International Journal of communication and computer Technologies, Vol. 12, No. 2 , 2024 (pp. 11-20) IJCCTS
RESEARCH ARTICLE WWW.IJCCTS.ORG

Techniques on Controlling Bandwidth and Energy Consumption for 5G and 6G Wireless Communication Systems

Baotic Antoniewicz*, Silva Dreyfus
Electronics Engineering Department, Universidad Tecnica Federico Santa Marla, Valpara´ıso, Chile

Keywords:
Bandwidth Efficiency;
Modulation Schemes;
NOMA (Non-Orthogonal Multiple Access);
Spectral Efficiency;
Waveforms

Corresponding Author Email:
Biotic.an@usm.cl

DOI: 10.31838/IJCCTS.12.02.02

Received: 11.07.24

Revised: 09.08.24

Accepted: 20.09.24

Abstract

This work aims at exploring novel modulation schemes and waveform designs for 5G and the emerging 6G telecommunication systems for high bandwidth utilization and energy consumption. Thus, as generation of wireless communication networks progresses, requirement toward higher data rate, lower delay and power consumption increases, encouraging the emergence of new layer of modulation. This paper reviews more advanced waveforms for 5G systems, such as f-OFDM, GFDM, and NOMA which enable higher spectral efficiency and better interference tolerance. Further, we unravel various modulation schemes including AMC and higher order QAM through which modulation and coding rate can be selected based on the quality of channel to allow maximum throughput with minimal power consumption. The efficacy of these new schemes in scenarios of the proposed system is tested through simulations and analysing analytical models by comparing parameter such as bandwidth usage, error rates and energy efficiency of these new schemes to conventional modulation techniques like OFDM. The analysis demonstrates that these novel solutions can enhance the total efficiency of the following generation communi- cation networks by enhancing the potential of the crucial use instances of 5G and 6G realizations, such as M ¤C, URLLC, and eMBB. Hence, this research is part of the continuing endeavours to advance better techniques for wireless communication.

How to cite this article: Antoniewicz B, Dreyfus S (2024). Techniques on Controlling Bandwidth and Energy Consumption For 5G and 6G Wireless Communication Systems. International Journal of communication and computer Technologies, Vol. 12, No. 2, 2024, 11-20

Introduction

Wireless technology has advanced at a fast pace over the recent past and the research on 6G wireless is the next frontier in telecommunication. With the world being a global village and human beings needing improved communication systems that are faster, more efficient, and less power hungry, 6G networks are the way to go as they are the next generation after the current 5G networks with groundbreaking applications and opportunities in the IoT, V2X and many others that current networks don't allow. In this article, the author presents the various modulation techniques that define the future of the new generation wireless technology known as the 6G. We will then look at problems affecting current 5G systems and discuss how new modulation schemes can improve system performance. Further discussion will be made with regard to the moderns approach to quantum inspiration, modulation at the terahertz band and the cognitive radio spectrum access. Moreover, the important factors in security in 6G modulation will also be discussed, along with how these enhancements will influence the performance and dependability of the upcoming wireless networking systems .[1-5]

The Promise of 6G Technology

With the world waiting for the next evolutionary era in wireless communication, enter, the 6G solution. This next-generation network is not an evolutionary one; it is a transformative network for the future, with an expected capability of facilitating ultra-high speed data, extremely low and precise delay, and massive connectivities for an emergent IoT environment.

