Exploration of Massive MIMO in 5G and its Detection Schemes

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Abstract— **Recently, there has been a major increase in the amount of mobile devices and handheld devices that are capable of having mobile data. With these devices, the demand for mobile data has massively increased. These devices give a lot more people a way to stream video, and various other internet protocols including M2M (machine to machine) communication. Having internet on a personal handheld device has drastically increased the number of things possible, which has in turn made having better data rates a necessity. The technology that's looked forward to the most for this demand is 5G and beyond 5G, as it aims to meet this large data rate, giving us the possibility of having GBps's of data with near 0 latency. A technology that can be used in 5G infrastructures that has huge potential is Massive MIMO (multiple input, multiple output). Using them in a 5G network promises data rates that are 100 times more than data rates provided by the standard LTE networks. They also aim to provide high spectral efficiency along with the energy consumed being less. However, this also comes with a few challenges that need to be dealt with to use them as we desire due to their massive size and large dimensions, such as parameter estimation and proper signal detection. A major constriction in getting the required benefits is designing realistic detectors with low complexity, since these systems are so massive. We hence look at different MIMO detection algorithms, and try to find one which has low and achievable computational complexity, along with desired performance which can work at a large scale with multiple transmit antennas. We review various detection algorithms, and check the ones designed for small / medium dimensions too, and combinations of them that might solve our problems. In this review we hence find that there's no single detector that is ideal for every situation we require massive MIMO to perform in, and we still can't achieve the best possible performance with low complexity required, and this is still a problem open to research.**

***Index Terms*— 5G network technology, Detection algorithm, Low complexity, Massive MIMO, Spectral efficiency.**

I. Introduction

There is an increasing demand for lesser latency and higher data rates with the huge increase in number of mobile communication devices available. Due to this, there is also a necessity to make use of the currently available spectrum better. MUMIMO (Multi user MIMO) helps us make the efficiency of the spectrum better since it lets a BS (base station) transmitter to communicate with many different MS (mobile stations) receivers at the same time, making use of the same time and frequency bands. Massive MIMO lets the order of the number of BS antennas be 10's or 100's. This increases the possible data streams in a cell to be of a very large value. 5G wireless systems also make use of mmWave (millimeter wave) bands, to make use of a much wider bandwidth. They also use antenna arrays on a large scale, to reduce the huge propagation loss in mmWave band. The wavelength in this band is a lot smaller than current wireless systems. Though this lets an array to store many more elements in a particular physical dimension, it gets a lot more expensive to make an RF chain or 1 TR (Transmit Receive) module. An answer to this is hybrid transceivers, as they combine analog beam formers in the radio frequency along with digital beam formers in baseband frequencies, and has less RF chains than transmit elements.

II. 5G and Beyond

The communication, data services that awaits in the near future requires a new network technology. This network service must provide higher multi-Gbps peak data speeds, ultra-low latency, more reliability, massive network capacity, higher performance and improved efficiency, and a more uniform user experience to more users.

A new mobile generation is introduced at nearly every decade since its inception with 1G network. Every upgrade has brought in magnificent amount of changes that defined communication for that decade. We are in the early stages of 5G network, we are yet to experience its fullest extent of services.

So what can we expect beyond 5G?

We can expect that 6G will explore and include relevant technologies that will be left out from 5G due to being too 'experimental and yet to prove', being too late or because it is just outside the defined scope of 5G. For beyond 5G networks, the key drivers will be the convergence of all the previous features such as low energy consumption, massive connectivity, high reliability, high throughput, network densification. It will continue the features of the previous generations with the addition of new services and technologies. It is also known to include Artificial intelligence (AI), implants, and smart wearables, computing reality devices, autonomous vehicles, 3D mapping and sensing. And the most important feature for beyond 5G network ought to be the capability of handling massive volumes of data and have an extremely high data rate connectivity per device.

The future generations are meant to increase performance and increase user QoS several times more than 5G. This will help secure the user data and the system. The per-user bit rate in beyond 5G network is estimated to be 1Tb/s in most of the cases. The wireless connectivity is meant to be 1000 times higher than 5G which is very useful as we move to an autonomous society. And as for the ultra-long range communication, it is expected to have less than 1ms latency which is fantastic for cloud gaming which is expected to be the future of gaming.

