MIMO decoding using QRDM algorithm

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Overview

- Motivation
- QRD-M Introduction
- Optimization Idea for QRD-M
- Simulation Results
- Conclusion

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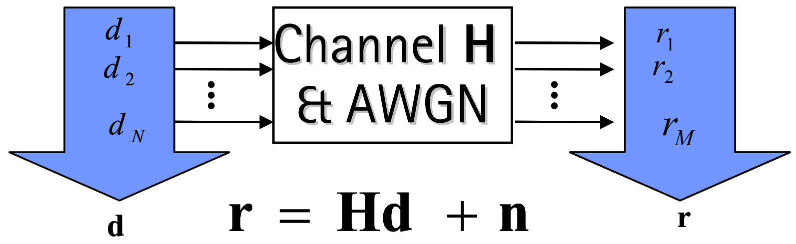
Motivation

- MIMO offers
  - Increase in link reliability (Spatial Diversity) and/or
  - Increase in data rate (Spatial Multiplexing and/or Spatial Diversity)
- Problem:
  - Simple detection approaches do not exploit full “MIMO” gain
  - Maximum Likelihood (optimum detection) leads to best performance but has very high complexity

- Optimized QRD-M detection leads to significant reduction of complexity and has comparable performance as ML

QRD-M Introduction (1/3)

- System Model:



$$\mathbf{r} = \mathbf{H}\mathbf{d} + \mathbf{n}$$

- Maximum Likelihood Equation:

$$\hat{\mathbf{d}} = \arg\min_{\mathbf{d}} \| \mathbf{H}\mathbf{d} - \mathbf{r} \|^2$$

- Problems: Complexity is very high!

  Example: 16^4 symbol combinations for 16QAM and 4x4 Spatial Multiplexing

- The QRD-M offers significant reduction of computational complexity
  - 1. Step: QRD

$$\hat{\mathbf{d}} = \arg\min_{\mathbf{d}} \left\| \mathbf{R}\mathbf{d} - \mathbf{Q}^H \mathbf{r} \right\|^2$$

  - 2. Step: M-search (Reduced breadth-first search algorithm)

QRD-M Introduction (2/3)
(Example for a 4x4 MIMO System)

ML after the QRD step:

$$\hat{\mathbf{d}} = \arg\min_{\mathbf{d}} \left\| \mathbf{R}\mathbf{d} - \underbrace{\mathbf{Q}^H \mathbf{r}}_{\mathbf{r}_q} \right\|^2$$

$$R_{11} d_1 + R_{12} d_2 + R_{13} d_3 + R_{14} d_4 - r_{q1}$$

$$\mathbf{R} \cdot \mathbf{d} - \mathbf{r}_q = \begin{pmatrix} R_{11} & R_{12} & R_{13} & R_{14} \\ 0 & R_{22} & R_{23} & R_{24} \\ 0 & 0 & R_{33} & R_{34} \\ 0 & 0 & 0 & R_{44} \end{pmatrix} \cdot \begin{pmatrix} d_1 \\ d_2 \\ d_3 \\ d_4 \end{pmatrix} - \begin{pmatrix} r_{q1} \\ r_{q2} \\ r_{q3} \\ r_{q4} \end{pmatrix} \quad \vdots$$

$$R_{44} d_4 - r_{q4}$$

Metric Calculation at each step for M=modulation order=16:

$$m_4^{(l)} = \| R_{4,4} \tilde{d}_4^{(l)} - r_{q4} \|^2$$

Take M best symbols ($l \rightarrow k$)

$$m_3^{(p)} = \| R_{3,3} \tilde{d}_3^{(l)} - \left(r_{q3} - R_{3,4} \tilde{d}_4^{(k)} \right) \|^2 + m_4^{(k)}$$

