} \|\mathbf{y} - \mathbf{H}\mathbf{s}\|^2$$

- Example: 16-QAM, 4 transmit antennas, OFDM (48 active subcarriers)
  - Number of searches

$$16^4 \times 48 \sim 3 \times 10^6$$

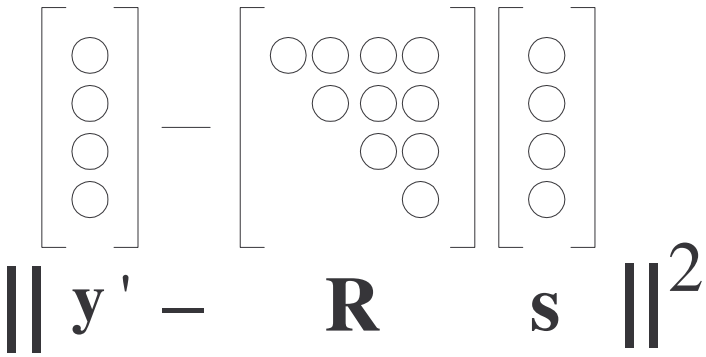
- Infeasible in MIMO Systems

- Solution: Sphere (Lattice) Detection

MIMO Detection

- M=4 Transmit Antenna
- BPSK Modulation
- Threshold (radius) = 6

$$\|\mathbf{y}-\mathbf{Hs}\|^2 = \|\mathbf{Q}^{\mathbf{H}}\mathbf{y}-\mathbf{Rs}\|^2 = \|\mathbf{y}'-\mathbf{Rs}\|^2$$



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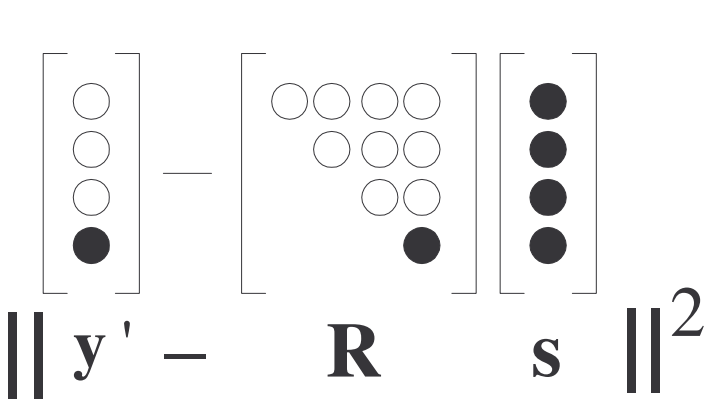

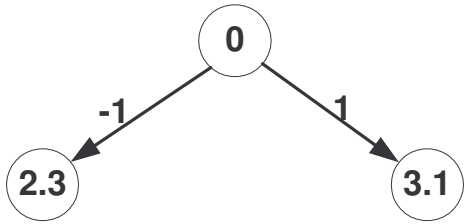

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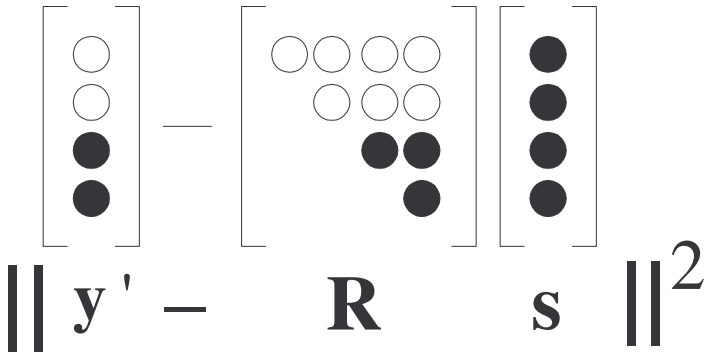

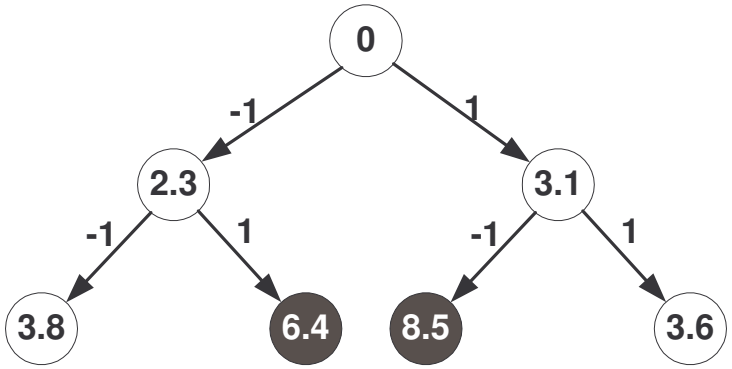

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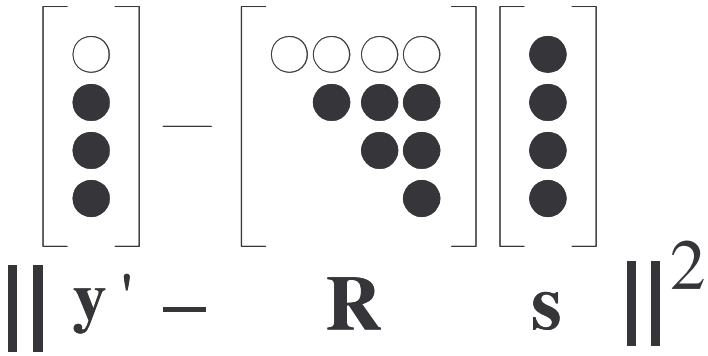

