Network Security Concerns in 5G MIMO Beamforming

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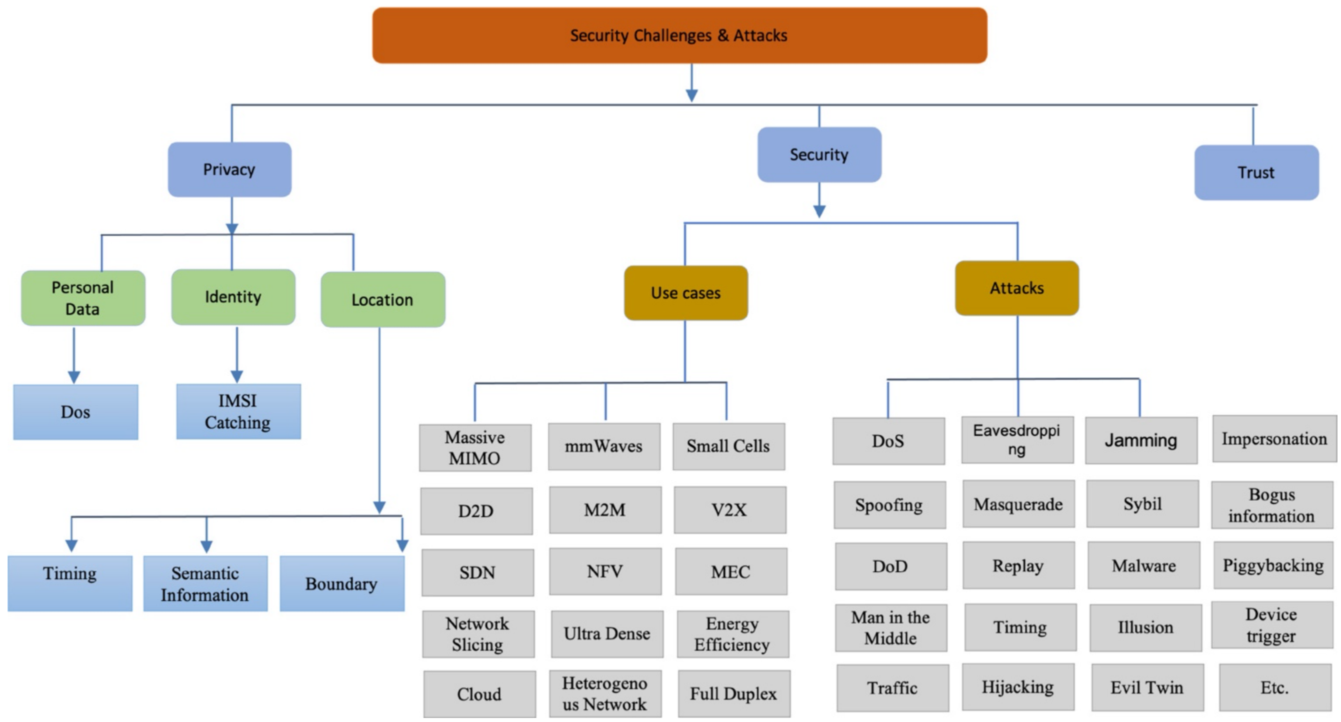
Abstract

MIMO technology is a key technology of 5G, which is widely used in next-generation scenarios such as heterogeneous networks, millimeter-wave networks, and automotive networks. How to build a large-scale MIMO system security situation assessment model for 5G has become the main topic of current concern. The broader reach of network infrastructure and transport layer cryptographic gains on 5G security tend to receive a large proportion of focus in threat modeling and mitigation, but the underlying physical layer backbone has seen significant changes with massive MIMO, beamforming, and mmWave spectrum use at the edge. Examples of the attacks against MIMO are those related to the decentralization of the RAN towards fog computing IoT technologies, the continued blurring of WLAN with Frequency Range 2 (FR2) small cells, and the perceived vulnerability to physical attacks that these spatially isolated networks exhibit further demonstrate the necessity of modeling preexisting threat profiles to be inclusive and emphatic of emerging physical layer attacks. We look at one threat for FR1 (pilot contamination) and one for FR2 (mmWave attacks), both utilizing the physical properties of beamforming and demonstrating the new concerns in the highly heterogeneous network architecture in use by 5GNR. In this paper, we focus on the security concerns related to the Massive MIMO.

Index Terms: Massive MIMO, security, 5G, RAN, privacy, trust.

1. Key security challenges in 5G

The Key security challenges in 5G include more security is required to guarantee the safety of the critical network infrastructure and the privacy of the user in a highly connected environment where everything is connected to the internet and exposed to different attacks. For instance, a security breach in one of the smart grid systems can lead to an electrical system damage and thus to the smart city depending on it. The consequence of the security breach can easily spread over the connected network to harm other systems and other services. In addition, user's privacy can be attacked while transmitting user's sensitive data over the 5G network. Therefore, there is an urgent need for security solutions to protect the 5G network while providing high data rate and low latency. Security challenges and issues can be classified according to which 5G use case is involved. Figure 1 illustrates these challenges and their taxonomy.