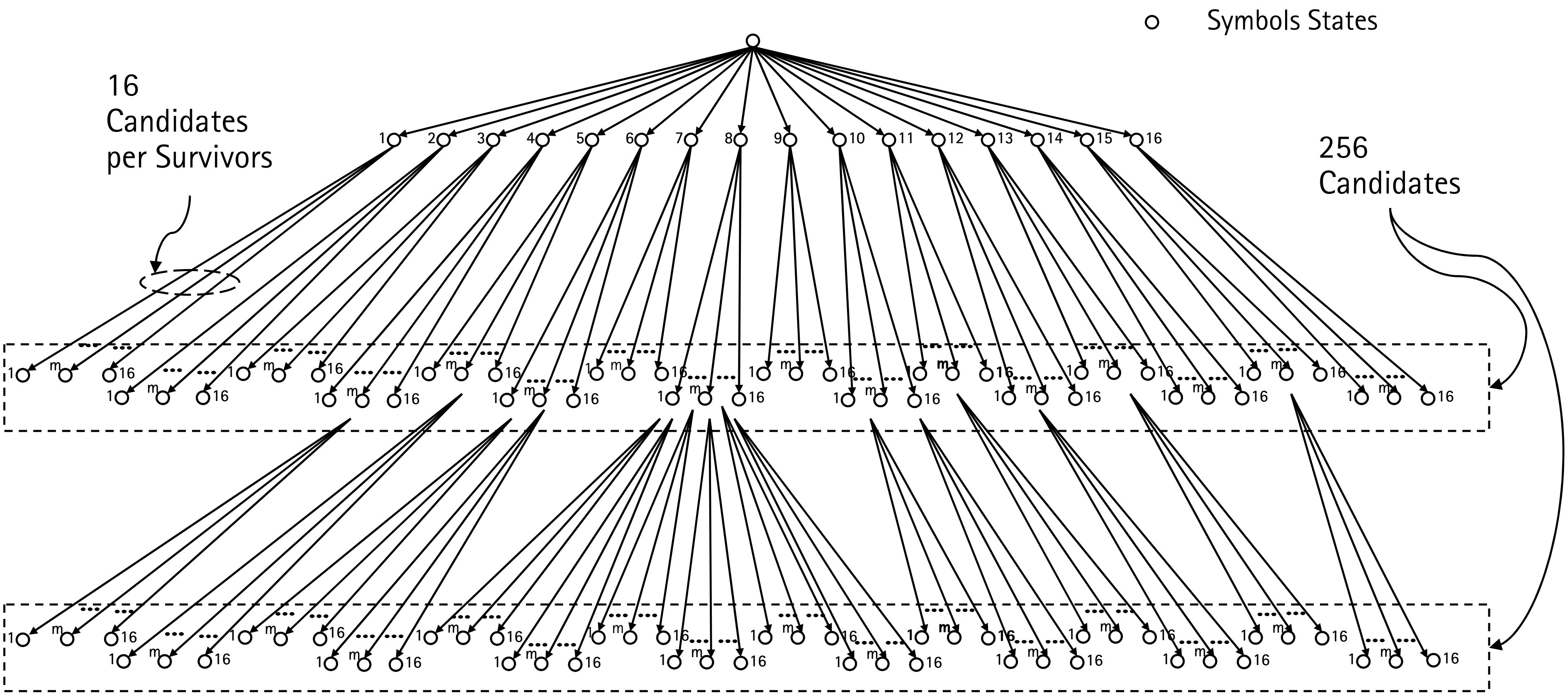
$$m_2^{(p)} = \| R_{2,2} \tilde{d}_2^{(l)} - \left(r_{q2} - \left(R_{2,3} \tilde{d}_3^{(k)} + R_{2,4} \tilde{d}_4^{(k)} \right) \right) \|^2 + m_3^{(k)}$$

$$m_1^{(p)} = \| R_{1,1} \tilde{d}_1^{(l)} - \left(r_{q1} - \left(R_{1,2} \tilde{d}_2^{(k)} + R_{1,3} \tilde{d}_3^{(k)} + R_{1,4} \tilde{d}_4^{(k)} \right) \right) \|^2 + m_2^{(k)}$$

Where k=1…16, l=1…16, p=1…256

QRD-M Introduction (3/3)

(Example: 16 QAM)



