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MASSIVE MIMO: DESIGN, APPLICATION AND CHALLENGES

MASIVNI MIMO: DIZAJN, PRIMJENA I IZAZOVI

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Abstract: In this paper we present an overview of massive Multiple-Input Multiple-Output (MIMO) technology and its most important concepts. The concepts analysed in the paper include: beamforming, antenna parameters, pilot contamination and modulation. The paper provides the guidelines for achieving a good design of antenna array and beamforming, and proposals to address the challenges faced by the massive MIMO technology. The main advantages of the massive MIMO technology include significantly improved network throughput and lower latency, which is why the massive MIMO is expected to be used in the architecture of various systems. The paper presents examples of the application of massive MIMO technology.

Keywords: MIMO, Network throughput, Internet of Things, Application

Sažetak: U ovom radu dat je pregled tehnologije masivni MIMO i njegovih najvažnijih koncepata. Koncepti analizirani u radu su: formiranje snopa, antenski parametri, pilot kontaminacija i modulacija. Također, u radu su date smjernice za dobar dizajn antenskog niza i tehnike formiranja snopa, kao i prijedlozi za rješavanje izazova sa kojim se suočava tehnologija masivni MIMO. Glavne prednosti tehnologije masivni MIMO su znatno poboljšanje mrežne propusnosti i manja latencija, zbog čega se očekuje primjena tehnologije masivni MIMO u arhitekturi različitih sistema. U radu su prikazani primjeri primjene tehnologije masivni MIMO.

Ključne riječi: MIMO, mrežna propusnost, internet stvari, aplikacija

INTRODUCTION

Wireless communication has been revolutionizing every decade with a new standard, which has been fuelled by a combination of market demands and technology advancement. The new standard, the fifth generation (5G), is in the research phase, with its commercialization expected in 2020.

5G technology will provide an innovation platform, which will be the basis for development of the new and improvement of the existing technologies, such as the Internet of Things (IoT), which will become integral parts of our economy and lifestyle. The 5G network will spur innovation across many industries, providing new features such as precise remote control, near-instantaneous communication, seamless connectivity, the use of autonomous vehicles, remote controlled equipment, smart houses, etc. These innovations will improve the quality of life for the wider population [1].

Although various new technologies will be developed for the needs of the 5G standard, the massive multi-input multi-output (MIMO) will be the most important of all, because it is precisely through spatial multiplexing and beamforming techniques (the basis of massive MIMO technology), that it will be possible to achieve the required spectral efficiency of the new communication standard.

The massive MIMO technology (also known as Large-Scale Antenna Systems, Very Large MIMO, Hyper MIMO and Full-Dimension MIMO), uses hundreds and more antenna elements on the base stations to direct signals to multiple individual users, which significantly increases system capacity and number of connected devices, and takes MIMO to an entirely new level. There are no strict requirements on the relation between the number of base station antennas and users, but the more antennas used, the finer the spatial focusing can be, making the dramatic increase in energy efficiency. This improved energy efficiency enables massive MIMO systems to operate with a total output Radio Frequency (RF) power at two orders of magnitude less than the current technology.

The use of large number of antennas at the base station is instrumental not only to obtain high sum spectral efficiencies in a cell, but, more importantly, to provide uniformly good service to many terminals simultaneously. An additional consequence to using large number of antennas is that the required signal processing and resource allocation simplifies signal processing and allocation of resources, owing to a phenomenon known as channel hardening. The significance of channel hardening is that the effects of small-scale fading and frequency dependence disappear when number of base station antennas is large [2].

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Some benefits of massive MIMO include: extensive use of inexpensive low-power components, accurately tracking of individual users, array gain, reduced latency, simplification of the Medium Access Control (MAC) layer, robustness against intentional jamming, coverage extension, spatial multiplexing, increase of capacity by 10 times or more and simultaneously improved radiated energy-efficiency in the order of 100 times, etc.

Another advantage of massive MIMO lies in its potential energy efficiency compared to a corresponding single-antenna system. It is shown in [3] that each single-antenna user in a massive MIMO system can scale down its transmitting power proportional to the number of antennas at the base station with perfect Channel State Information (CSI) or to the square root of the number of base station antennas with imperfect CSI, to get the same performance as a corresponding single-input single-output (SISO) system. This leads to higher energy efficiency and is very important for future wireless networks where excessive energy consumption presents a growing concern [4].

