Analysis of the massive MIMO technology

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Abstract. The article discusses the features of the Massive MIMO technology, the structure of the antenna array, as well as the advantages and example of using the massive MIMO system. The use of Massive MIMO opens up new opportunities and makes a significant contribution to achieving the stated requirements for the further evolution of LTE and 5G.

1. Introduction

Every year, the demand for mobile high-speed data transmission services increases, and this requires a significant increase in bandwidth. Mobile communication of the 5G generation can help with this. If in the 3G and 4G generations this requirement was achieved mainly due to the introduction of new signal-code structures, the optimal distribution of the frequency resource and the expansion of the frequency spectrum, at present there is an acute shortage of the frequency resource, and the possibilities for its expansion are very limited. The development of mobile communication technologies in such conditions forces us to look for new ways and solve complex technical problems that ensure compliance with the requirements for increasing the capacity of 5G networks.

One of the most effective ways to increase throughput is the MIMO (multiple input multiple output) spatial multiplexing technology. MIMO allows you to transmit multiple data streams using the same time and frequency resource, where each data stream can be formed as a beam. MIMO is based on a basic principle: when the quality of the received signal is high, it is better to receive multiple data streams with reduced power per stream than a single stream with full power. The potential increases when the quality of the received signal is high and the streams do not interfere with each other. The potential decreases when the mutual interference between the streams increases. MIMO works in both UL and DL. The 4G generation uses MIMO 2x2 and 4x4 configurations.

Consider the requirements for 5G mobile networks:

• Achieve peak data transfer rates of up to 20 Gb/s for DL
• and 10 Gb/s for UL;
• Providing a data transfer rate of 100 Mb/s simultaneously for many users in megacities;
• increased spectral efficiency up to 30 bps/Hz for DL
• and 15 bit/s/Hz for UL;
• Simultaneous connection of several hundred thousand wireless sensors;
• Achieving ultra-high network reliability (in some cases, the probability of successful packet delivery within 1 millisecond should reach 99.9999%);
• Saving QoS when mobile terminals travel at speeds of up to 500 km/h;
• Increasing the network capacity to 1,000,000 terminals per 2 kilometers.

As you can see, the 2x2 and 4x4 MIMO configurations are no longer sufficient to meet the above requirements, so the 3GPP and IEEE organizations have developed the next-generation multi-antenna system technology-massive MIMO. These systems have the potential to significantly improve performance indicators such as link reliability, spectral and energy efficiency.

2. Massive MIMO technology
Massive Multiple-Input-Multiple-Output, a system for multi-channel independent processing of re-reflected decorrelated subscriber signals. The massive MIMO-enabled base station supports about a hundred ports and a whole array of antennas.

Simply put, a Massive MIMO system is:
• Large number of transceivers (TRX);
• The possibility of spatial multiplexing;
• Multi-user planning (MU-MIMO);
• Large antenna array with high gain in uplink (UL) and downlink (DL).

In a massive MIMO system with large antenna arrays, the signal can be adjusted both azimuthally and vertically, which allows for better energy focus and accuracy of direction to a specific terminal device, thereby reducing inter-cell interference and supporting spatial multiplexing with a large number of subscriber devices.

3. Antenna array structure
The purpose of using a rectangular antenna array (see Fig. 1a) is to enable high-gain beams and make it possible to control these beams in a range of angles. Gain is achieved in both UL and DL by constructively combining signals from a number of antenna elements. The more elements of the antenna, the higher the gain. Controllability is achieved by individually controlling the amplitude and phase of the smaller parts of the antenna array. This is usually done by dividing the antenna array into so-called subarrays, groups of non-overlapping elements (see Fig. 1b) and by applying two dedicated radio lines to each subgroup (one per polarization), enable control. Thus, it is possible to control the direction and other properties of the generated beam of the antenna array [1].

Array amplification occurs when all signals of a subarray are constructively (in phase) multiplied. The size of the array gain relative to the gain of one subarray depends on the number of subarrays – for example, two subarrays give an array gain after a certain change in the phase of the subgroup signals, this gain can be achieved in any direction.