Current Metric i: m_i = current symbol metric and old layer metric

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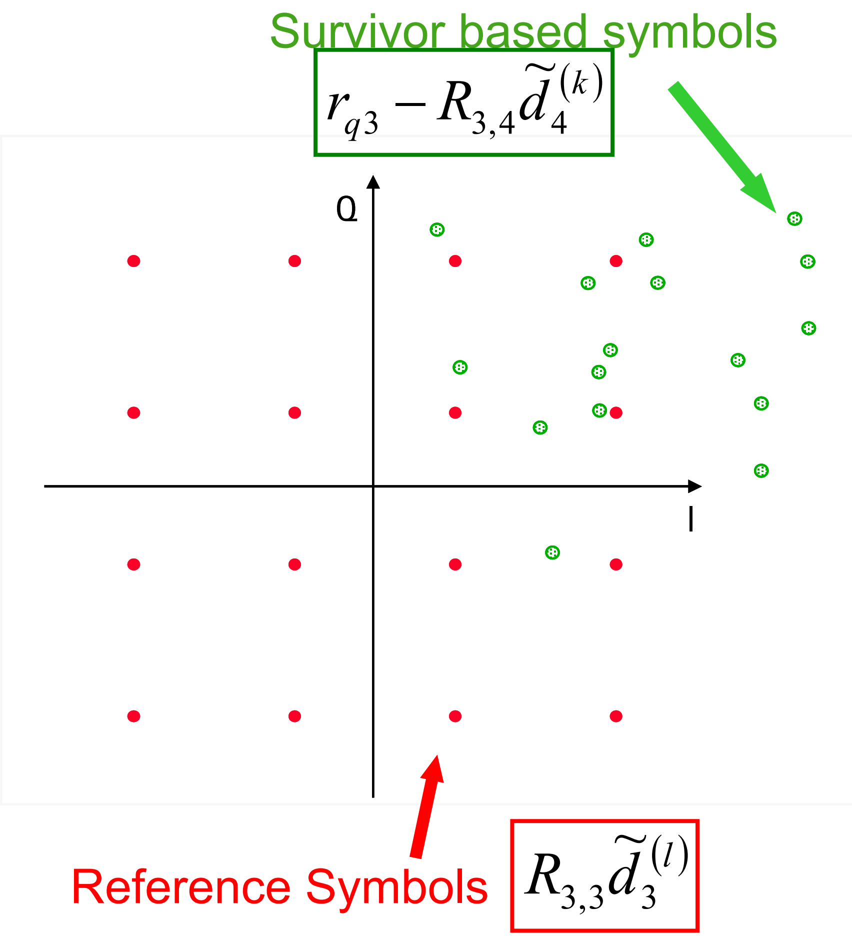
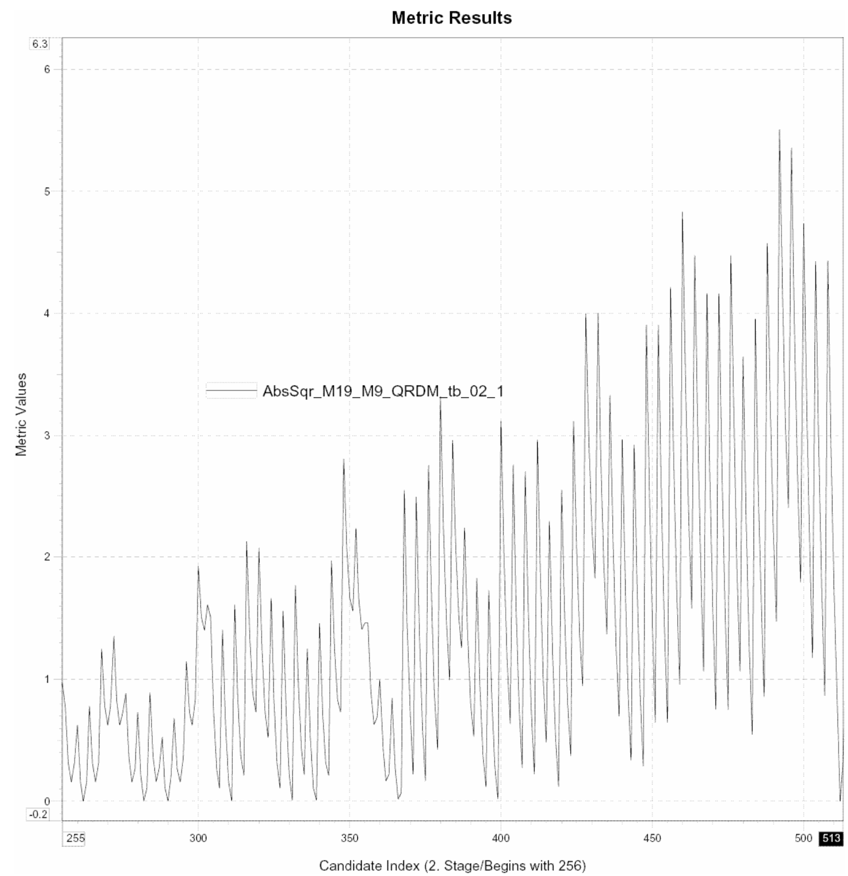
Optimization Idea for QRD-M (1/2)