In order to meet the requirements of pedestal 5G, apart from the massive MIMO technology, it is proposed to work in a millimetre wave. 5G systems deployed in higher frequency bands such as centimetre Waves - cmWaves (6–30 GHz) and millimetre Waves - mmWaves (30–100GHz), large-scale antenna arrays will be a prerequisite for overcoming the poor propagation characteristics in those bands [5].

In [6] combination of millimetre wave communications, arrays with a massive number of antennas and small cell geometries are considered as a symbiotic convergence of technologies that have the potential to dramatically improve wireless access and throughput.

Smart grid system is the upcoming power control system working as an autonomous system by incorporating number of energy resources, two way wire and wireless communication. A reliable operation requires multiple, high-data-rate, two-way communications links among all communicative nodes of a smart grid network [7]. Therefore, in order to accomplish high speed two-way communications links, it is proposed to use the system based on MIMO technology and recently a massive MIMO technology.

This paper analyses the design of SG communication architecture with massive antennas, the advantages of implementing massive MIMO technologies, challenges and proposals for overcoming them.

In addition to the above mentioned applications, in this paper we describe the application of massive MIMO technology in systems that are already being established and the existing ones that will be improved and modified using this technology.

While the concepts of massive MIMO have been mostly theoretical so far, stimulating much research particularly in random matrix theory and related mathematics, basic testbeds are becoming available [3], and initial channel measurements have been performed [8]. Huawei has deployed massive MIMO sites in more than 30 Chinese cities for China Mobile. The partners have tested and verified massive MIMO in four main commercial application scenarios: high rise buildings, high traffic, high interference, and limited uplink [9].

Although the technology of applying a large number of antennas to the base station, the massive MIMO technology, is relatively new this topic has recently sparked a flurry of research activities aimed at understanding the concept, signal processing and information theory of massive MIMO system designs. In [8]-[10], massive MIMO systems are reviewed from various perspectives, including fundamental information theoretical gains, antenna and propagation aspects, reducing internal power consumption, finding new deployment scenarios and transceiver design. The application of the massive MIMIO technology in small cells was analysed in [11], while all the aspects of application in millimetre wave is descried in [6].

Taking into account all the benefits of this technology, its importance for the further development of wireless networks, the possibility of using it in various existing and new systems that change our lifestyle, and the fact that there is a lack of practical testing are the reasons to master all the concepts, challenges and ways of applying technology massive MIMO in various systems.

In this paper, we provide a more comprehensive overview of the massive MIMO concept, design, challenges and application. In addition to reviewing these aspects, there are also guidelines on how to achieve a better design of antenna array and beamforming. The main challenge facing this technology is pilot contamination. The paper describes the methods, techniques and algorithms which make it possible to coordinate the use of pilots or adaptively allocate pilot sequences, thus reducing the impact of pilot contamination on system performance. And for all the other challenges of the massive MIMO technology described in this paper, there are suggestions for solving or at least reducing their impact on the success of applying this technology.

1. BEAMFORMING AND DESIGN OF MASSIVE MIMO SYSTEM

There are many interconnected design issues that need to be properly understood and solved before widespread deployment of the massive MIMO technology. This section describes the basic characteristics and challenges of designing a massive MIMO system, as well as the concept of beamforming techniques.

Massive MIMO relies on beamforming which is a technique that enables transmission of different signals to different users simultaneously in the same frequency band, focusing the signal from multiple antennas into one strong beam, minimizing energy in side lobes at the transmitter end. On the other hand, beamforming relies on the base station having good enough channel knowledge, on both the uplink and the downlink. It is easy to accomplish good channel knowledge in the uplink because terminals send pilots, based on which the base station estimates the channel responses to each of the terminals. Problems with accomplishing this in the downlink of massive MIMO system are: amount of time-frequency resources needed for downlink pilots scales with the number of antennas which leads to 100 times more resources than a conventional system. Additionally, the number of channel responses each terminal must estimate is also proportional to the number of base station antennas. Therefore, resources needed to inform the base station of the channel responses would be up to 100 times larger than in conventional systems.

