[700.698] Research Seminar in Embedded Communication Systems

Massive MIMO

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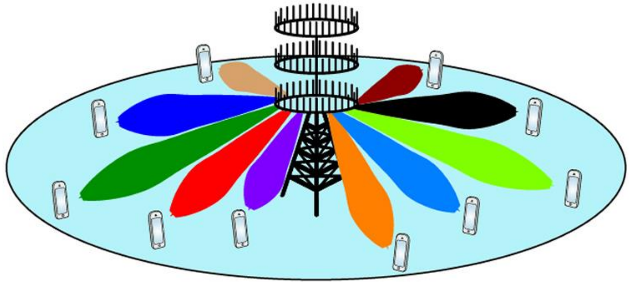
Introduction

- With the increase in the number of mobile users: the mobile traffic has increased, every user wants higher data rate with more accuracy and reliability – challenging.
- Future generation network (5G) must accommodate this traffic and address the current limitation (data rates, reliability, efficiency).
- MIMO is the emerging technology for the next generation of wireless communication systems that can provide: higher spectral efficiency, wider coverage area and better the system capacity.

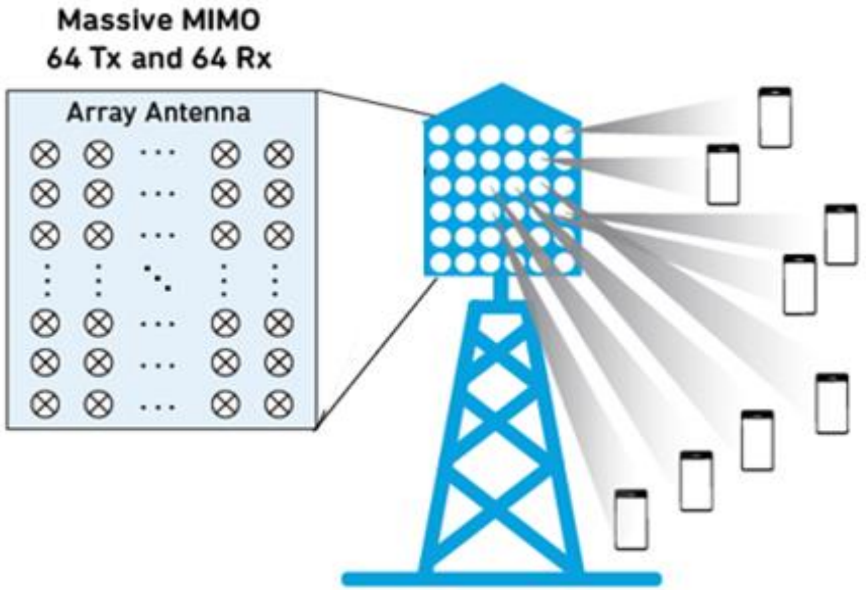
Massive MIMO



- MIMO – multiple input, multiple output - method for multiplying the capacity of a radio link.
- Massive MIMO - groups together antennas at the transmitter and receiver to provide better throughput and better spectrum efficiency.
- „Massive“ - number of antennas, not physical size.
- Uses hundreds or even thousands of antennas at the base station
- Can serve tens of users simultaneously - to achieve high diversity and multiplexing gains to improve reliability and increase data rate.
- The main idea: to maximize the benefits of conventional MIMO, but in a greater scale.

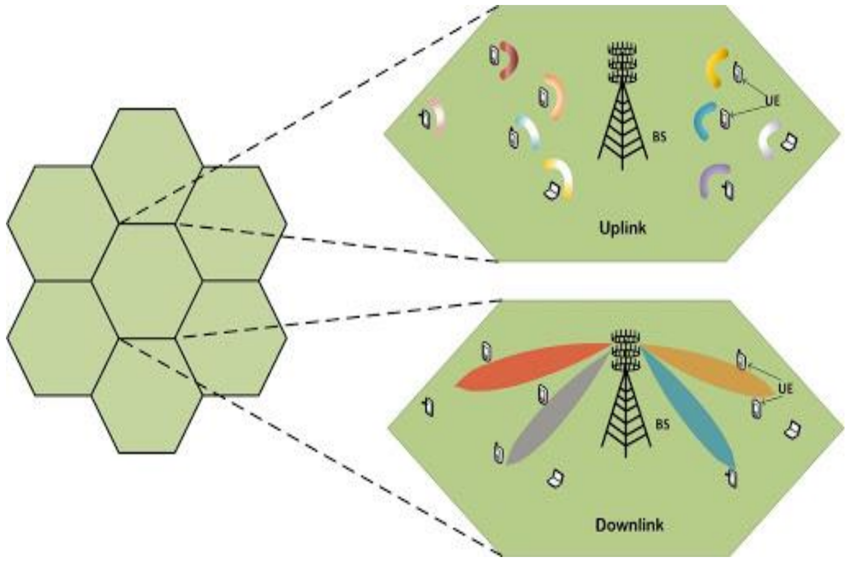
Working principle (1)