Metric within the QRD-M Detection (Example: 16 QAM)

Metric Calculation at i =3:

$$m_3^{(p)} = \| R_{3,3}\tilde{d}_3^{(l)} - \left(r_{q3} - R_{3,4}\tilde{d}_4^{(k)} \right) \|^2 + m_4^{(k)}$$





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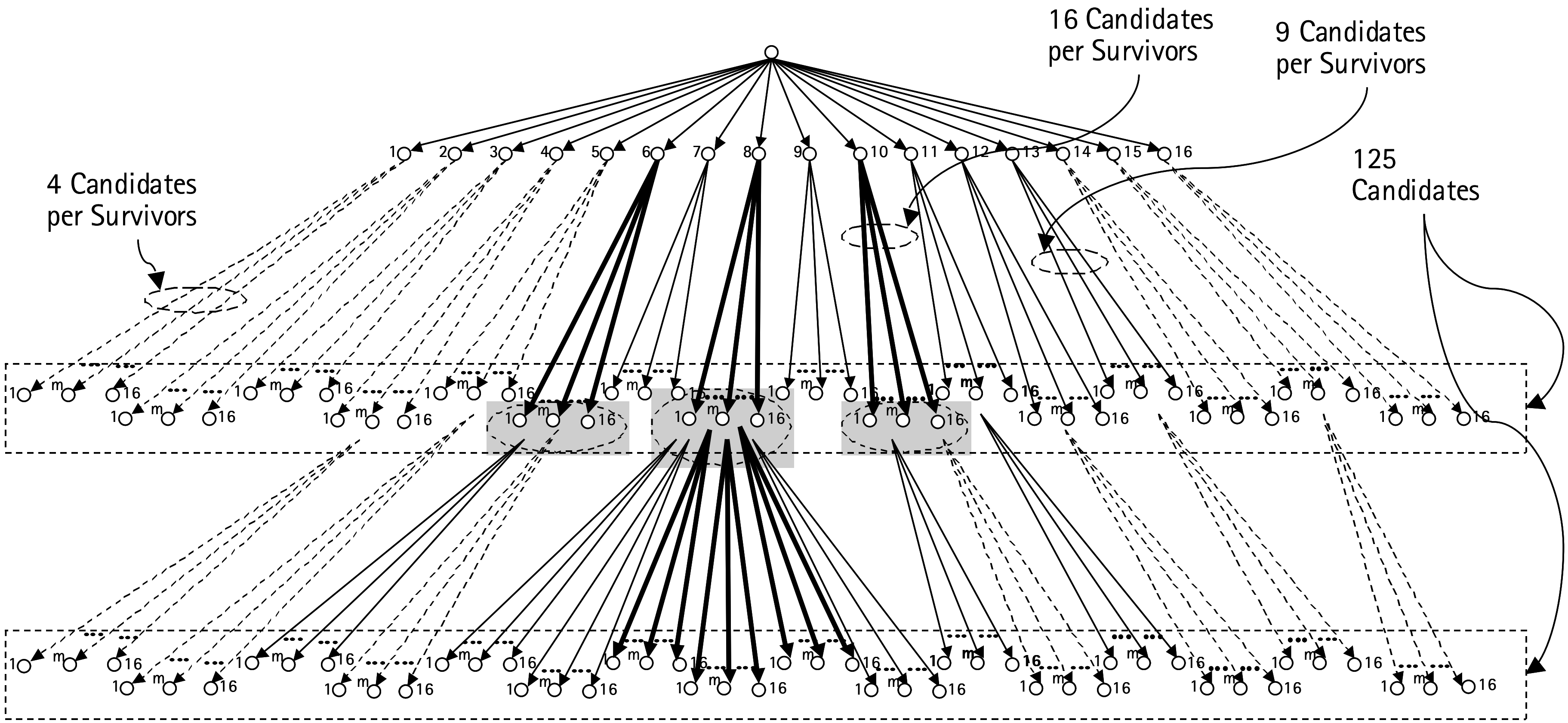
Optimization Idea for QRD-M (2/2)
(Example: 16 QAM)