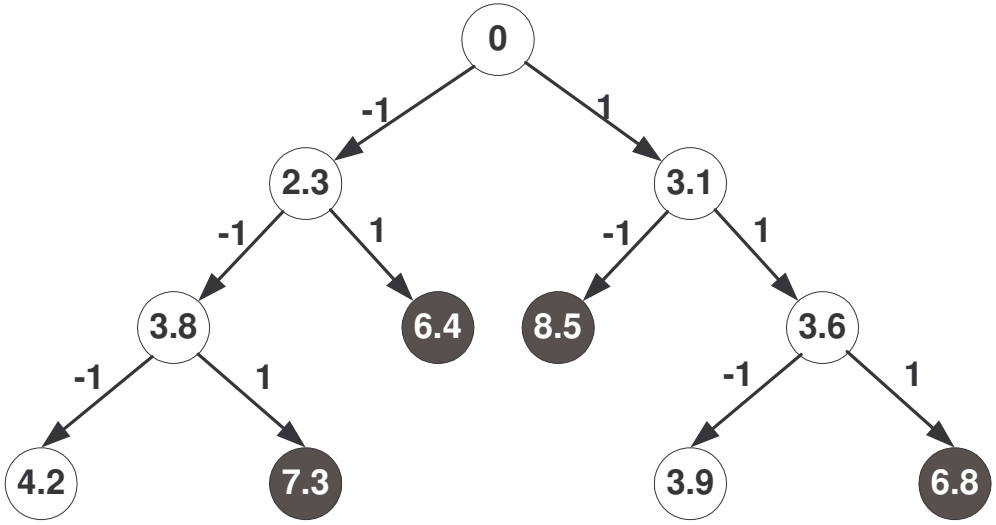

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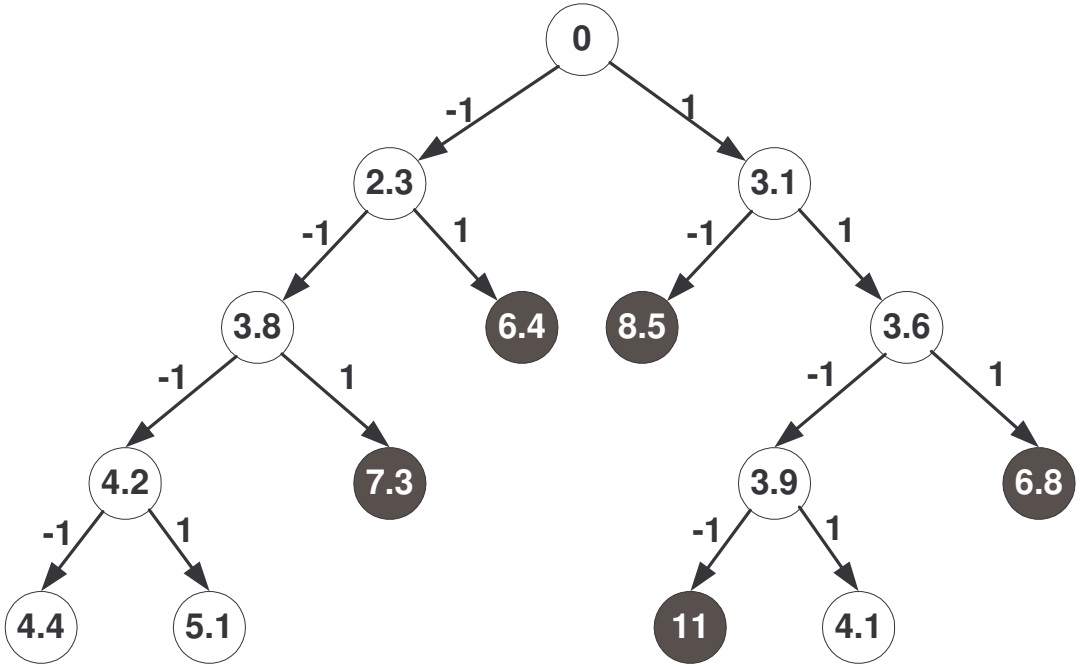
$$\left\| \begin{bmatrix} \bullet \\ \bullet \\ \bullet \\ \bullet \end{bmatrix} - \begin{bmatrix} \bullet & \bullet & \bullet & \bullet \\ & \bullet & \bullet & \bullet \\ & & \bullet & \bullet \\ & & & \bullet \end{bmatrix} \begin{bmatrix} \bullet \\ \bullet \\ \bullet \\ \bullet \end{bmatrix} \right\|^2$$

$$\| \mathbf{y}' - \mathbf{R} \quad \mathbf{s} \|^2$$



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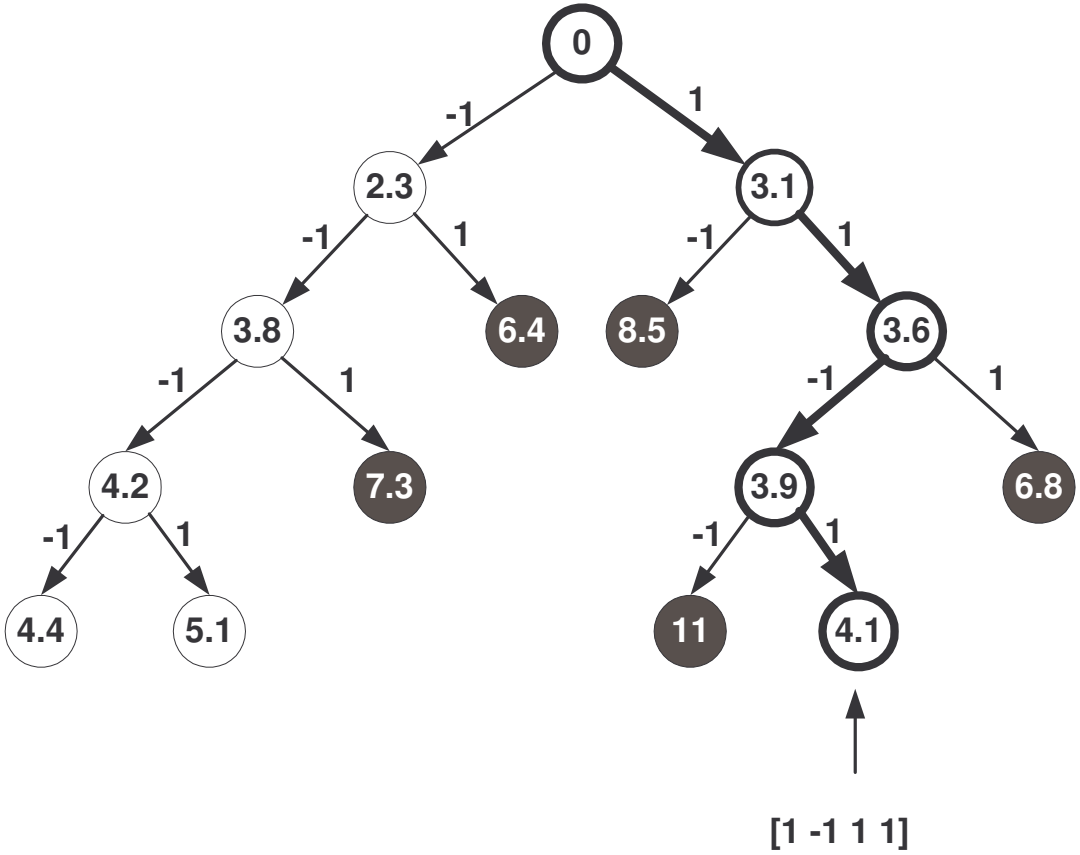
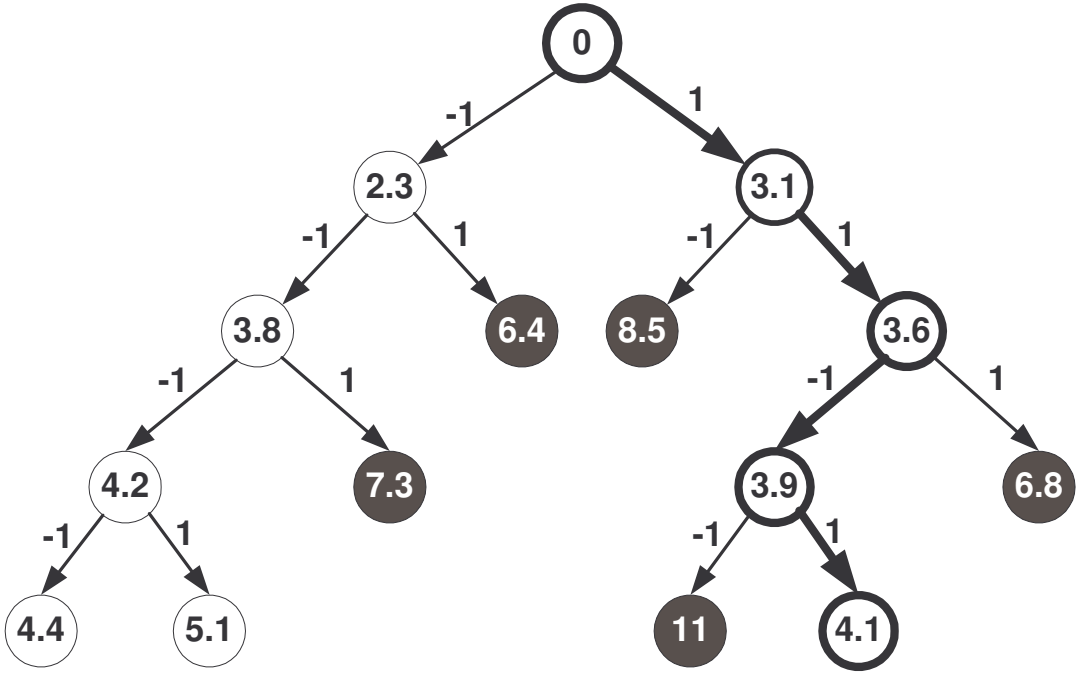