The most impressive feature of beyond 5G technology is the inclusion of fully supported AI for driving autonomous systems. We will finally be able to stream 8k and possibly 16k videos if supported by YouTube and other streaming services with ease. The most important technologies that will be enriched with the availability of beyond 5G technology are- the terahertz band, AI, optical wireless communication, 3D networking, unmanned aerial vehicles, and wireless power transfer.

A. *Abbreviations and Acronyms*

MIMO- Multiple Input Multiple Output, MUMIMO-Multi user MIMO, BS-Base Station, mmWave-millimeter wave, MS-Mobile Stations, TR-Transmit Receive, 5G- Fifth Generation, BER- Bit Error Rate, SNR- Signal to Noise Ratio, RF-Radio Frequency.

III. BEAMFORMING, SPECTRAL EFFICIENCY, BIT ERROR RATE

As above mentioned latest communication needs the use of Massive MIMO and the efficiency of particular MIMO array antenna type is estimated using the below techniques.

Beamforming, spectral efficiency, BER these aspects of a Massive MIMO array antennas define its ability to decide the course of intrigue and send/receive a stronger beam of signals in that specific direction, to calculate the total system error mistake execution, to estimate the number of users before saturation of signal due to coherence.

A. *BEAMFORMING:*

Beamforming is a procedure by which an array of antennas can be controlled to transmit radio signals a particular direction. Instead of just broadcasting energy/signals in all direction, the antenna use beamforming , decide the course of intrigue and send/receive a stronger beam of signals in that specific direction as shown in Fig(1).

This method is largely used in radars and most importantly in communications mainly 5G, Where high information rates are required and the best way to help this is amplify transmit and get proficiency by utilizing beamforming.

In this procedure, every antenna component is taken care of independently with the sign to be transmitted. The phase and amplitude of each signal is then included valuably and dangerously so that they move the energy into a narrow beam or lobe.

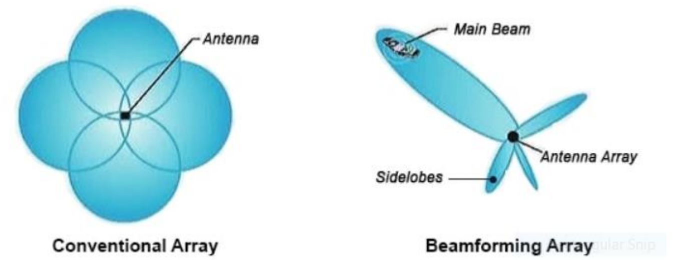

Figure 1: Difference between conventional array and Beamforming array

The basic flow chart of variations in beamforming technique. This also defines the architecture of beamforming architecture in a structural manner.

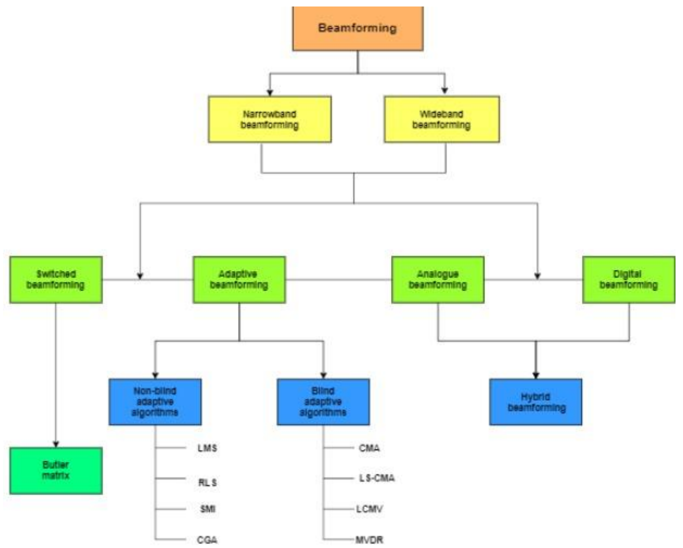

Figure 2: The basic architecture of beamforming procedure

Here we can notice a difference between fully digital beamforming and Hybrid beamforming.

This difference can be briefly explained as follows:

(1) Digital has RF chain equal to their number of transmit antennas on transmitter side and equal to receive antennas on receiver side

(2) Hybrid beamforming involves less usage of RF chains

B. *Spectral efficiency*

An incredible method to improve the spectral efficiency is to at the same time serve numerous client terminals in the cell, over a similar data transfer capacity, by methods for space division multiple access. This is the place Massive MIMO is above all else. There is no uncertainty that this innovation can improve the spectral efficiency.