- The key concept: to equip base stations with arrays of many antennas, which are used to serve many terminals simultaneously, in the same time-frequency resource.
- Uses large antenna arrays (typically: 16, 32, or 64) to exploit spatial multiplexing which delivers multiple parallel streams of data within the same resource block.
- Expanding the total number of virtual channels - increase capacity and data rates (without additional towers and spectrum).



Working principle (2)

- User sends pilot towards the base station.
- Based on these pilot signals base station estimates the channel between it and the user.
- The base station should have knowledge of channel during both uplink and downlink.
- Massive MIMO is scalable with respect to the number of base station antennas.
- Base stations in Massive MIMO operate autonomously.



Advantages

- High spectral efficiency,
- Antenna array gain,
- High reliability,
- Robustness to internal jamming and interference and
- Energy efficiency.

➢ The higher the number of antennas, the better the performance can be realized.

Challenges (1)

- High computational complexity and poor bit error rate (BER) performance
  - higher number of antennas at the base station and more number of users
  - signals are superimposed at the base station and interfere with each other
  - more advanced processing capability
- Low-cost low-precision components
- Reducing internal power consumption
- Number of antennas
  - Capacity gains and link reliability
  - Increase in system complexity
  - Question: How many antennas should be required to satisfy different service requirements?

Challenges (2)

- Critical factor: the theoretical models which are used for representing the MIMO transceiver.
- Mutual coupling
  - due to electromagnetic interactions between the antennas in both transmitter and receiver.
  - available space for placing the antennas is restrictive
- Previous study: 2.6 GHz – not suitable for future broadband technology (IoT)
- Full-duplex single-channel (FDSC) system (receive and transmit simultaneously on a single channel)
  - double throughput
  - self interference - multiple antennas to transmit signals on the same frequency; strong interference signals at the receiving antennas on the same side

Focus of the presentation

- The number of antennas required to satisfy different service requirements [1]
- The effect of self interference on the system performance (BER and channel capacity) [2]
- The comparison of different algorithms for efficient and low complex uplink detection for Massive MIMO systems [3]

Bibliography

[1] Long, Yin, Zhi Chen, and Jun Fang. "Minimum number of antennas required to satisfy outage probability in massive MIMO systems." *IEEE Wireless Communications Letters* 5.4 (2016): 348-351.

[2] Larashati, Giashinta, Rina Pudji Astuti, and Bambang Setia Nugroho. "Modeling of massive MIMO transceiver antenna for full-duplex single-channel system (in case of self interference effect)." *2017 International Conference on Signals and Systems (ICSigSys)*. IEEE, 2017.