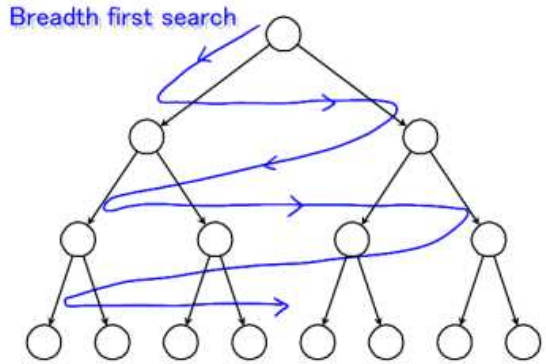
MIMO Detection(cont'd)

- Reduced number of visited nodes:
  - Only 9 nodes rather than 32 nodes
- Reduction in complexity
- Efficient tree pruning
- High data rate

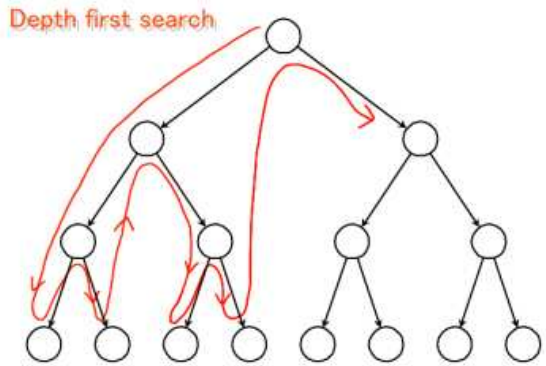


Tree Search

- Two search schemes:
  - Breadth-first based (K-best)



  - Depth-first based



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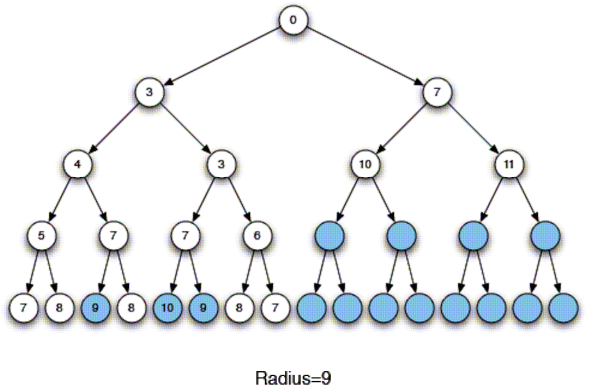
Proposed Scheme

- Based on Depth-First Search
  - Higher Possible Throughput
- Radius update when each leaf is reached
  - Accelerating the tree pruning
- Initial Radius
  - Minimum path, an efficient method for calculating the initial radius



- Our Contribution:
  - Dynamic threshold updating based on the depth of the tree

$$D_i\left(S^i\right) \le R_i$$

  - Finding the minimum among of the children of one node rather than a complete sorting

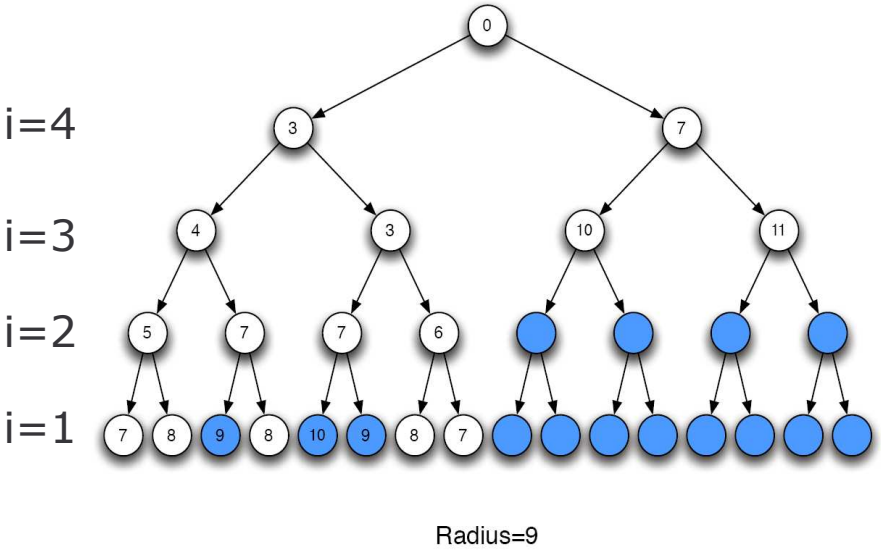
Dynamic Threshold

- Partial distances increasing for lower tree levels,
- Additive component has the same statistical mean,
- Thresholds change linearly.

$$\mathbf{y} - \mathbf{H}\mathbf{s} = \mathbf{n}$$

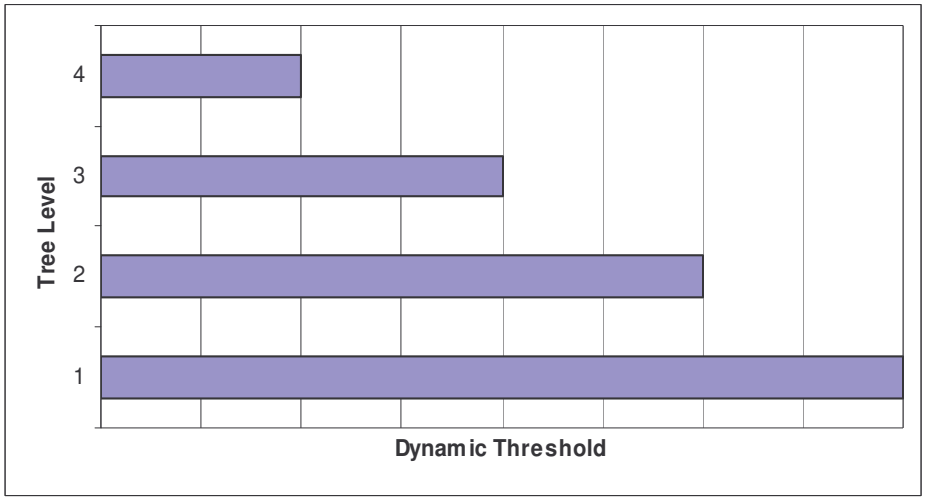
$$\mathbf{Q}^{\mathbf{H}}\mathbf{y} - \mathbf{R}\mathbf{s} = \mathbf{Q}^{\mathbf{H}}\mathbf{n}$$

$$\| \mathbf{y} - \mathbf{H}\mathbf{s} \|^2 = \| \mathbf{Q}^{\mathbf{H}}\mathbf{y} - \mathbf{R}\mathbf{s} \|^2$$