The advantages of multiantenna transmission depend on whether the channels from each transmit antenna to each receive antenna experience different multipath propagation (i.e., the signals travel different routes). The important thing is that the antennas are sufficiently separated to be able to observe different signal routes. The wavelength decides what is a good separation, and it is short when the frequency is high and vice versa [12].

Beamforming techniques are categorized into [10]:

- Fixed beamformers that employ fixed weights and phases to combine the signals without considering the properties of the received signals.
- Adaptive beamformers that may steer the direction of the main lobe in the desired direction, adaptively minimizing interference.

Hybrid beamforming is a technique to partition beamforming between the digital and RF domains to reduce the cost associated with the number of RF signal chains. Hybrid beamforming combines multiple array elements into subarray modules, with one transmit/receive (T/R) module dedicated to a subarray in the array. A key challenge in hybrid beamforming design is to meet the required performance parameters while constrained by the implementation cost [13]. Systems such as the one shown in Figure 1 are complex to develop. You can use modelling techniques to design and evaluate massive MIMO arrays and the corresponding RF and digital architectures needed to help manage their complexity. With these techniques, you can reduce risk and validate design approaches at the earliest stages of a project [14].

Optimal beamforming is a compromise between delivering the maximum power to an individual user, and reducing or eliminating the interference of the signal at the other users. With the Maximum Ratio Transmission (MRT) technique, the beam to the intended receiver is strong, but it is clear that the technique makes no attempt to prevent interference to the other receivers. The Zero Forcing (ZF) technique, on the other hand, is extremely successful in suppressing the signal to the other receivers, creating nulls around their positions. By coherent processing of the signals over the array linear transmit precoding can be used in the downlink to focus each signal at its desired terminal and receive combining can be used in the uplink to discriminate between signals sent from different terminals [15].

Low-complexity precoding methods are mandatory and critical to minimize the computational complexity of the precoder [15]. Unlike the conventional MIMO, massive MIMO uses linear precoders, such as maximum ratio combining (MRC), matched filtering, conjugate beamforming, minimum mean squared error (MMSE) receive combining, and zero-forcing (ZF) [10].

In MRC, the multiple antenna transmitters use the channel estimate of a terminal to maximize the strength of that terminal's signal by adding the signal components coherently. MRC precoding maximizes the SNR and works well in the massive MIMO system, since the base station radiates low signal power to the users on average.

ZF precoding is a method of spatial signal processing by which the transmitter can null out multiuser interference signals. In general, ZF precoder performs well under high Signal-to-Noise Ratio (SNR) conditions. Minimum mean squared error MMSE precoding is the optimal linear precoding in a massive MIMO downlink system. This technique uses the mean square error (MSE) and balances between amplifying signals and suppressing interference. It was shown in [16] that under certain special structure of MIMO channels, employment of the minimum-mean-squared-error (MMSE) channel estimator and a simple pilot assignment scheme can efficiently mitigate the pilot contamination effect in the large antenna regime. The complexity difference between MR and ZF/MMSE