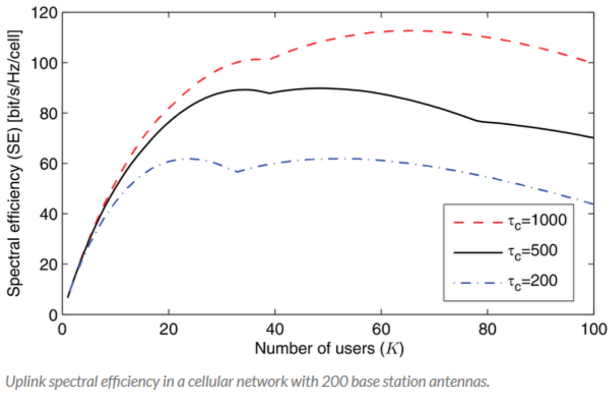

Figure 3: Spectral efficiency in a cellular network with 200 base station antennas

Fig (2): Spectral efficiency in a cellular network with 200 base station antennas.

From the above graph fig (2) it can be said that the spectral efficiency grows linearly with the number of users for initial 40 users. For large number of users, the spectral efficiency saturates due to interference and limited channel coherence. The top value of each curve is in the range from 60 to 110 piece/s/Hz, which are astounding upgrades over the 3 piece/s/Hz of IMT Advanced.

The Spectral efficiency of various antenna arrays with different RF chains is being estimated and certain inferences are made:

i. 16*4 with 4 RF at both the ends

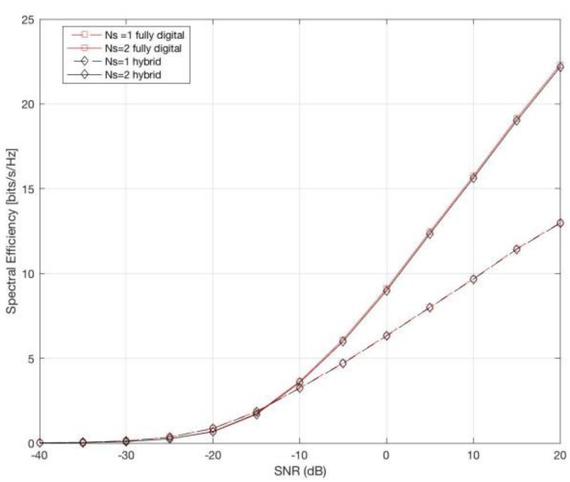

*Figure 4: Spectral efficiency v/s SNR for 16*4 with 4 RF at both the ends*

ii. 64*16 with 4RF at both the ends

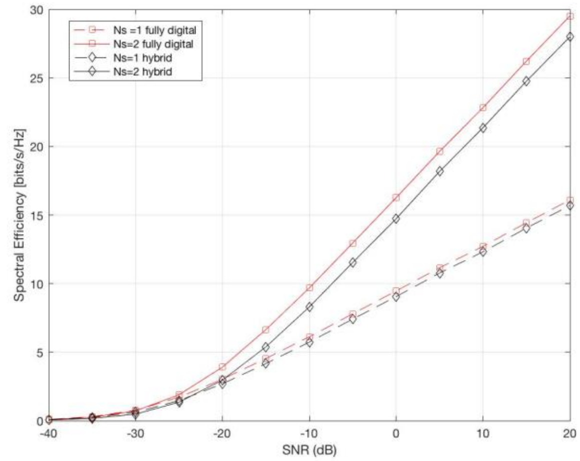

*Figure 5: Spectral efficiency v/s SNR for 64*16 with 4RF at both the ends*

iii. 64*16 with 8RF at both the ends

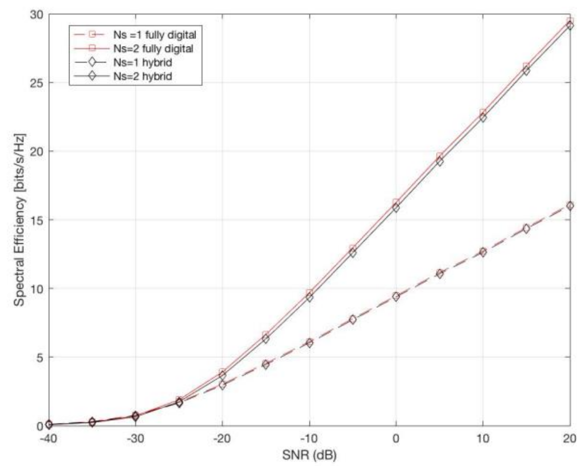

*Figure 6: Spectral efficiency v/s SNR for 64*16 with 8RF at both the ends*

iv. 256*64 with 8RF at both the ends

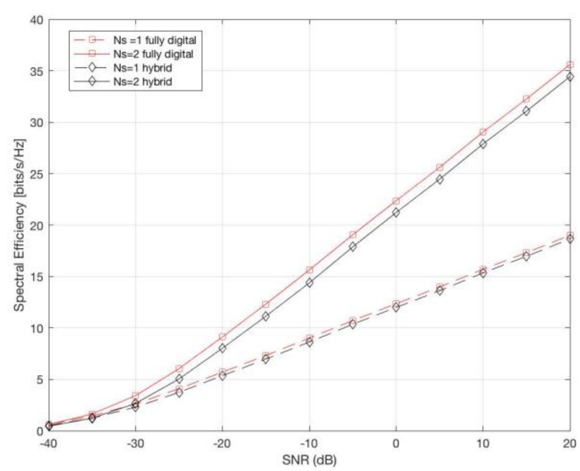

*Figure 7: Spectral efficiency v/s SNR for 256*64 with 8RF at both the ends*

Inference from above figures is as follows:

The above figure 4, figure 5, figure 6, figure 7 plot the spectral efficiencies achieved in 16X4 with 4RF, 64X16 with 4RF, 64X16 with 8RF and 256X64 with 8RF at both the ends MIMO systems with different number of RF chains respectively.

Comparing the spectral efficiency of 16X4 MIMO system (4RF chains) with 64X16 MIMO system (4RF chains), it has been observed that the spectral efficiency is improved in 64X16 MIMO system.

Comparing the spectral efficiency of 64X16 MIMO system (4RF chains) with 64X16 MIMO system (8RF chains), it has been observed that the spectral efficiency of the hybrid system almost matches the spectral efficiency of fully-digital system when the number of RF chains are increased. But, increase in RF chains will increase the cost of the system and the difference between the spectral efficiency in the above MIMO systems with 4RF chains and 8RF chains is very minute and thus we can use less RF chains and reduce cost and power of the MIMO system.

C. Bit Error Rate (BER):

Bit Error Rate (BER) calculates the total system error mistake execution. Execution gain accomplished for Single Input Single Output (SISO), Single Input Multiple Output (SIMO), Numerous Input Single Output (MISO) and MIMO has been thought about for an alternate blend of reception apparatuses by evaluating the BER over a scope of Signal-to-Noise Ratio (SNR).

Bit Error Rate, BER is utilized as a significant parameter in describing the performance of information channels. When transmitting information starting with one point then onto the next, either over a radio/remote connection or a wired media communications interface, the key parameter is what number of errors will show up in the data that shows up at the remote end.

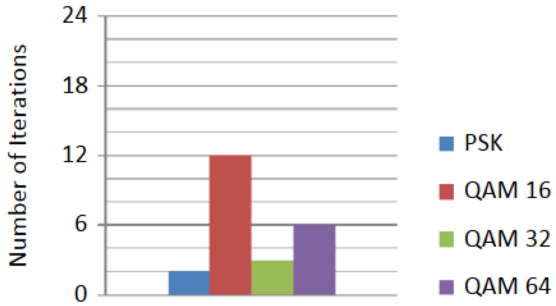

Figure 8: Minimum number of Bit Error Rate for different Modulation techniques

IV. DETECTION TECHNIQUES

Detection Schemes

A. Conventional detection schemes

i. Matched – Filtering

The matched filters also known as the maximum ratio combining receivers (MRC) are the ones with least complexity and detect linearly and are also the practical choice for massive MIMO systems. Their performance depends on two factors mainly and they are available antennas number and SNR of the operating channel. We can obtain the highest SNR by using these receivers and also ignore influence of interference caused by multiusers. These receivers also make signal processing process very easy. However, one of the drawbacks of these receivers are in situations where interference is limited the effects of interference caused by multiusers is not addressed properly but these receivers consider the effects caused by noise which are often not addressed by ZFRs.