The gain and beam width depend on the size of the sublattice and the properties of the individual antenna elements. There is a trade-off between the gain of the submatrix and the beam width – the larger the subarray, the higher the gain and narrower the beam width.

Figure 1. A typical antenna array (a) consists of rows and columns of individual antenna elements with double polarization. Antenna arrays can be divided into sub lattices (b), with each subgroup connected to two radio circuits, usually one per polarization.
4. Advantages of massive MIMO systems

Gain in spatial diversity. The main advantage of massive MIMO over single-antenna or traditional MIMO systems is the possibility of adaptive diagramming, or the formation of multiple beams (beamforming) in multi-user mode (multi-user massive MIMO), in which data streams are transmitted to pre-assigned users (see Fig. 2) [2]. In this case, one AC (subscriber station) is allocated the same resource blocks as other AC within the same cell.

The beams generated by the antenna system are constantly adapted to the environment, providing high performance in both UL and DL. By means of such separation in space, the time-frequency resource is saved, or, in other words, the spectral efficiency is increased. In addition, since the potential accuracy of the concentration of the directed beam at a given mobile terminal is quite high, interference interference between the beams should be significantly reduced.

Energy efficiency. Massive MIMO systems, in comparison with traditional MIMO systems, significantly benefit in energy efficiency. The number of bits characterizes energy efficiency/s per 1 W of signal power related to the noise spectral density; therefore, the higher the energy efficiency, the lower the signal-to-noise ratio required to transmit a single bit of data. The use of massive MIMO technologies in mobile communication systems, which have high energy efficiency, reduces the energy consumption of equipment, improves electromagnetic compatibility by reducing the radiated power, and also increases the environmental safety of transmitting radio equipment, especially AS.

Spectral efficiency is characterized by the data transfer rate per unit width of the frequency spectrum and is measured by the ratio of bits/s/Hz. When the number of antennas on the BS is much greater than the number of terminals in the cell, in the 20 MHz frequency band, the total bandwidth of the cell is 730 Mb/s, which corresponds to the spectral efficiency of 36.5 bits/s/Hz [2].

Improved channel reliability (channel hardening) is another distinctive advantage of massive MIMO systems, based on spatial diversity. Spatial diversity helps to reduce the adverse effects of fast fading on the transmission channel. In this case, the probability P that all spaced channels are affected by fast fading, for the case of independence and statistical uniformity of channels, can be described by the expression:

\[ P = P_1^M, \]

where \( P_1 \) – is the probability of a single-channel communication system being exposed to rapid fading, \( M \) – is the number of antennas in the system.

Let, for example, the risk that one channel in a single-antenna system may be affected by fast fading is \( P_1 = 0.1 \); then, by introducing diversity into the transmission system by increasing the number of antennas to \( M = 128 \), the probability that all channels in the system will be affected by fast fading is negligible: \( P_{all} = 0.1128 \) [4, 6, 7].

5. Example of the implementation of the massive MIMO technology

MTS has installed more than 70 Ericsson AIR 6468 base stations for the 2018 FIFA World Cup (see Figure 3). In more than 40 venues in seven cities with Massive MIMO technology. The Ericsson AIR
6468 supports 64 transmitting and 64 receiving antennas. The technology was implemented in the LTE-TDD band of 2,600 MHz.

Measurements made during the tournament show that the Ericsson base stations with Massive MIMO technology in the MTS network allowed for a five-fold increase in throughput [3].

Figure 3. AIR6468 Ericsson equipment

6. Conclusion
The use of Massive MIMO opens up new opportunities and makes a significant contribution to achieving the stated requirements for the further evolution of LTE and 5G. The advantages of massive MIMO include the improvement of the reliability of the transmission channel, the increase in spectral and energy efficiency, and, consequently, reduced vulnerability to Jamming – errors arise for this reason, errors, increase data transfer speed and increases network capacity to the value required for re – average sales networks of the fifth generation [5].

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