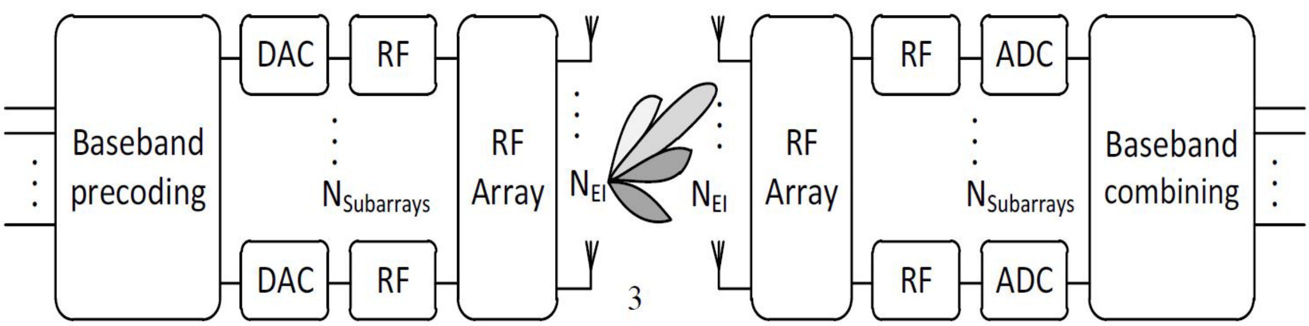

Figure 1: Hybrid beamforming architecture

is relatively small since the precoding/combining matrices are only computed once per coherence block—the bulk of the complexity comes from fast Fourier transform (FFTs) and matrix-vector multiplications performed at a per symbol basis [15]. To study the behaviour of massive MIMO systems, channel measurements have to be performed using realistic antenna arrays. This is so because the channel behaviour using large arrays differs from the one usually experienced using conventional smaller arrays. The most important differences are that [8]:

- There might be large-scale fading over the array.
- The small-scale signal statistics may also change over the array.

Thus, antenna configurations for use in massive MIMO schemes for 5G should be investigated and analysed. For example, rectangular, circular, and cylindrical array configuration could be studied in terms of their element numbers, resulting pattern beam width, gain, mutual coupling, and their effects on coverage, the received signal strength and channel capacity.

Several antenna element types could also be used such as dipole, horn antenna, and printed antennas [17].

The compact circular array has inferior performance compared to the linear array due to its smaller aperture [8].

Typical array designs include parameters such as array geometry, element spacing, the lattice structure of the elements, element tapering, and the effects of mutual coupling. By adjusting the design parameters, you can achieve tapering of the rows and columns of the array to reduce side lobe levels. Achieving an optimal design thus requires combined models of the antenna arrays and beamforming algorithms to simulate their interaction and impact on system performance. To achieve better beamforming control and flexibility, it would be ideal to have an independent weighting control over each antenna array element, with a transmit/receive (T/R) module dedicated to each element. But this is generally not practical due to cost, space, and power limitations [13].

A major impediment to using conventional multi-antenna transceivers in a massive MIMO implementation is the need to replicate multiple transmit/receive (TRX) chains, one for each antenna. Conventional designs would need proportionately higher power consumption, chip area, input/output and control signalling, LO routing and distribution, and so on. This strongly suggests that implementation of massive MIMO transceivers will encounter a roadblock unless innovative solutions are explored to share RF resources [6].

Other approaches exist for addressing the hardware requirements associated with handling massively parallel RF channels. One such approach based on the use of a discrete lens array (DLA) was recently constructed and experimentally analysed in [18]. A planar DLA is used to generate narrow beams whose outputs are combined into a small number of digital channels via beam space processing. Other hybrid analogue/digital beamforming architectures have also been proposed that trade off signal processing flexibility (e.g., constrained or simplified precoding) for hardware complexity [6]. Another alternative is the use of parasitic antenna arrays [19], which actually exploit the presence of mutual coupling between active antenna elements and neighbouring passive ones. Such an approach could allow a small number of active antennas to achieve a higher degree of spatial multiplexing or beamforming gain by carefully controlling the coupling with adjacent parasitic antenna elements.

Innovative and highly integrated antenna and circuit architectures will be required that are power-efficient, resilient to mutual coupling, and effectively handle the massive multiplication of data channels.

In [20] authors have analysed the far more realistic scenario of having inexpensive hardware constrained massive MIMO arrays and the impact of such hardware imperfections at the base stations by studying an uplink communication model with multiplicative phase-drifts, additive distortion noise, noise amplifications, and inter-carrier interference. Impact of hardware impairments at the Base Station (BS) vanishes as $N \to \infty$.

Taking into account all the previously stated, the design guidelines for antenna array and beamforming are:

- Use low-complexity signal processing -> linear processing (linear combing schemes in the uplink and linear precoding schemes in the downlink).
- MMSE precoding is the optimal linear precoding in a massive MIMO downlink system.
- Carefully adjust antenna and array configuration and their elements and parameters (array size, total number of antenna elements, antenna element types, radiation pattern, beam width, gain).
- Separation between the antenna elements is an important factor affecting the array radiation.
- Integration of the active transceiver unit array into the passive antenna element array -> active antenna system (AAS - can support adaptive electronic beamforming by controlling the phase and amplitude weights applied to individual antenna elements).
- Reduce hardware complexity and signal processing (decrease the size of the antenna element -> working with millimetre wave antennas operating at high frequency ranges, use electromagnetic lens antenna or parasitic antenna arrays).
- TDD operation is preferable (channel estimation overhead is independent of number of BS antennas).
- Optimal design requires combined models of the antenna arrays and beamforming algorithms.