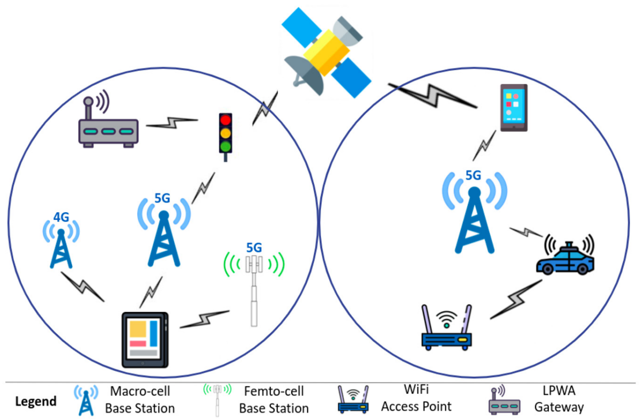

Fig. 1: Exploring New Modulation Schemes for 6G Wireless Efficiency

Enhanced Mobile Broadband

The 6G wireless technology described should be capable of achieving the highest data transmission rates ever, which is something that its predecessors are unable to offer. It is designed for a throughput of Terabit per second [Tbps], significantly better than the gigabit per second capacity of 5G. These new speeds increase will make it even easier to create various forms of interaction such as holo calling and better vr interactions. The efficiency in mobile broadband that is carried by 6G will use the bands of frequencies, particularly the sub-terahertz (sub-THz) frequencies. This entry into other hitherto unutilised spectrum bands will improve bandwidth and address the 10-fold growth in the number of connections which is expected. The spectral efficiency is expected to reach its peak at 40 bits in per channel use, seeing that the current 5G is estimated to be around 25 bits, 6G will be instrumental in enabling applications attaining instantaneous response to the intricate command and control tasks in addition to massive data throughput. The two are: 2 Large Machine-Type Communications eliver unprecedented data rates, significantly surpassing its predecessors. It's expected to achieve terabit-per-second (Tbps) speeds, a substantial leap from the gigabit-per-second capabilities of 5G. This quantum jump in speed will enable a new era of immersive experiences, including holographic communication and advanced virtual reality applications. The enhanced mobile broadband capabilities of 6G will utilize higher frequency bands, including sub-terahertz (sub-THz) frequencies. This expansion into previously unused spectrum areas will enhance bandwidth and support the exponential growth in connected devices. With a peak spectral efficiency projected to reach 40 bits per channel use, up from around 25 in 5G, 6G will provide the foundation for applications requiring instantaneous response times and massive data throughput.[6-7]

Massive Machine-Type Communications

6G network is expected to drastically change the architecture of the connections regarding various machine-type communications with the possibility to connect record-breaking number of devices. Whereas 5G is able to accommodate approximately one million devices per square kilometre, 6G will be able to accommodate around ten million. This immense connectivity growth will be a prerequisite addend for establishing smart cities, industrial revolutions and IoT. Such an efficiency to support such denser device populations will open up new applications across different industries. For example, in agriculture, 6G may permit the use of numerous numbers of sensors for enhancing productivity throughout resource usage in precision farming. In urban centres, it could allow for a full supervisory control of city systems in real time to promote efficiency and sustainability of cities.

Ultra-Reliable Low-Latency Communications

One of the key benefits that has been considered to be true for the 6G is its capability to provide ULRQ communications. Whereas 5G was striving for latencies of about 1 ms, 6G is believed to advance the frontier to the microsecond-level. This dramatic reduction in delay in conjunction with reliability rates of up to 99.99999%, will free up further opportunities for application, which was unforeseeable before. Such low latency and high reliability mean many things. In healthcare, for example, it might allow surgeons to perform operations with remotely with the sense of touch. It could offer the immediate connection that is required for fully self-contained vehicles to drive safely and effectively in heavy traffic systems. In industrial applications, it could enable a fine system of control of most machines for instance robots to increase on productivity and reduce on accidental incidences. Furthermore, URLLC is expected to support the growth of the tactile internet, using touch and movement over 6G to be accessible in real-time over the network. It could dramatically alter professions such as distant education making it possible to offer practical sessions no matter how far apart. To sum up, it is worth noting that the discussed prospect of 6G technology is not limited to the achievement of higher speed rates of Wireless Internet. It is a completely new concept of how we navigate through the environment, which is partly physical and partly virtual. With the further development of the R&D process, it is obvious that the potential of 6G has not been fully disclosed yet and, it defines the new level of connectivity and advancements.

Current Limitations in 5G Modulation

First of all, it is worthy to note that 5G has become feasible for wireless communications though it has certain challenges that affect its optimal functionality. These restrictions are mainly due to Sub-Optimal EE spectral, energy, and scalability constraints. Thus, solving these questions becomes important for advancement of future 6G wireless networks with need for faster and more reliable connection.