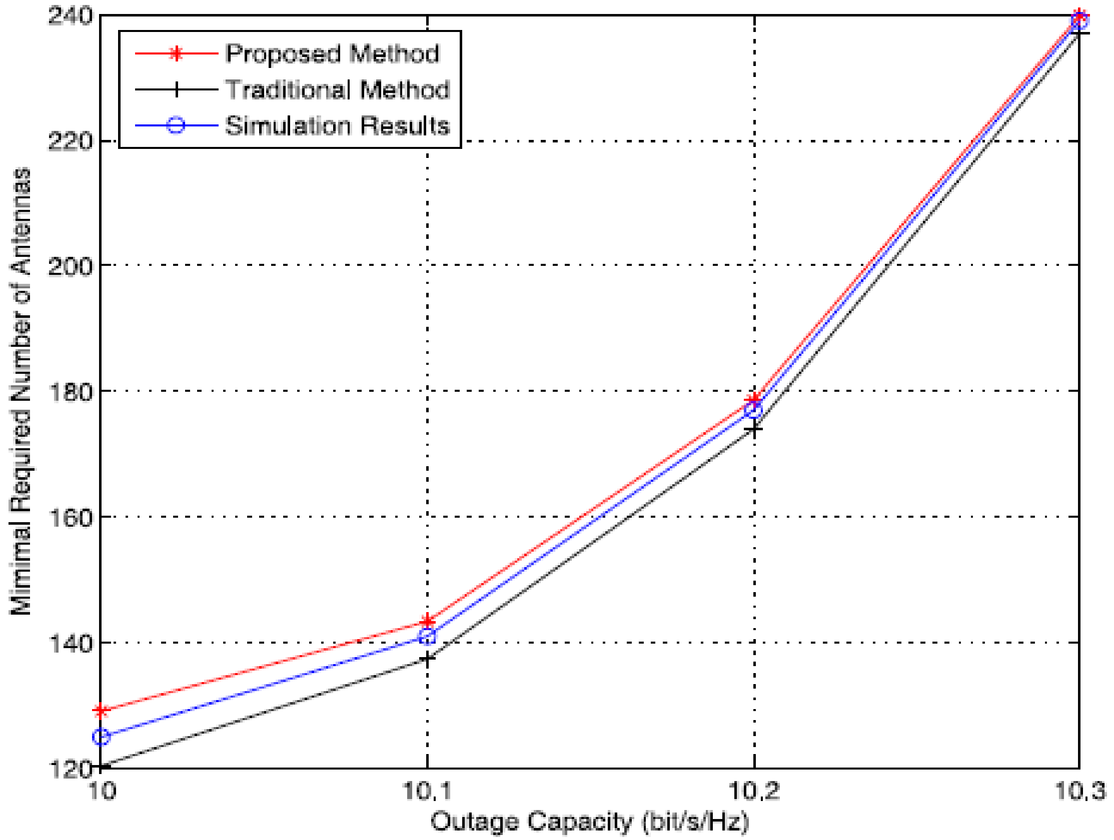
[3] Chataut, Robin, and Robert Akl. "Efficient and low complex uplink detection for 5G massive MIMO systems." *2018 IEEE 19th Wireless and Microwave Technology Conference (WAMICON)*. IEEE, 2018.

[1] Minimum Number of Antennas Required to Satisfy Outage Probability in Massive MIMO Systems

- Novel method is presented using recent non-asymptotic result, rather than calculating the limiting mean and variance of capacity.
- Exploit the statistical bounds on MIMO capacity to derive the equivalent problem of determining the number of antennas needed to satisfy outage probability constraints.
- The equivalent problem is solved by the bisection method.

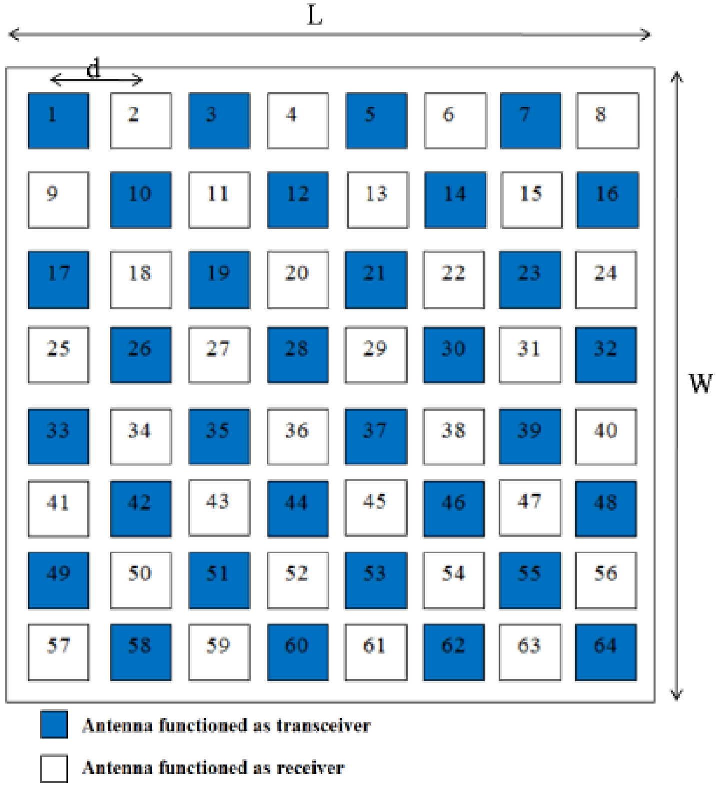
Simulation and Conclusion

- Required minimum number of antennas obtained by:
  - the proposed method is greater than the simulation results,
  - the traditional method is smaller than the simulation results.
- As the required number of antennas increases: approximation error of the proposed method vanishes faster.
- The result obtained by the proposed method is more accurate than that obtained by the traditional method using the Gaussian approximation.