2. CHALLENGES AND ISSUES OF MASSIVE MIMO TECHNOLOGY

In order to use all the advantages and possibilities of the massive MIMO, it is necessary to consider the challenges and problems associated with this technology. If potential problems and challenges are well understood, it will be possible to quicker find the solution for them.

2.1. Pilot contamination

For the successful implementation of beamforming on which the massive MIMO is based, it is necessary to know the information about the state of the channel (Channel State Information - CSI).

CSI estimation in a massive MIMO environment poses a serious challenge and significantly complicates the resource allocation problem. Ideally, the pilot sequences transmitted by the users to assist the BS in estimating the CSI of the users should be mutually orthogonal. However, accommodating a large number of users in the neighbouring base stations makes it necessary to reuse the orthogonal sequences among users, which creates interference and causes imperfect CSI estimation [21].

In [8] it was argued that pilot contamination constitutes an ultimate limit on performance when the number of antennas is increased without bound, at least with receivers that rely on pilot-based channel estimation.

A detailed analysis of the research with the focus on the problem of pilot contamination; potential solutions for the same are summarized in [8], [10] and those are:

- The allocation of pilot waveforms can be optimized - use a less aggressive frequency reuse factor for the pilots. It is also possible to coordinate the use of pilots or adaptively allocate pilot sequences to the different terminals in the network. Some of the methods include:
    - Optimum Pilot Reuse Factor Methods: based on choosing a reuse factor greater than unity optimized in some sense.
    - Pilot Sequence Hopping Methods: switch users randomly to a new pilot between time slots, which provides randomization in the pilot contamination.
    - Time-Shifted Pilot Based Methods: based on insertion of shifted pilot locations in slots (or a shifted frame structure).
- Clever channel estimation algorithms or even blind techniques that circumvent the use of pilots altogether may mitigate or eliminate the effects of pilot contamination.
- New precoding techniques that take into account the network structure, such as the pilot contamination precoding, can utilize cooperative transmission over a multiplicity of cells - outside of the beamforming operation - to nullify, at least partially, the directed interference that results from pilot contamination.

2.2. Channel estimation with hardware imperfections

Channel knowledge at the base station is a must for precoding/beamforming and coherent detection.

Discussion about the perfect channel estimation with hardware imperfections is impossible. The estimation accuracy is fundamentally limited by distortions for high SNR, coherence time and correlation of distortion noise for long pilot sequences. Hardware qualities of the User Equipment (UE) and the BS are equally important. The channel model largely impacts the estimation accuracy: Correlated channels are easier to estimate [22].

2.3. Channel Reciprocity

Massive MIMO systems exploit the reciprocity to estimate the channel responses on the uplink and then use the acquired channel state information (CSI) for both, uplink receives combining and downlink transmits precoding of payload data. Since the transceiver hardware is generally not reciprocal, calibration is needed to exploit the channel reciprocity in practice [15].

In [23] authors treat reciprocity calibration for a 64-antenna system in some detail and claim a successful experimental implementation.

2.4. TDD and FDD Modes

Much of the present-day massive MIMO research is based on the Time Division Duplex (TDD) transmission mode due to channel estimation issues. Many of today's global cellular bands are allocated strictly for Frequency Division Duplex (FDD). Therefore, according to some research, it is possible to enable FDD mode in massive MIMO systems.

One way is to design efficient precoding methods based on partial CSI [24] or even no CSI. Another way is to use the idea of compressed sensing to reduce the feedback overhead [4].

2.5. Modulation

To construct a base station with a large number of antennas, low-cost power-efficient RF amplifiers are necessary, and problems with high Peak-to-Average Power Ratio (PAPR) can impede good performance for Orthogonal Frequency Division Multiplexing (OFDM) [25]. In [4] this problem was considered and it was concluded that a single-carrier transmission is able to achieve near-optimal sum-rate performance at low-transmit-power-to-receiver-noise-power ratios, without requiring equalization at the receiver and multi-user resource allocation.