ii. MMSE

MMSE also known as minimum mean square error receivers are another practical choice when it comes to massive Multiple Input Multiple Output (MIMO) systems. The above mentioned systems makes use of the spatial diversity phenomenon to see an increase in the data rates and the spectral efficiency. The major obstacle in this systems design is in the data detection complexity and the receiver end. MMSE receivers mainly focus on reducing mean square error of the transmitted signal and the estimated signal. The performance of these systems have been looked at and also carefully reviewed from multiple viewpoints based on the characteristics of different linear receivers. The results showed us that these MMSE receivers perform very similar to that of the MF receivers with much lesser antennas, specifically under conditions involving interference. Maximum Likelihood (ML) criterion is the most widely used MIMO data detection technique. ML detection does give us the proper solution but it still encounters problems because it has a high computational complexity. Hence we have to look at the other variations of MIMO detection schemes to get both better performances and lesser complexities. MMSE receivers have also been compared to the ZFR receivers and the performance can be seen to be slight enhanced in the case of MMSE receivers but one issue is that the noise variance must be given at the receiving MMSE. This causes complexity issues with systems which have large number of antennas and hence in the case of massive MIMO systems ZFR have been focused upon in recent studies.

iii. SIMO

Single Input Multiple Output also known as SIMO is a type of MIMO which occurs when we have multiple antennas at the receiving end and a single antenna at the transmitting end. This phenomenon is also called as receiver diversity. This detection scheme is useful when we have a receiver system which is receiving information from multiple independent sources and is effective in reducing the effects of fading. SIMO detection schemes are also very prevalent in underwater optical wireless communication which undergo high turbulence and scattering effects. This detection scheme has been in use for many years now with the use of short wave listening and receiving stations to remove or lessen the effects of fading and interference caused by the ionosphere.

B. Approximate Inversion Based Detection

i. *Neumann – Series Approximation*

The traditional detection schemes suffer from a lot of issues pertaining to either low complexity or high performance and hence to counter these issues we look at the Neumann series approximation. This is very apt for large MIMO systems containing large number of antennas and is very suitable for the hardware implementation aspect too.

ii. Gauss – Seidel Detection

Compared to the Neumann series approximation the Gauss Seidel detection algorithms are inversion matrix independent and hence have been found to be more efficient in terms of detection. The basic methodology behind these algorithms is to merge the expected iterative step of (n+1) with iteration of the previous step i.e. (n-1). These algorithms have shown to produce massive improvement in the convergence speed of the iterative schemes. Theoretically after analyzing these algorithms, studies have found that they reduced the complexity of computation from O (N3) TO O (N2), where the N denotes the number of users. The simulation results of these algorithms (DRGS) have also shown and verified that we can achieve performance almost similar to that of MMSE Detection with a small number of iterative steps.

iii. Conjugate – Gradient Detection

In MIMO systems we use the CG detection scheme to reduce the data detection (uplink) and its pre-coding (downlink) complexity. While it is pretty direct to pre-code using CG detection schemes, soft output data detection based on CG gives us a reason to compute the post equalization signal to interference and noise ratio (SINR), and this needs the explicit inverse of the channel matrix. Also when these algorithms are compared based on their exact and approximate methods, the results showed that the methodology proposed performs so much better than the algorithms that already exist for massive MIMO systems with realistic antenna configurations.

C. Box detection based methods

i. ADMIN detection algorithm

The Admin algorithm is an iterative algorithm and it has performance outmatching those of linear detectors on the condition that the number of users is minimal compared to that of the number of antennas present in the BS i.e. Base Station. The algorithm has a large number of iterations and in its first iteration it calculates the solution for the linear minimum mean square error i.e. MMSE. This algorithm is performed as an application specific integrated circuit i.e. ASIC and also as a FPGA (Field Programmable Gate Array). It also utilizes a multimode pre-coder ASIP. This algorithm multiple features in its primary design such as scheduling based on norms, QR decomposition, Pre-coding of MMSE and dirty paper coding (DPC) related pre-coding.

ii. OCD detection algorithm

This algorithm lets us implement pre-processing with bare minimum hardware overhead and it's because of its regularity algorithmically (OCD). The algorithm also enables us to get VLSI system designs with very high throughput which are usually less complex than those state of the art designs. This is also applicable to designs and systems which have huge number of base station antennas and tens and thousands of subcarrier stations.