[2] Modeling of Massive MIMO Transceiver Antenna for Full-Duplex Single-Channel System (In Case of Self Interference Effect)

- Massive MIMO transceiver antenna system at 60 GHz.
- The number of antennas that being used in this work is 64x64 - all antennas functioned as receiver and 32 antennas functioned as transmitter.
- The MIMO Coding that being used is Quasi Orthogonal Space Time Block Code (QO-STBC).
- Full duplex single channel - uses the same frequency and time to transmit and receive data.
- The effect of self interference is varied from 10% to 100% - to find the maximum tolerance value of self interference.



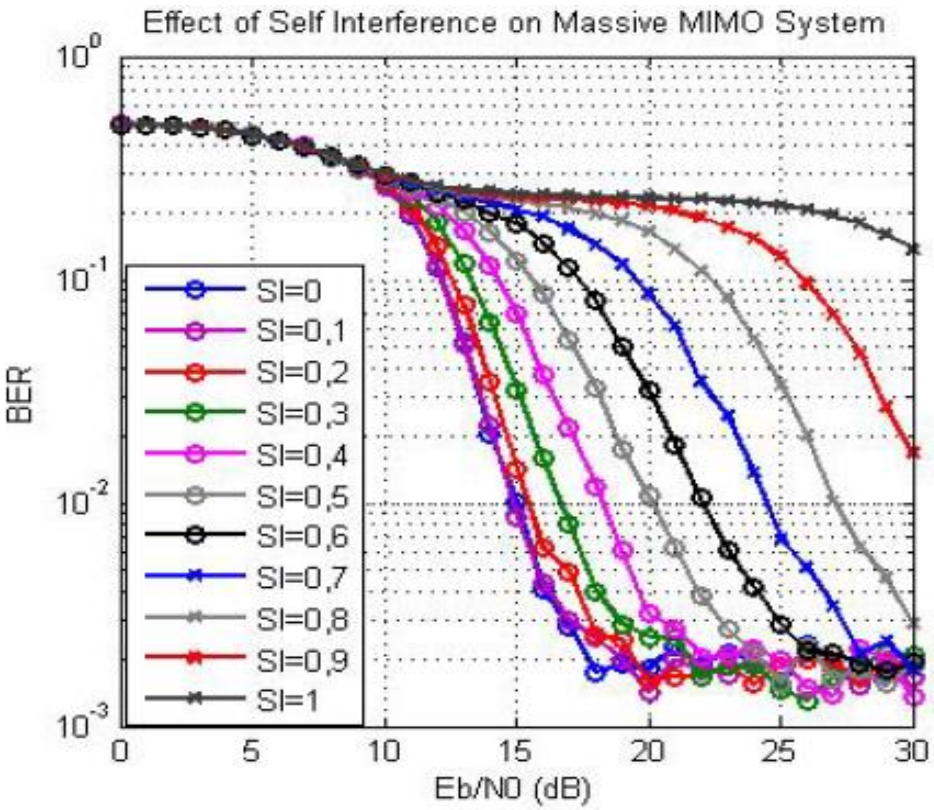
Simulation and Conclusion (1)

- The comparisons of various effect of self interference on the system performance.

➢ <u>The first simulation</u>:

- The purpose: to determine the acceptable tolerance of self interference.
- The effect 10% and 20% of self interference did not significantly affect the BER performance.
- The conclusion: the maximum acceptable tolerance of self interference is 20%.