2.6. Resource allocation

Resource allocation usually means that the time-frequency resources are divided between the terminals, to satisfy user-specific performance constraints, to find the best subcarriers for each terminal, and to combat the small-scale fading by power control. Frequency-selective resource allocation can bring substantial improvements when there are large variations in channel quality over the subcarriers, but it is also demanding in terms of channel estimation and computational overhead since the decisions depend on the small-scale fading that varies at the order of milliseconds. If the same resource allocation concepts would be applied in massive MIMO systems, with tens of terminals at each of the thousands of subcarriers, the complexity would be huge. Fortunately, the channel hardening effect in massive MIMO means that the channel variations are negligible over the frequency domain and mainly dependant on large-scale fading in the time domain, which typically varies 100–1000 times slower than the small-scale fading [15].

Everything above indicates that resource allocation can be greatly simplified in massive MIMO systems. However, there are various other factors that limit the performance of the system, such as: pilot assignment, energy efficiency, the duration of the training phase and the transmission and others that need to be analysed during resource allocation.

In [16] authors analysed joint pilot assignment and resource allocation for system energy efficiency (SEE) maximization in the multi-user and multi-cell (MU-MC) massive MIMO network.

In [26] authors investigated the resource allocation issue between downlink training stage and data transmission stage for the FDD massive multiple-input multiple-output system from the viewpoint of energy efficiency (EE). Whereas, the training overhead for downlink channel estimation scales up with base station antenna number in massive MIMO FDD system, which will be unaffordable as the antenna number grows large.

In addition to the research problems listed above, there are still many more which include the following: Distributed massive MIMO, Optimization of CSI feedback, Hybrid Beamforming, MAC layer control, etc.

3. APPLICATION OF MASSIVE MIMO TECHNOLOGY

Taking into account all the characteristics and advantages of the massive MIMO technology described in the previous sections, it can be concluded that this technology will have a wide and varied application and will be the basis for a digital society infrastructure that will connect the Internet of people and Internet of things, with clouds and other network infrastructure. This section will describe the application of massive MIMO technology in systems where transmission speed, latency and energy efficiency are factors crucial for successful implementation and operation.

3.1. Internet of things (IoT)

The Internet of Things (IoT) describes the coordination of multiple machines, devices and appliances connected to the Internet through multiple wired and wireless networks [27].

IoT is characterized by intelligent data analysis. It is believed that IoT will lead to changes in various branches of industry. Bottleneck for realizing the efficient IoT is created by transmission and processing of large amounts of data, as well as their security during transmission, which the current communication infrastructure is unable to support because of the increasing number of devices that have become part of the IoT.

Massive connectivity is a key requirement for future wireless cellular networks that aim to support IoT and machine-type communications (MTC). In a massive device connectivity scenario, a cellular base-station (BS) may be required to connect to a large number of devices (in the order 104 to 106), but a key characteristic of IoT traffic is that BS needs to dynamically identify the active users before data transmissions take place [28].

End-to-end reliability, latency, and energy consumption comprising both, up- and downlinks, can be enhanced in IoT if the new wireless communication standard, 5G, and its massive MIMO technology are used. A new trend in device-to-device communication (D2D) is the introduction of sensors and sensor-based system, while 5G can extend sensor based IoT capabilities by applying robots, actuators and drones for distributed coordination and low latency reliable performance.

3.2. Intelligent transport systems

Information system and communications technology are integrated to the transport infrastructure and vehicles to improve safety and reduce vehicle wear, transportation times, and fuel consumption etc.

Performance (low latency) is a requirement for the quick reaction times needed for autonomous and semi-autonomous vehicles. As our automobiles become more like mobile devices on wheels, security will become an imperative to keep malicious hackers from creating dangerous situations on the road. And the automotive industry is interested in device-to-device capabilities to implement vehicle-to-vehicle, vehicle-to-infrastructure, and vehicle-to-pedestrian communications to reduce crashes and improve safety [29]. This system represents a part of the IoT as it establishes the connection of cars with various other devices. All these factors that affect system performance: latency, security, real-time local updates, path planning and the like, will be improved by applying technologies massive MIMO because Massive MIMO can increase the capacity 10 times or more and simultaneously improve the radiated energy-efficiency and allow a significant reduction of latency on the air interface.