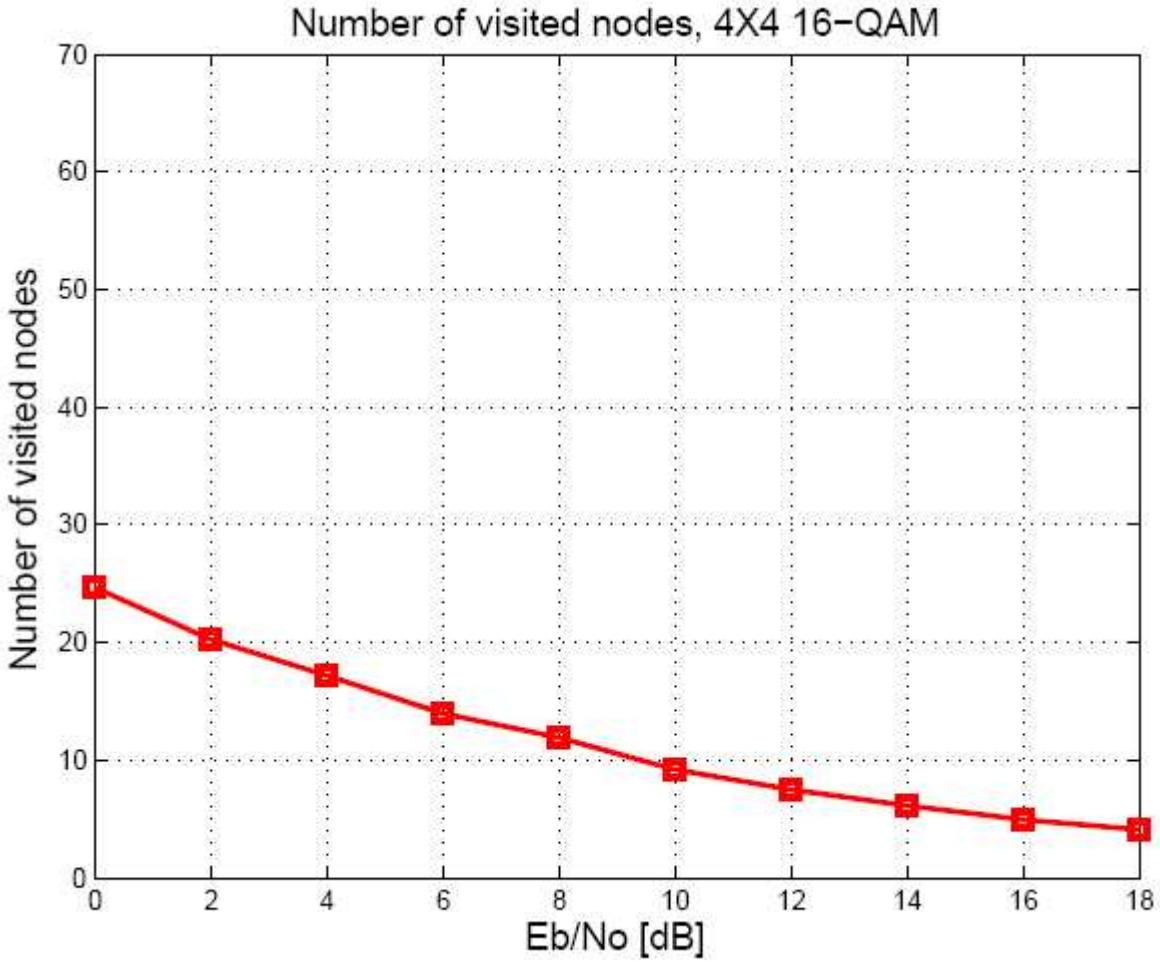


Radius=9

$$M = 4 \Rightarrow R_i = \frac{5R}{4} - \frac{R}{4} i$$



Complexity Comparison



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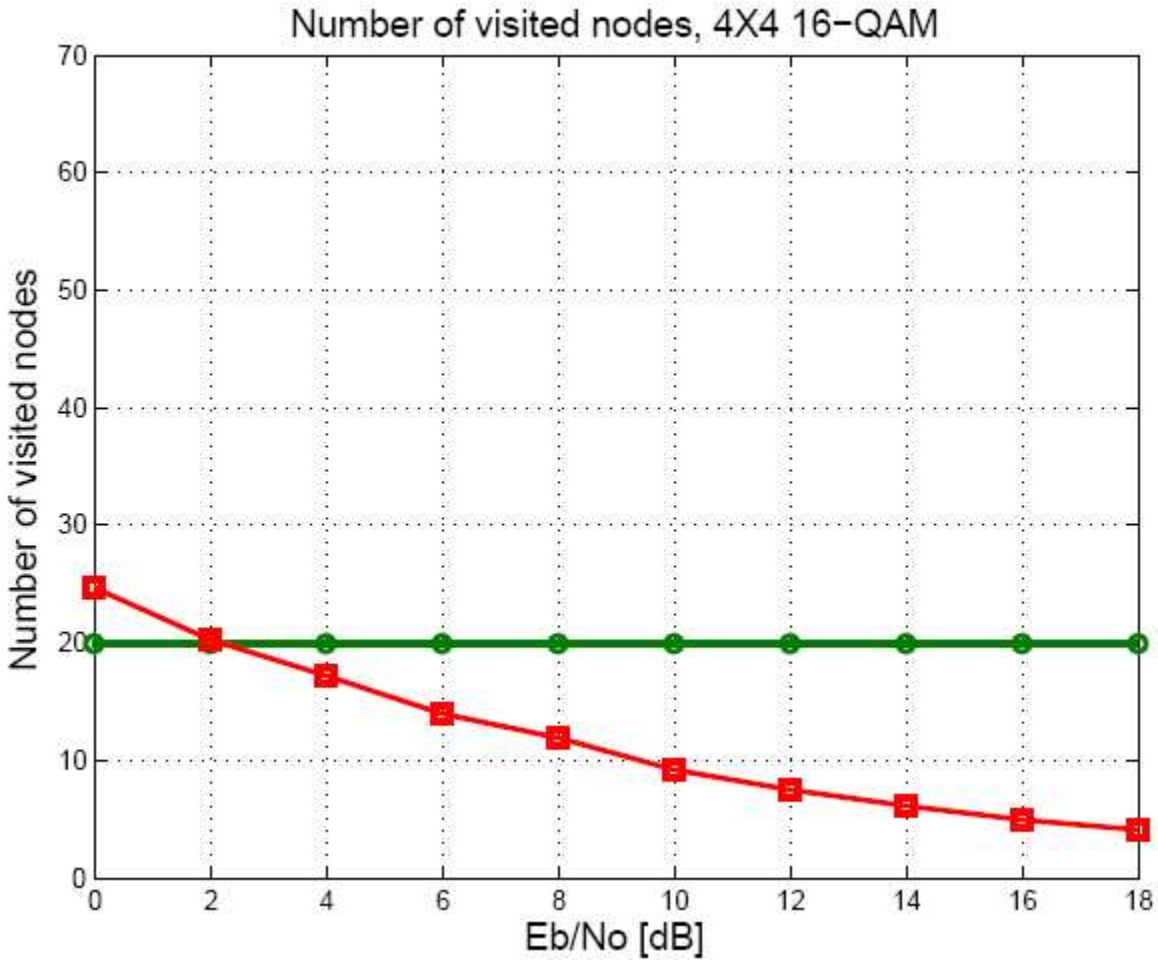