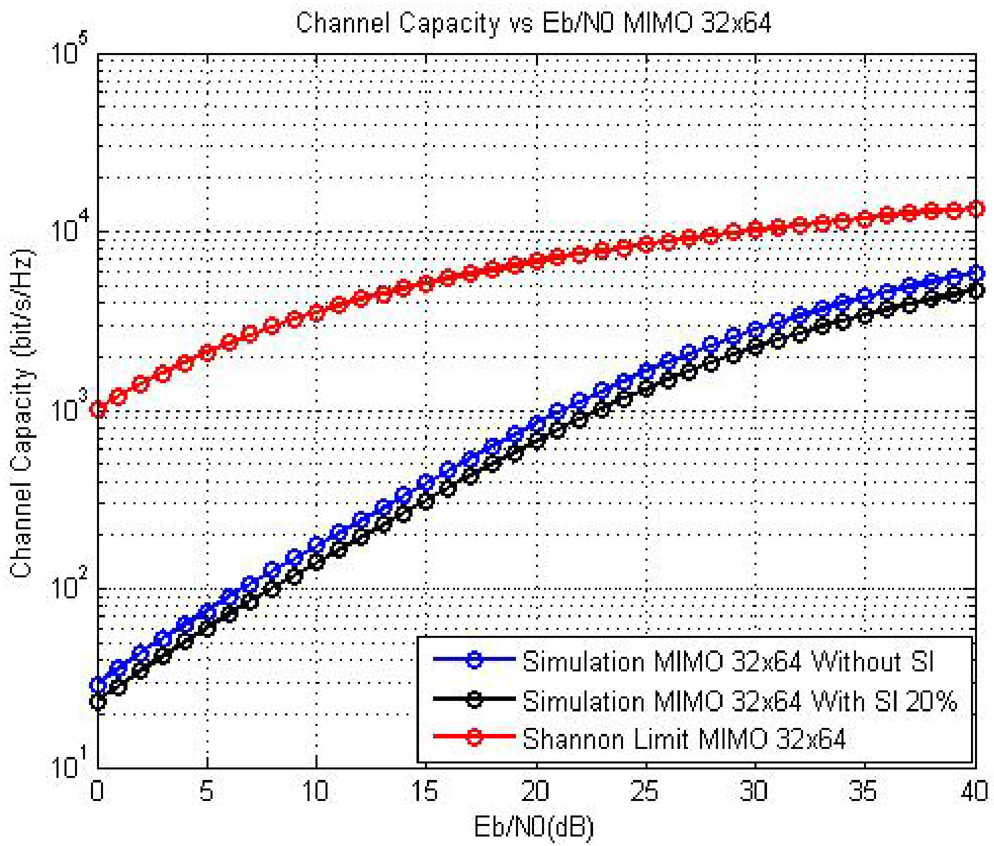
SI	BER
0	0.010013021
0.1	0.008548177
0.2	0.014267578
0.3	0.032138672
0.4	0.071171875
0.5	0.121787109
0.6	0.178525391
0.7	0.206764323
0.8	0.227216797
0.9	0.235016276
1	0.242718099



Simulation and Conclusion (2)

➢ <u>The second simulation:</u>

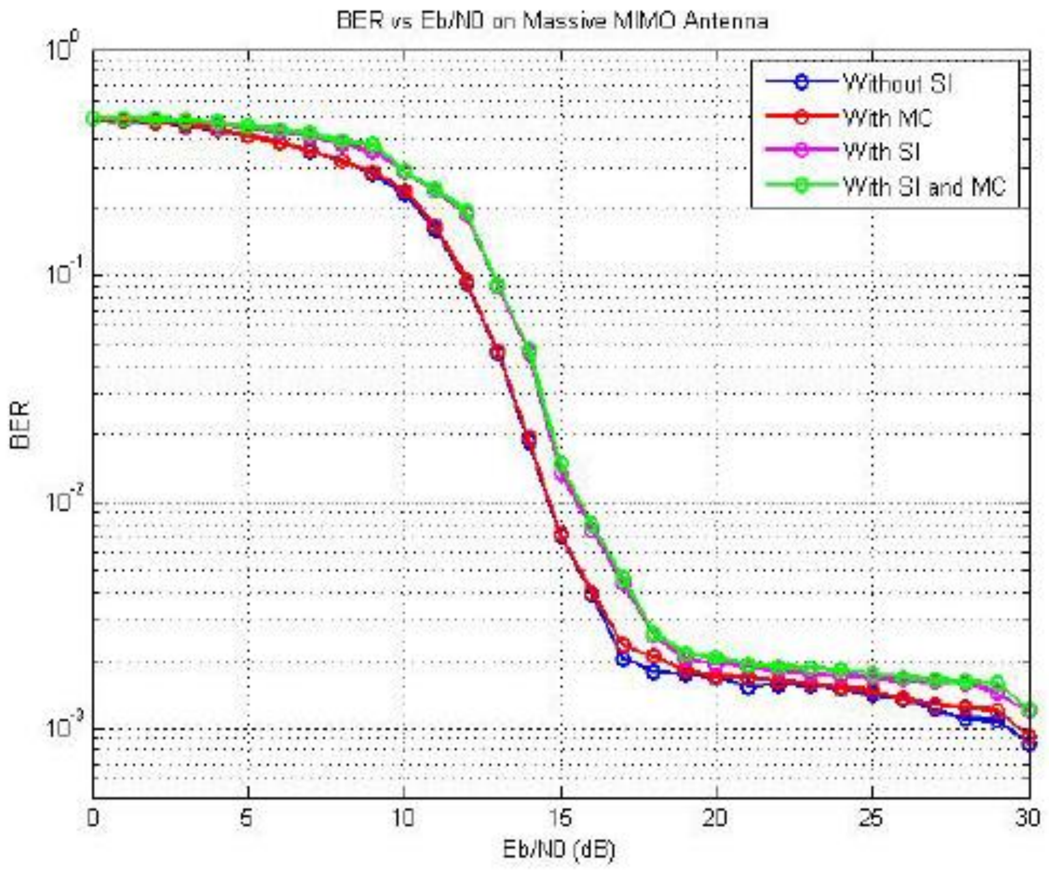
- Effect from 32x64 antennas on channel capacity performance with consideration on an acceptable tolerance of self interference (20%).
- Acceptable tolerance of self interference resulting the channel capacity decreased by 20%.