3.3. Wireless sensor network

Wireless sensor networks (WSN) are a special kind of monitoring networks, aiming at detecting, measuring, monitoring certain physical phenomena, such as temperature, humidity, pressure, vibration, etc. Each device in the WSN is termed as a node that exchanges information with its neighbour. All data will be poured into a BS node, or a sink, which in turn relays the information to an outside user, or a server to process it. WSN may be composed of hundreds or thousands of nodes to provide coverage on a large scale. Recently, several research efforts have been addressed to discuss the benefit of introducing a massive number of antennas at the BS, or the sink node. Multiple antennas at the BS improve the detection performance, the estimation performance, and energy efficiency, even when using simpler algorithms, and linear receivers with partial CSI knowledge [10].

3.4. Unmanned aerial vehicles (UAVs) or drones

Several applications, such as surveillance, disaster management, and drone racing, place high requirements on the communication with the drones – in terms of throughout, reliability, 3-dimensional (3D) connectivity, and latency. Existing wireless technologies, notably WiFi, that are currently used for drone communications are limited to short ranges and low mobility situations. A new, scalable technology is needed to meet future demands. Massive MIMO, a promising technology component of emerging 5G cellular networks, has the potential to meet these requirements. Specifically, massive MIMO offers significant range extensions, support for fast-moving drones, and the possibility to spatially multiplex entire swarms of drones communicating simultaneously [30].

Several 5G use cases for drones were identified by 3rd Generation Partnership Project (3GPP) [31]: broadband access to under-developed areas, hot-spot coverage during sporting events, and rapidly deployable "on-demand" densification.

Features of massive MIMO described in this paper naturally make the technology suitable for drone communications. Ground station (GS) comprises a uniform linear or rectangular array with a large number of antenna elements, while drones are equipped with a single antenna. The channel between each GS antenna and the drone's antenna is characterized by a free-space path loss, a polarization mismatch loss, an antenna gain, and a phase shift.

By virtue of the spatial multiplexing capability of massive MIMO, many drones can simultaneously transmit high-resolution imagery to the GS. Compelling features of massive MIMO for this application include: high throughput, spatial multiplexing, coverage extension and high-mobility support [30].

3.5. Smart grid

Smart Grid (SG) is a modernized electrical grid that uses information and communications technology for improving the efficiency, reliability, and economics of the traditional electrical grid [32].

In general, a SG communication architecture consists of a home area network (HAN), neighbour area network (NAN), and wide area network (WAN) [33].

Considering the components of the SG communication architecture, it can be concluded that the choice of communication technologies has a crucial role for the successful implementation of the SG. In [32] is analysed implementation of massive MIMO technique, which improves the transmission reliability and system throughput for SG communications.

Taking into account the complexity of implementation of such a system for SG, a large number of antennas and higher power consumption, it is proposed in [32] i that the number of RF chains at the base station be smaller than the number of antenna elements to reduce the hardware complexity and high cost, and use appropriate antenna selection to preserve the gain provided by the large number of antennas.

The smart grid is considered with new features and capabilities such as high penetration of renewable energy source (RES), two–way energy demanding and demand-side-management (DSM) which clearly holds exploiting the potential of future in wireless communication. Toady's challenge of smart grid system is track disturbance in real time which means power grid should be responsible, awake and communicative on every node. A practical smart grid models which coordinated with cellular networks are developed and work on energy efficient resource allocation, energy management, MIMO – downlink transmission, and transmit-beam forming design for minimize the cost factor. A smart grid system by using MIMO concept enhanced the closed loop system within large geographical area maintaining a high data rate transmission. Selection of active users in real time effectively provides the space for active control sensor signals. An intelligence smart grid system consists of a large number of sensor control signals which is acceptable by the MIMO configuration [7].

To improve reliability and performance in smart grids it is proposed to introduce hybrid wireless/powerline communication.