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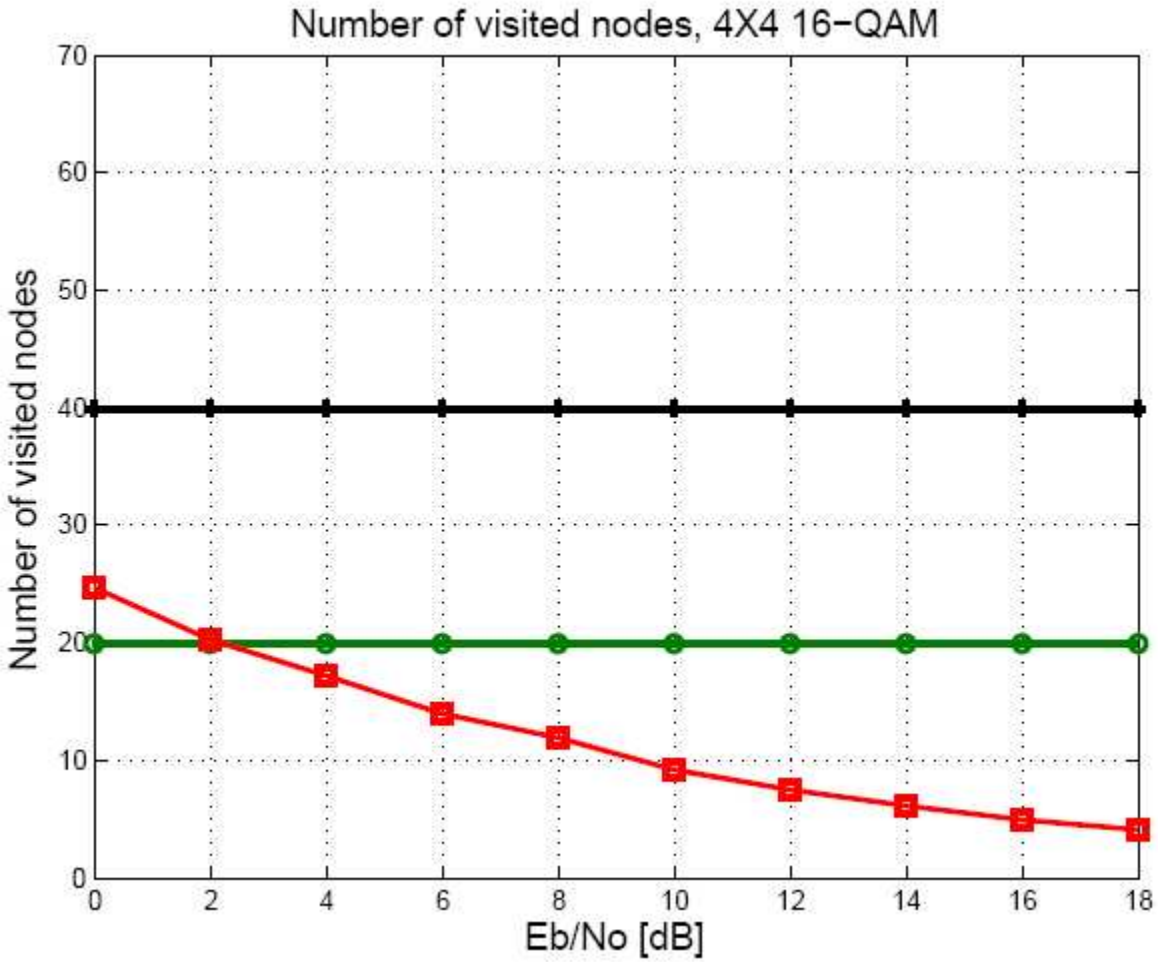