Simulation and Conclusion (3)

➢ <u>The third simulation:</u>

- How mutual coupling affects the massive MIMO system.
- The mutual coupling effect is equal to zero - the mutual coupling did not affect the performance of massive MIMO system.
- The performance of the massive MIMO system with mutual coupling and without mutual coupling is close to each other.



[3] Efficient and Low Complex Uplink Detection for 5G Massive MIMO Systems

- Detection is required at the base station to separate signal transmitted by each user from the received signal.
- Non-linear and optimal detectors
  - high computational complexity
- Linear detector
  - computationally less complex
  - degraded performance, but satisfactory

Work

- Approximate Message Passing (AMP) algorithm is computationally less complex but its error performance is not very good.
- Proposed algorithm:
  - based on AMP
  - good tradeoff between computational complexity and BER performance
  - efficient for detection of Massive MIMO systems
- During each iteration, they try to minimize the residual error until a maximum number of iteration is reached.

Pseudocode for the proposed algorithm

Detection of Massive MIMO Systems

Initialization: $r^0 = y$

Initialization: $X^0 = 0_{N\times 1}$

for $j = 1$ *to* $j_{maximum}$ **do**

  $\alpha = X^{j-1} + H^T * r^{j-1}$

  $\theta = |\mathrm{real}(\min(\alpha))|$

  $X^j = S(\alpha, \theta)$

  $b = \frac{1}{M} * \frac{\|X\|_2}{\|X\|_1}$

  $r^j = y - H * X^j + b * r^{j-1}$

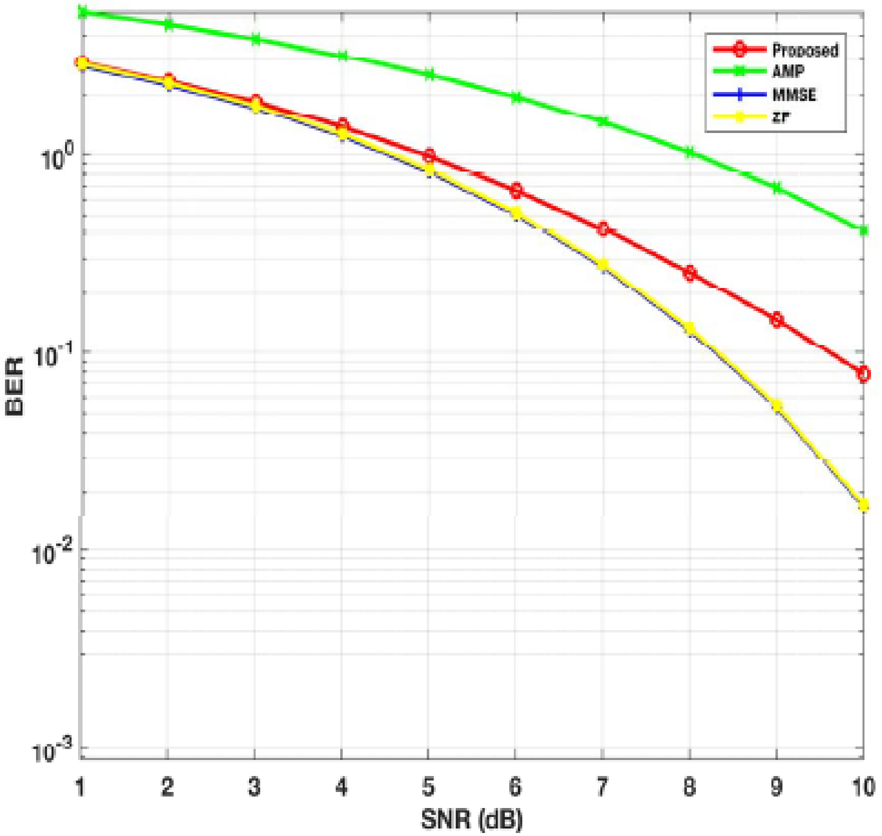
end

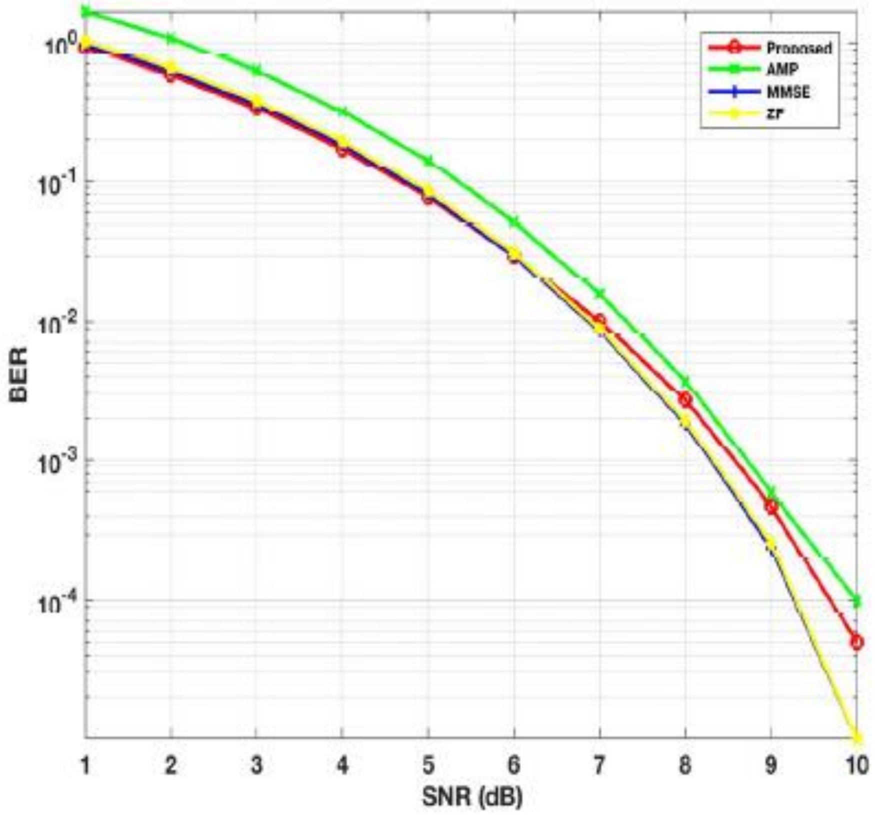
return $X^{j_{maximum}}$

Simulation and Conclusion (1)

➢ <u>The first simulation:</u>

- Approximate Message Passing (AMP)
- Minimum mean square error (MMSE)
- Zero-Forcing