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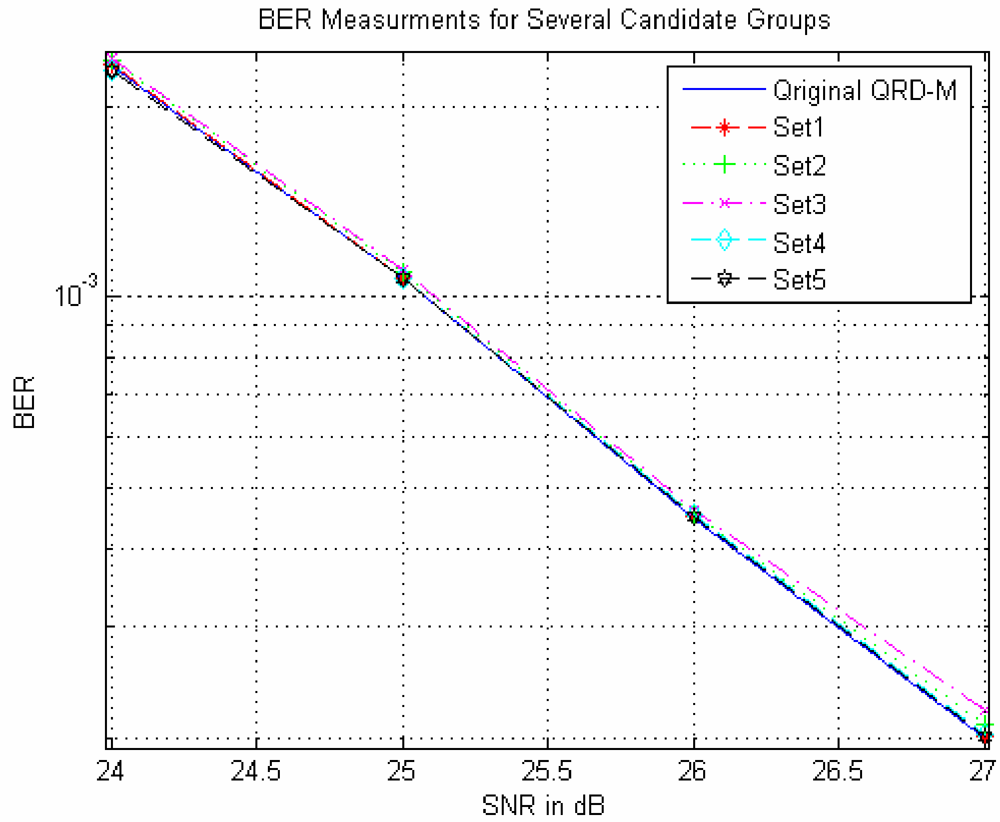
BER Simulation Results for the Analyzed Sets

- Used Channel:
  - 4x4 MIMO (Spatial Multiplexing)
  - Block Flat Fading
  - AWGN

- Analyzed survivor selection set

Set	Number of considered symbols for corresponding survivor (First value for the best survivor/ candidate sum in brackets)
1	16, 16, 8, 8, 8, 8, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3 (97)
2	16, 16, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3 (77)
3	9, 9, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3 (63)
4	16, 16, 16, 16, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4 (116)
5	16, 16, 16, 16, 9, 9, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4 (126)



Conclusion

- The (optimum) maximum likelihood detector is very complex for implementation (large number of constellations and antennas)
- The QRD-M offers significant reduction of complexity and further reduction opportunities
- The optimized survivor selection can reduce the complexity by factor 2
- The optimized survivor selection has the same performance
    - Very simple pre-selection approaches can be used

- Implementation problems:
    - Large block delay
    - Complexity of the M part is high
- In some scenarios the QRDM is not so good as other alternatives