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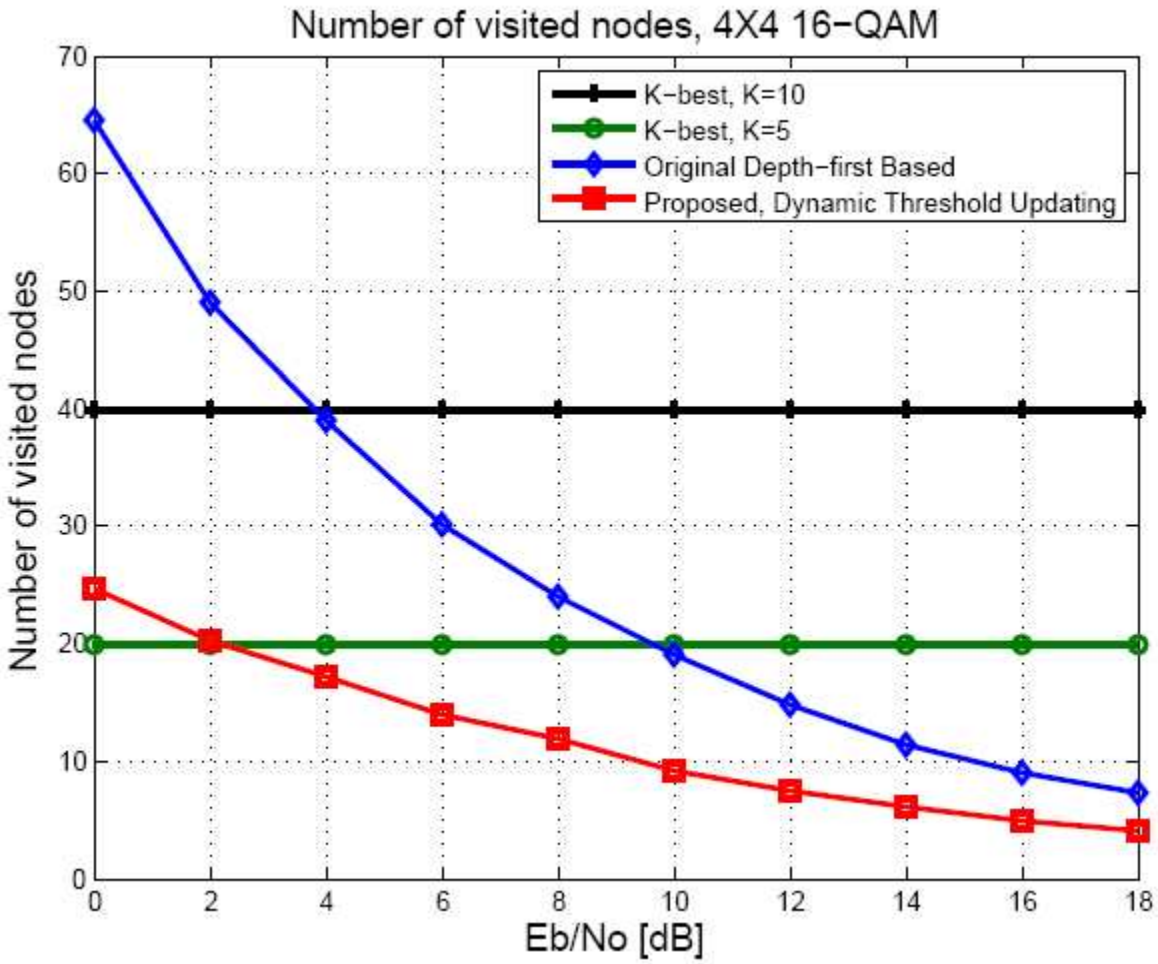
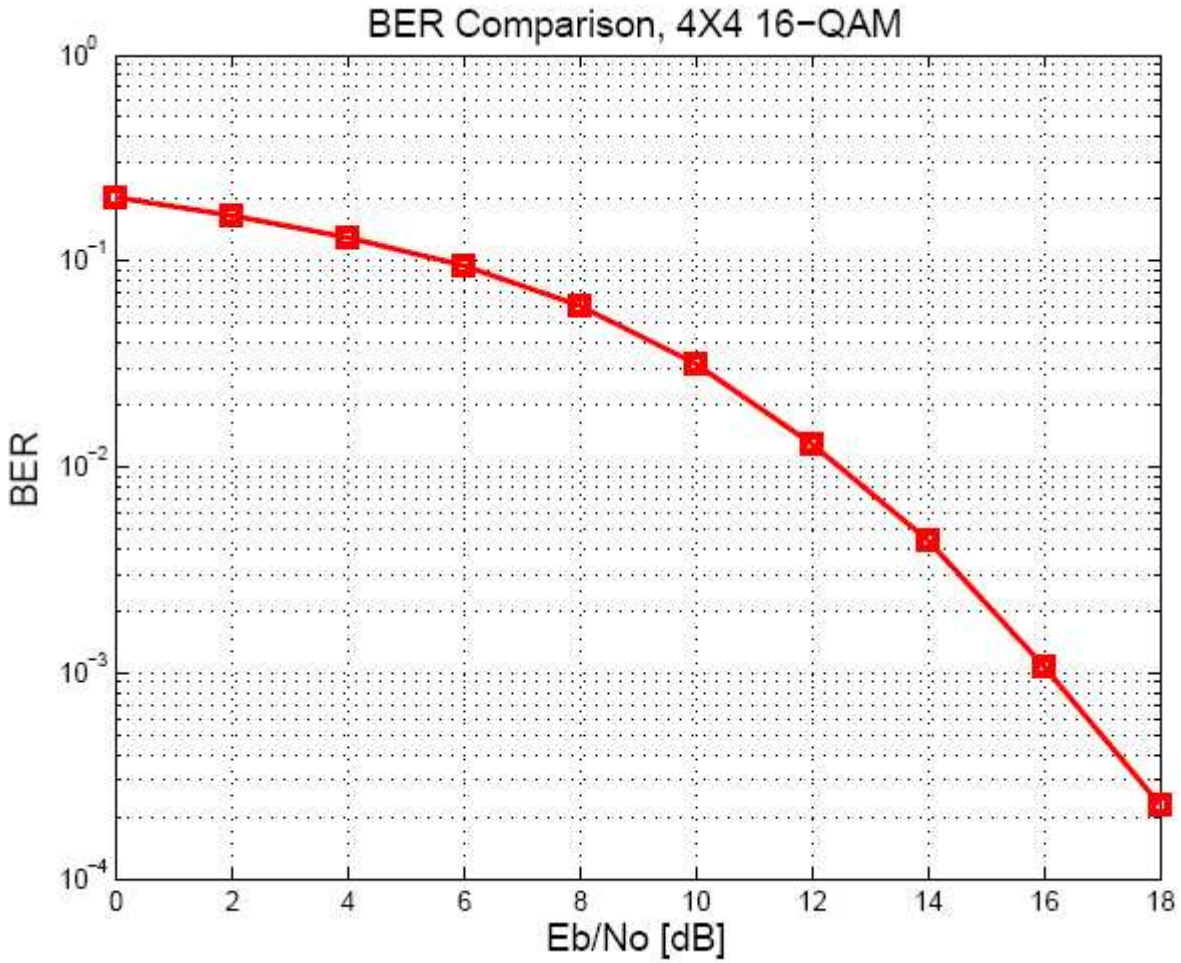


- Significant complexity reduction compared to original depth-first scheme
- Less visited nodes compared to K-best with K=10
- Less visited nodes compared to K-best (K=5) for a large range of SNR

Performance Comparison



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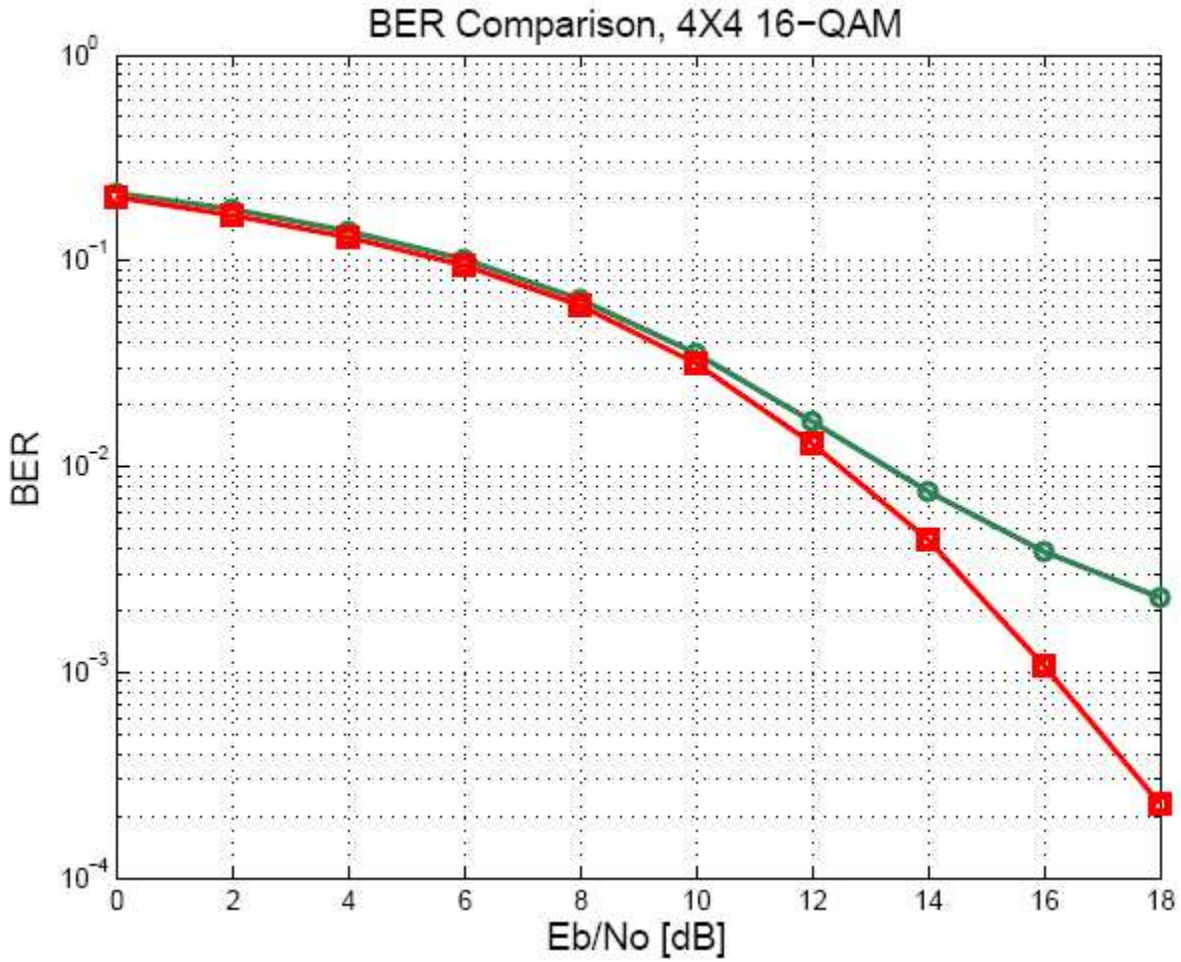