Spectral Efficiency Constraints

The major challenge to 5G modulation is that of restricted spectral efficiency. Although, relative to its forerunners, 5G is not awful, the former still has problems adjusting the radio resources of the corresponding frequency range. Over time, the current 5G NR standard enables devices and towers to deploy 800 MHZ of spectrum at one time, compared to 4G LTE's 100 MHZ usage. However, this expansion alone is not sufficient to meet this ever increasing demand in data transmission. The presented theoretical peak rates for the 5G networks are not always reached in the real conditions. They think that the difference is caused by factors such as signal overlap, network intensity, and physical constraints of the equipment used. Hence, realized spectral efficiency of 5G networks is lower than their potential, and the prospects of eMBB services remain partially unleashed. Besides, there are extra complications when deploying higher frequency bands including mmWave. Despite giving wider bandwidths these bands are more vulnerable to signal loss and have very poor penetrating ability. This constrains the availability of the high-band 5G to the urban and suburban only hence the rural areas will be lagging behind.

Energy Consumption Issues

Another major issue in 5G network is the energy factor which has been another major planning concern. It is a fact that today ICT industry uses about 4 % of the total electricity available in the entire world. However, with the projected increase in 5G capacity and the upcoming launch of higher frequency mmWave transmission this could well easily rise to over 20% by 2030. While the use of technologies such as massive MIMO aiding spectral efficiency has numerous advantages, it also has the disadvantage of high power consumption. A relatively simple 64T64R massive MIMO deployment consumes power 3.3 times more than a 4G LTE radio. As the requirement for power surges, network operators face difficulties in operating costs and environmental effects. Additionally, much higher densification of the networks needed for 5G coverage results in a greater number of base stations which still remain power greedy. The introduction of edge computing along with massive IoT deployment deepens energy consumption problem, which would be the key research field in next-generation 6G wireless networks.

Scalability Challenges

As 5G will have to address demand from a huge number of connected devices, the problem of scalability arises. The current 5G infrastructure we have still finds it very hard to manage the growth of the number of connected devices most especially when dealing with mMTC and IoT. Theoretically, 5G networks should be capable of handling up to 1 million connected devices per square kilometer The reality of reaching that target is far from what it is expected. These are to do with issues such as reducing interference between devices, guaranteeing efficient use of the resources, and get low delay for important uses (Table 1).

Table 1. Modulation Schemes for 6G

Modulation Scheme	Key Features	Data Rate Efficiency	Spectral Efficiency	Use Cases for 6G	Limitations
OFDM (Orthogonal Frequency Division Multiplexing)	Multi-carrier, robust to multipath	High	Moderate to high	Wireless communication, IoT, smart cities	High PAPR (Peak-to-Average Power Ratio)
FBMC (Filter Bank Multicarrier)	No need for cyclic prefix, low out-of-band emissions	Moderate	High	Ultra-dense networks, high-frequency bands	Complex implementation

Modulation Scheme	Key Features	Data Rate Efficiency	Spectral Efficiency	Use Cases for 6G	Limitations
GFDM (Generalized Frequency Division Multiplexing)	Flexible, allows non-orthogonal subcarriers	High	Very high	Low-latency applications, IoT, M2M communication	High complexity
OTFS (Orthogonal Time Frequency Space)	Robust in high Doppler environments	High	High	High-mobility scenarios (e.g., vehicles, drones)	New, less mature than OFDM
DPSK (Differential Phase Shift Keying)	Phase-based, no need for coherent detection	Low	Moderate	Simple IoT devices, low-complexity systems	Lower spectral efficiency, lower data rates
8-PSK (8-Phase Shift Keying)	Uses 8 distinct phase shifts for encoding	Moderate	Moderate	Moderate-speed communication	Higher error rates compared to QAM

The scalability problem is also then exacerbated by the variation in functionality demanded by different scenarios. For example, ultra-reliable low-latency communications (URLLC), require very low latency and high reliability which may be difficult to achieve when operating at large scale. Likewise, the responsibility of providing supporting intelligence to millions of low power IoT devices at the same time as high-bandwidth usage generates a set of challenging equations for network operators. Overcoming these limitations shall present as fundamental tasks in the definition of the 6G wireless networks. Future modulation schemes and network architectures to overcome these challenges, so as to bring the promised penetration in connectivity for the development of groundbreaking application in V2X communications, blockchain technology, etc.