Below is an example of a design an energy efficient (EE) massive MIMO system in a smart grid NAN scenario. Focus is on implementing a massive MIMO technique that improves the transmission reliability and system throughput for SG communications [34]. We considered an SG NAN (neighbour area network) consisting of a concentrator and a number of data aggregate points (DAPs), as shown in Figure 2. The NAN connects smart meters in a HAN (home area network), and interacts with a utility's head-end system in a WAN (wide area network). In the NAN, the concentrator is equipped with an N-antenna and the value of N is large. The concentrator communicates with K single antenna Dual Antenna Positioning System (DAPs), and the communication is operated on a time division duplexing (TDD) mode with channel reciprocity.

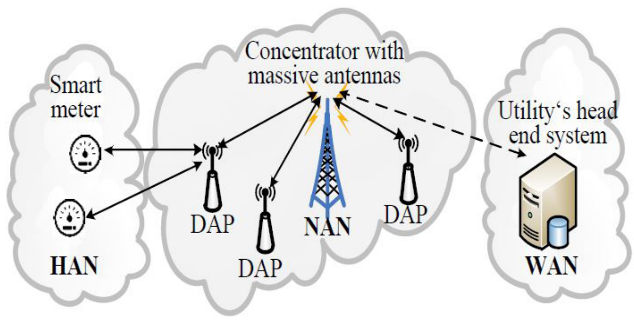

Figure 2: SG communication architecture with massive antennas at a concentrator in a NAN

We aim to use antenna selection to reduce the cost of too many RF chains and to improve the system EE for SG communications. Suppose that at the concentrator, the number of RF chains Nt is smaller than N. We propose to select Nt out of N transmit antennas based on the EE maximization criterion, as shown in Figure 3, using only LTCS (long-term channel statistics). The channel statistics normally vary with the antenna spacing, the single scattering angles and the path loss, and thus may change very slowly. As a result, the proposed selection process does not change at each channel instance, but is updated when the channel statistics vary or new DAPs enter.

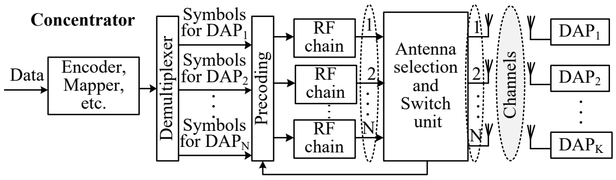

Figure 3: Massive MIMO system with antenna selection for the SG NAN scenario

Figure 3 shows a block diagram of antenna selection for the NAN implemented with the massive MIMO technique. From a communications perspective, the concentrator comprises a baseband unit including a forward error correction encoder, a symbol mapper, a demultiplexer, and a precoder, Nt RF chains, an antenna selection and switch unit, and N antennas. In the antenna selection and switch unit, LCS is obtained and then used to select the best Nt antennas out of N antennas. The selection criterion will be shown in the following. The selected Nt antennas are connected to the RF chains and then used for transmission; and the selected antenna index is feedback to the precoder such that the updated Nr-by-K channel matrix is used for precoding.

4. CONCLUSION

The massive MIMO technology is considered crucial for the further development of wireless networks, and due to its characteristics and capabilities it represents the basic technology for achieving the requirements that are set for the 5G standard. In this paper, we have comprehensively described major elements of massive MIMO systems: beamforming, design of antenna array, precoding methods, resource allocation, pilot contamination and others challenges of this technology.

This paper also gives detailed overview of some of the research efforts done in this area so far. However, there are still challenges ahead to realize the full potential of the technology and additional research is needed on a number of issues, and some of them have been analysed in this paper.

The described features, design concepts and challenges of massive MIMO technology need to be known and mastered in order to achieve the successful incorporation of this technology in various systems, especially those where the current wireless communication networks do not offer satisfactory transmission speed, latency, energy efficiency, security and reliability.

In this paper we describe the scenarios of the application of the massive MIMO technology in IoT, and its integration into SG communication architecture. With the massive MIMO technology concept of digital society, will become feasible as it will achieve mass connectivity that will connect Internet of People and Internet of Things with clouds and other network infrastructure and all due to higher speeds and lower latency. The application of massive antennas at a concentrator in NAN of SG communication architecture requires the use of antenna selection to reduce the cost of too many RF chains and to improve the system EE.

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