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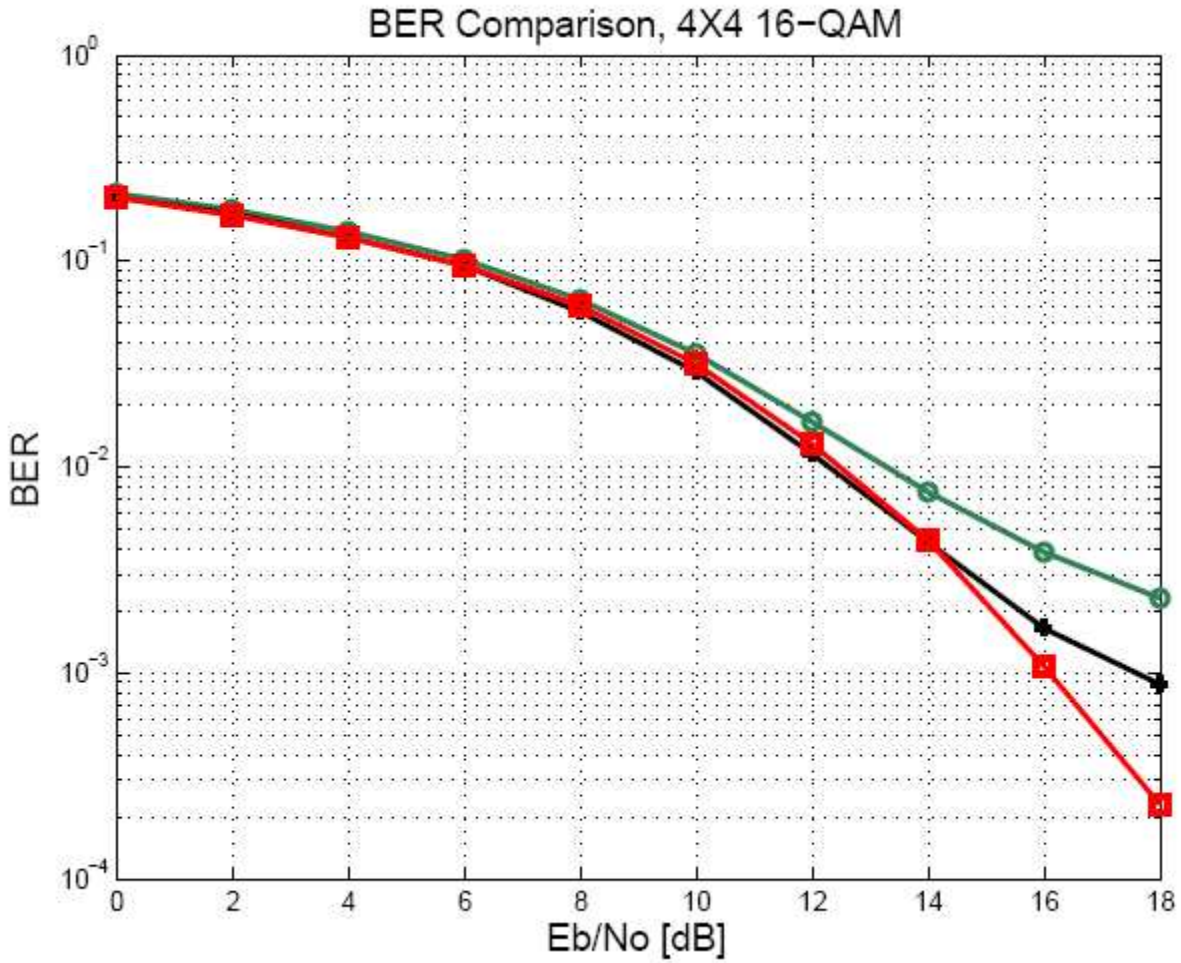

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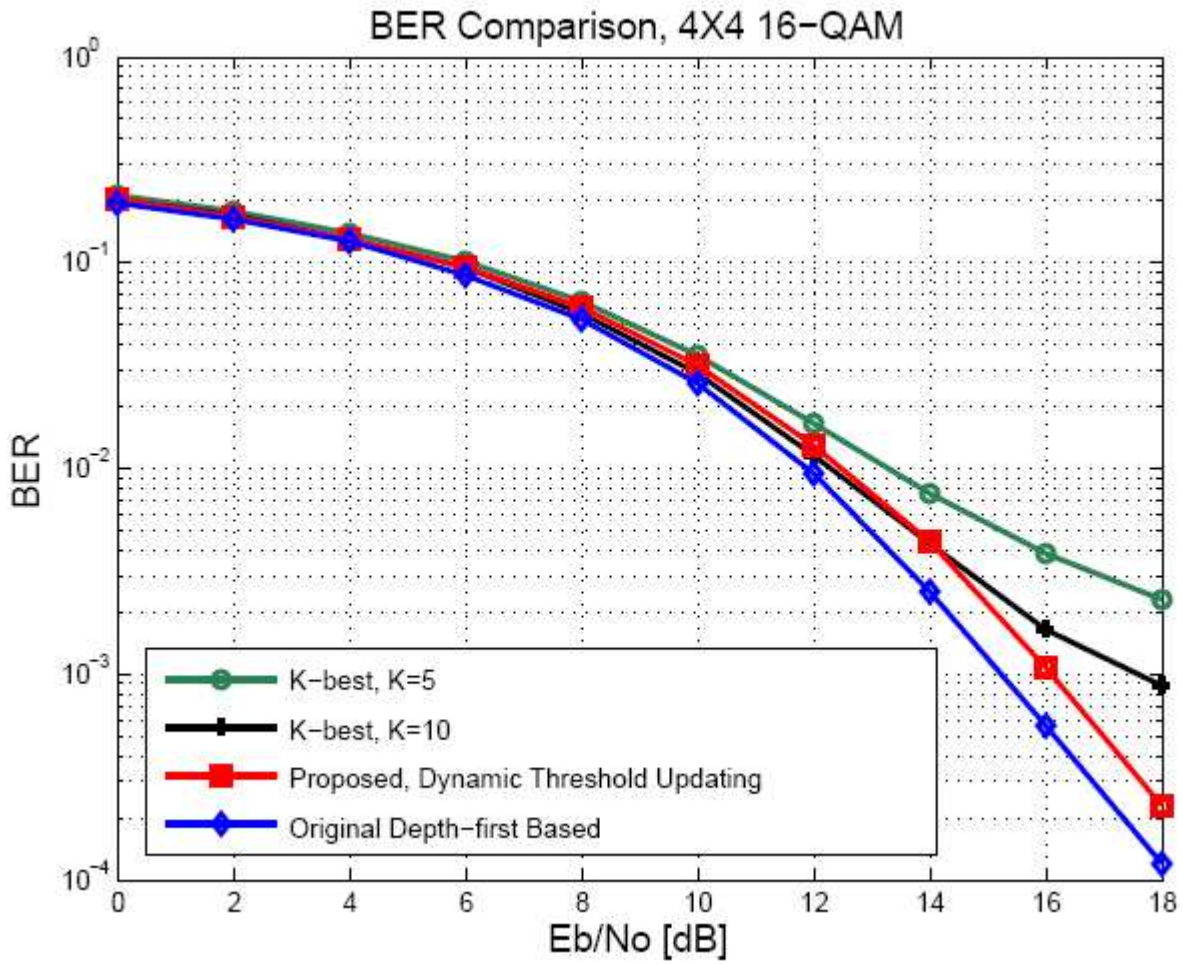