V. WORKING WITH THE 'MIMO' ARRAY ANTENNAS WITH VARIOUS DETECTION SCHEMES

Here in this sub-heading the MIMO antenna characteristics for different detection schemes is being estimated using various matlab techniques

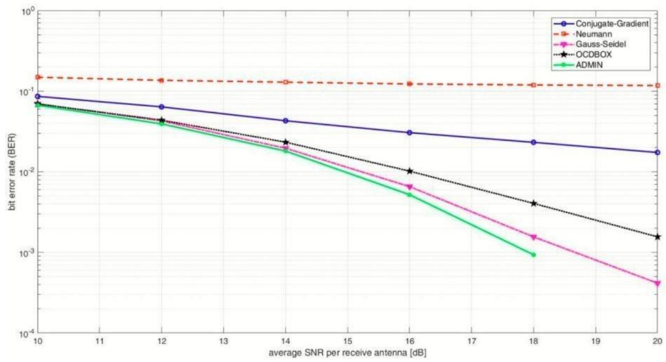

Figure 9: Simulation result of BER v/s average SNR per receive antenna for different detection schemes

We analyzed how the average SNR per receive antenna varies with the bit error rate,

We see that the ADMIN filter from the BOX detection methods engages with the maximum variation whereas the Conjugate Gradient varies the least.

VI. FUTURE TRENDS AND EMERGING TOPICS

In this segment, we examine some future signal identification and estimation trends in the area of massive MIMO systems and point out certain topics that may attract analysts. The topics are organized as:

A. Signal detection:

Decoding strategies with low delay: In audio and video streaming, the development of decoding strategies for DAS configurations with reduced delay will play a key role because of their delay sensitivity. Hence, we novel message passing algorithms with more brilliant strategies to trade data ought to be examined along with their application to IDD schemes.

B. Cost-effective detection algorithms:

Techniques to perform dimensionality reduction for identification issues will assume a significant role in massive MIMO devices. If the number of effective processing elements are reduced then the detection algorithms can be applied. To remove the complexity gap between RMF and costly detectors the development of schemes based on RMF with non-linear interference cancellation capabilities can be a good option.

C. Mitigation of impairments:

The delays caused by DAS schemes need mitigation by smart signal processing algorithms. The identification of impairments started in the RF chains of massive MIMO systems .For instance, I/Q imbalance may be managed utilizing widely- linear signal processing algorithms.

D. Detection techniques for multicellular scenarios:

The advancement of detection algorithms for situations with multiple and little cells requires approaches which limit the requirement for channel state data from adjacent cells and the decoding delay.

E. Parameter estimation:

Blind algorithms: For mitigating the problem of pilot contamination, the development of blind estimation algorithms for the channel and receive filter parameters is important.

F. Reduced-rank and sparsity-aware algorithms:

The advancement of reduced-rank and sparsity-aware algorithms that exploit the numerical structure of massive MIMO channels is a significant point for the future along with features that lend themselves to execution.

VII. RESULT

The results of Spectral efficiency for different array antenna setups for different RF chains is obtained and were inferred as antenna array with more number of antennas showed higher spectral efficiency when compared smaller antenna array.

However with the increase in RF chains the increase in increase in spectral efficiency is very and is also not cost efficient.

Therefore antenna arrays with larger array size and required RF chains is proven to have better spectral efficiency and working.

Some important detection schemes were also discussed and the best for each function of the array antenna is mentioned.

From the above mentioned detection schemes ADMIN detection method showed larger variations in bit error rate (BER) when compared to conjugate gradient detection from Approximate Inversion Based Detection

VIII. CONCLUSION

This chapter has presented signal detection and estimation techniques for multiuser massive MIMO systems. We consider the application to cellular networks with massive MIMO along with CAS and DAS configurations. Recent signal detection algorithms have been discussed and their use with iteration detection and decoding schemes has been considered. Parameter estimation algorithms have also been reviewed and studied in several scenarios of interest. Numerical results have illustrated some of the discussions on signal detection and estimation techniques along with future trends in the field.

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