In this paper, we focus on the Massive MIMO security. Although its advantages, it can be under several attacks and vulnerabilities, which releases some of the security concerns. Examples of attacks targeting the massive MIMO include jamming, eavesdropping, and pilot spoofing. Jamming attacks are one of the prime security issues threatening the massive MIMO systems. By using multiple antennas with high degrees of freedom, these systems can discard the suspicious signals from malicious users. In [1] the authors suggested reducing the jamming attacks impact by using joint channel estimation and decoding to estimate the channel state instead of using the uplink pilots waveforms. In [2] the authors proposed an energy efficiency method by optimizing the power consumption by increasing the number of antennas at the base stations. However, using more antennas cannot decrease the power consumption anymore at some saturation points. Beamforming has been used to provide more secure MIMO networks and fight against passive eavesdropping attacks. Massive MIMO is one of the promising technologies for the 5G network and beyond. However, it is considered as the most disruptive use case as it uses a large number of antennas to serve a massive number of users simultaneously, which opens the physical layer to many security attacks. These attacks can be either active or passive. Active attacks aim at disrupting, corrupting, or transmitting signals over a legal transmission. They include jamming and contamination attacks. Passive attacks aim at eavesdropping and spying the legal transmissions. Jamming attackers send junk signals to the users or base stations to disrupt the legal transmission. Contamination, also known as pilot spoofing, attackers contaminate the pilots by pretending to be a legal user. Machine learning has been used to protect massive MIMO systems by detecting active attacks [3]. However, massive MIMO involves a large amount of data coming from a high number of antennas and users, which results in a high amount of data overhead and requires a massive amount of data to train the machine learning algorithm. Each base station needs a training dataset per antenna, which requires extra data processing, storage, complexity, and more time by the intrusion detection systems. Moreover, with this large number of users in mobility, machine learning algorithms will not be able to train dynamic environment with changing parameters over time.

The mmWaves communication is another challenge. In [4] the authors proposed to combine the mmWaves with beamforming MIMO to offer more secure communication.

2. 5G MIMO Beamforming Security Concerns

A key component of 5G, massive MIMO, also prompts new security threats to address. Pilot contamination attack on massive MIMO [5], session hijacking by redirection in beamforming towards the attacker, is of primary interest to mitigate. During negotiation when the client sends pilot signals to the base station, those signals can be repeated by the attacker to contaminate the uplink channel training in the attacker's favor. This particular vulnerability relates to the use of Time Duplex Division (TDD) and the need for user pilot signals to estimate the channel for downlink. While the channel, once negotiated, is considerably hardened by the properties of beamforming against eavesdropping, these properties are negated if the eavesdropper's pilot signal power was sufficient to overwhelm the real client's, resulting in the base station beamforming towards the eavesdropper. Humayan *et al.* [5] provides an overview of work done in simulating and mitigating such an attack on Table V of their paper. Some of the promising solutions include matching filter precoding on weak and strongly correlated channels to the attack, hiding the pilot signal within an enlarged set, and employing a sliding length secrecy key based on information leakage estimates. Of note about all three proposals is an active analysis of the pilot contamination attack in the creation of the unique mitigation.

Another of the key components of 5G, millimeter-wave frequency use with small cell base stations, has a similar but distinct threat profile from massive MIMO outside at the micro-wave level. Compared to micro- and macro- cells, small cell sites (pico- and femto- cell) work under different propagation laws and are particularly susceptible to blockage [6]. The short range combined with that susceptibility to blockage results in low visibility of signal on weakly correlated channels and outside of the propagation path [5], making the overlap of the user and eavesdropper particularly important to the level of secrecy in mmWave transmissions. Some proposals found in Humayan *et al.* (on Table VI) [5] vary based on the simulation constraints placed the eavesdropper, single antenna versus multi-antenna being the primary differential. A particularly interesting solution is utilizing antenna subset modulation per symbol in transmission for the desired user, resulting in eavesdroppers receiving statistical noise.

Conclusion

While there is a continuity in 5G of the security concerns of 4G and prior generation architecture, 5GNR has special considerations that must be made. With widespread rates of adoption of 5GNR worldwide in the years preceding 2023 and continued growth in that sector, 5G is no longer just an emerging technology and its attack vectors have now become a facet of the overall attack surface of telecommunication infrastructure in use in production networks. Proposed security solutions can see live testing, analysis, iteration, and implementation while network adoption still outpaces user equipment support and use [6]. For future, we plan to extend the current work with the interested studies introduced in [7-81].

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