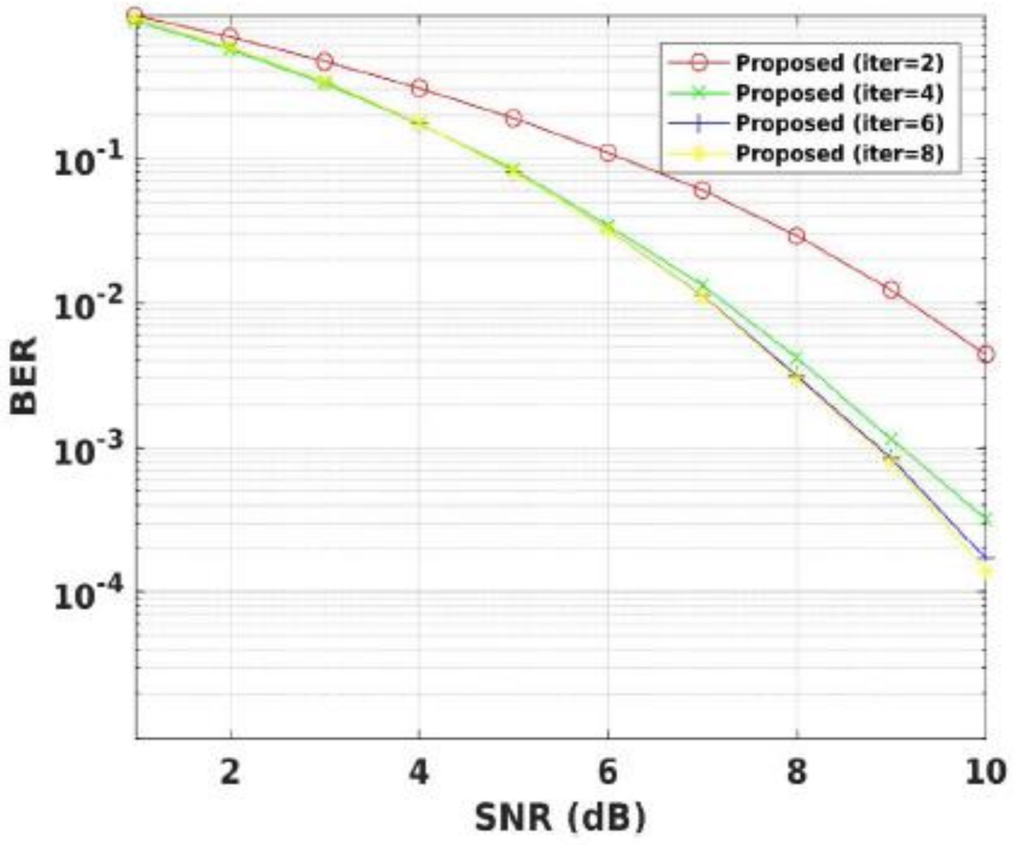




- The proposed algorithm has better BER performance than the AMP algorithm
- All the detection methods have improved the BER performance with the higher number of receive antennas.

Simulation and Conclusion (2)

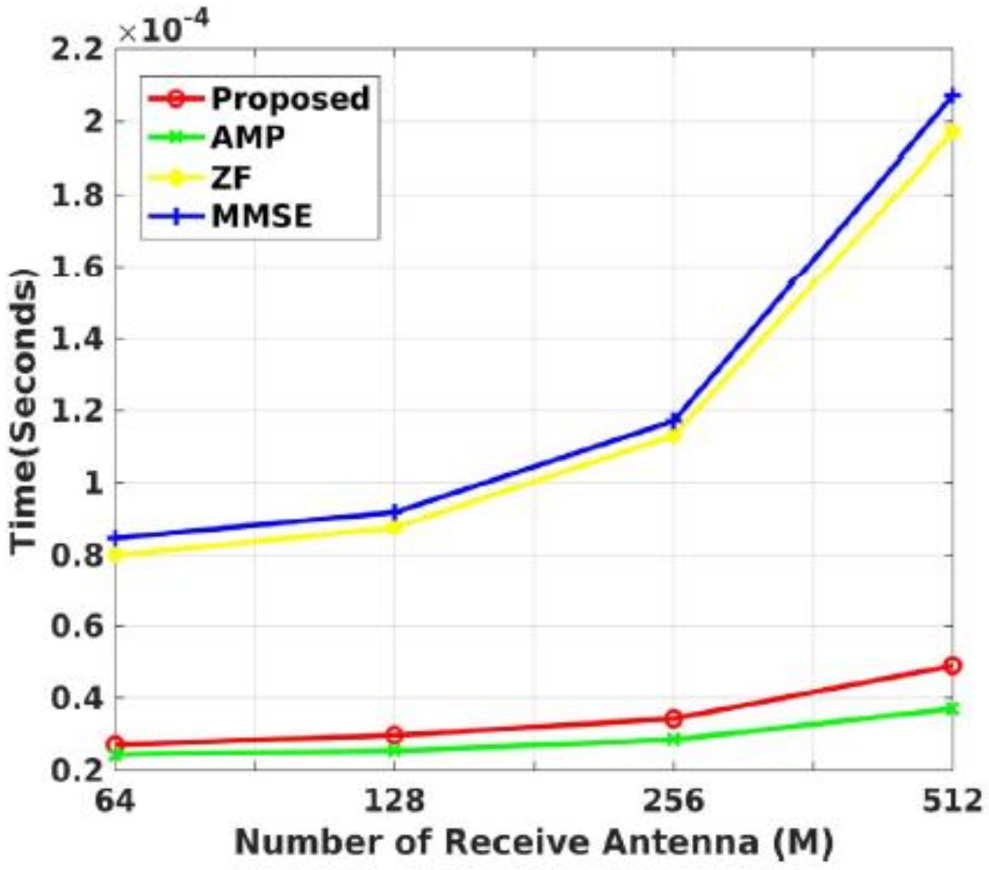
- Figure: the performance of proposed detection method with a different number of iterations.
- BER performance of the proposed algorithm will increase with an increase in a number of iterations.
- The performance will saturate after a certain number of iterations is reached.



Simulation and Conclusion (2)

➢ <u>The second simulation:</u>

- Comparison in complexity.
- With higher number of receive antennas complexity
  - increases drastically for ZF and MMSE
  - Increases slightly for proposed and AMP
- The proposed algorithm has complexity less than that of ZF and MMSE and it has almost similar complexity as AMP algorithm.



Thank You!