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Architecture, Hardware Implementation

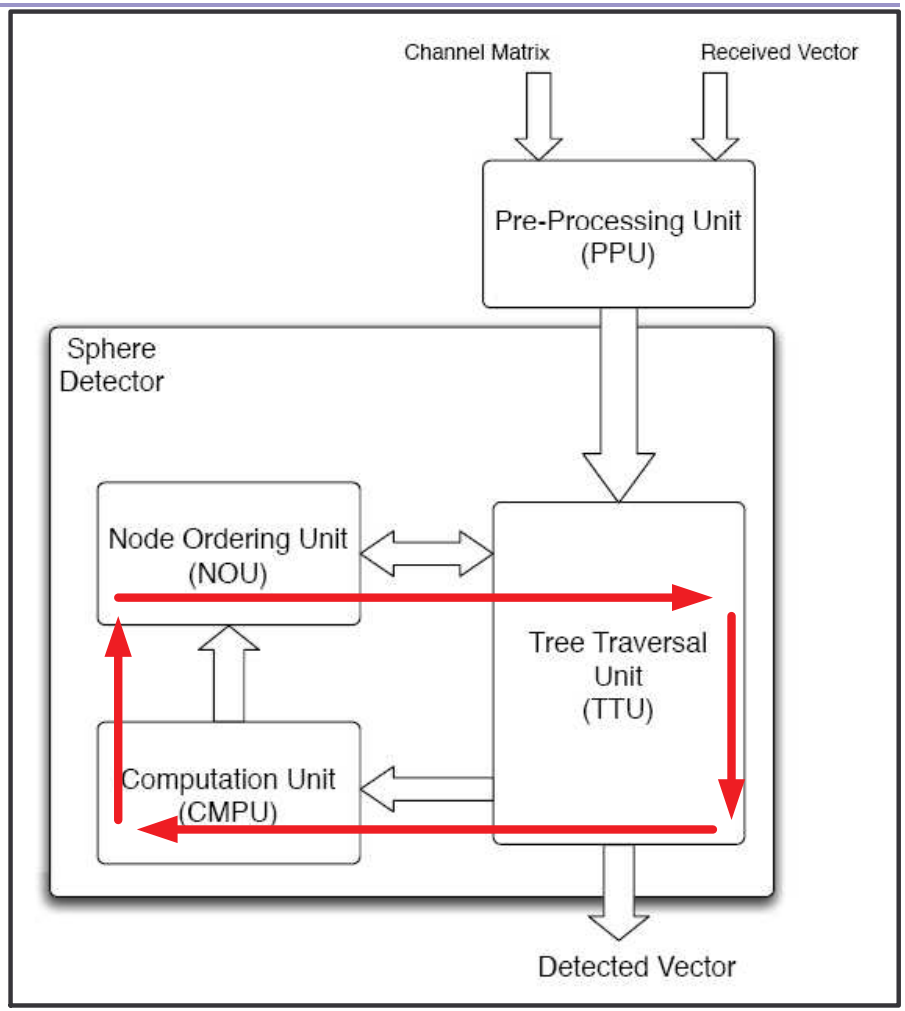
- 4 X 4 , 16-QAM system
- Xilinx System Generator

- Tree Traversal Unit (TTU)
  - 1 or 6 cycles

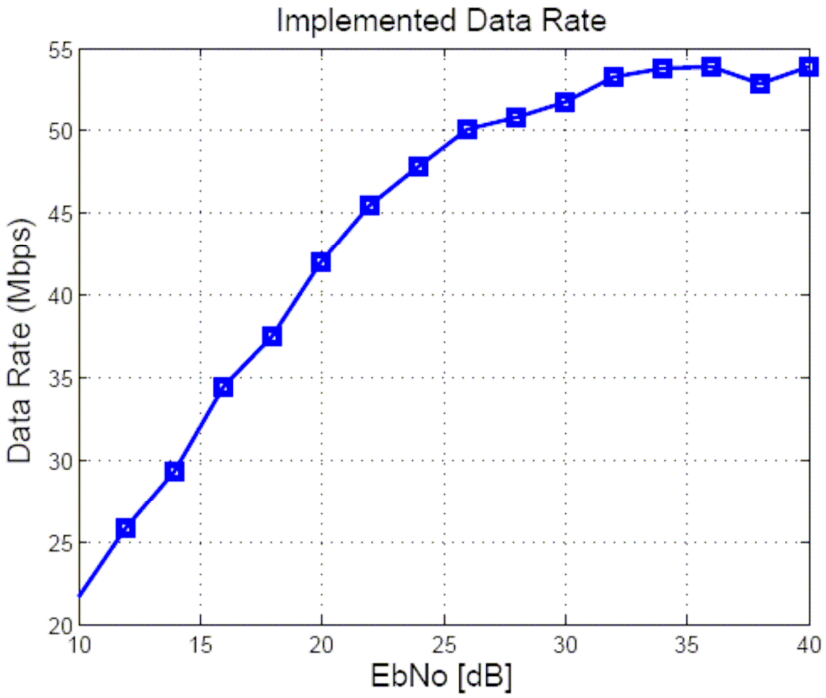
- Computation Unit (CMPU)
  - 6 cycles

$$\sum_{i=M_T}^{1} |y_i' - \sum_{j=i}^{M_T} R_{ij} s_j|^2$$

- Node Ordering Unit (NOU)
  - 1 cycle



Implementation Results



Device	Xilinx Virtex4 Xc4vfx100-ff1517
Number of Slices	4708/42176 (11%)
Number of FFs	3,272/84,352 (3%)
Number of LUTs	7,001/84,352 (8%)
Number of RAMB16	9/376 (2%)
Number of DSP48s	104/160 (65%)
Max. Freq.	125.3 MHz

- Maximum throughput: 53 Mbps
  - Faster than other FPGA implementations, 35.75 Mbps
  - Altera Stratix EP1S10

J. Ma and X. Huang, "A system-on-programmable chip approach for MIMO sphere decoder," *IEEE Symposium on Field-Programmable Custom Computing Machines*, pp. 317–318, Apr. 2005.

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Conclusion & Future Work

- Summary:
  - Proposed scheme to reduce the complexity
    - Dynamic threshold,
    - Minimum finding
  - Increase in the speed
  - Negligible BER degradation
  - Scheme implemented
  - MIMO
- Future Work
  - CMC WARP