Novel Modulation Techniques for 6G

Because there is an increasing approximation to the development of the 6G wireless technology system, the discovery of new modulation techniques falls under investigation with an aim of extending the coverage and overcoming the shortages of the existing 5G systems. These novel approaches can be expected to increase spectral efficiency, decrease energy consumption, and provide connectivity to a huge number of IoT and V2X devices. In this subsection, three potentially revolutionary modulation methods that can be applied within 6G networks are discussed [8]-[12].

Index Modulation

Due to the mentioned attractive advantages, the Index Modulation (IM) scheme has recently been recommended as a candidate technology for 6G networks. This technique is easy to implement, gives improved error rate performance and has higher spectral and energy efficiency when compared with other simple modulation and multiplexing techniques. There is a particular variant of IM known as Spatial Modulation that aims at using the spatial domain to convey information. To meet the rate matching and adaptation needs in FSM systems, a fresh method in communication called GAM-FSM has been developed. This technique works in a much better way when the network demand is dynamic as is the case with 6G networks where the available spectrum can be utilised in a more flexible manner. C-GQSM is another technique based on IM and can be implemented in a signaling message instead of the new negotiation message Flower; It is a new signaling message Composition aided Generalized Quadrature SM (C-GQSM). This method enhances the spectral efficiency of the fundamental GQSM systems by utilizing the power domain DOF. Thus, the introduction of combinatorial tools, C-GQSM realizes an enhancement to transmission techniques and may bring improved data rates in the 6G wireless communication.

Orbital Angular Momentum Modulation

Optical Orbital Angular Momentum (OAM) modulation is being adopted as a valuable asset for high data rate wireless transmission in 6G networks. OAM take advantages of the features of the electromagnetic wave carrying different OAM modes in different orthogonal operation. The advantage of this orthogonality is the capability of multiplexing multiple data streams while enhancing the capacity of wireless systems. Current studies have also shown that through OAM modulation it is possible to attain data rates of between 100Gbit/s and 1Tbit/s in application. These findings have revived the interest of OAM multiplexing technology as an appealing technology compared to existing MIMO/SISO methods.

To fully harness the potential of OAM in 6G networks, researchers are exploring various aspects of this technology, including:

1. Multi-plexing capacity assessment of the uniformly circular array (UCA) based omni-directional amplifiers and multiple input-multiple output systems
2. OAM multiplexing combined with dual-pol
3. We compare the performance of OAM-MIMO system that employs the SIC technique with the system that does not employ any form of interference cancelation.
4. Inter- mode interference suppression due to misalignment of the beam axis

Holographic MIMO

Holographic Multiple Input Multiple Output (HMIMOS) is an emerging idea that is already starting to reshape the 6G wireless networks technology. This technology involves the use of cheap, thin planar structures containing sub-wavelength metallic or dielectric scattering particles for engineering of electromagnetic waves towards specific goals. HMIMOS is proposed to extend the concept of massive MIMO systems with recent achievements in the area of programable metamaterials. These surfaces can be placed on all sorts of objects making the wireless environment a programmable smart entity. This approach can help to realise the very challenging target set for 6G networks which include supporting the vision of connection and intelligent efficient and software based control of the environment.

Key advantages of HMIMOS include:

1. Low cost, size, and weight
2. Low power consumption
3. One capability is the ability to turn the wireless environment into a program with malleability.
4. Opportunity to integrate with new technologies including IoT, V2X, and even blockchain

The investigations carried out in HMIMOS are expected to help improve the 6G systems and their efficiency in future smart cities where the integration of smart surfaces into the buildings, and other structures would be of interest. Therefore, such new modulations as Index Modulation, Orbital Angular Momentum Modulation, and Holographic MIMO are the developments that enhance the progress of wireless communications. The above stated ideas will be highly useful as 6G technology advances in achieving the requirements for high-speed data transfer, network density and superior power efficient in the new generations of wireless communication..

Quantum-Inspired Modulation Schemes

Ongoing advancements in 6G wireless technology have led to attempt of using quantum modulation to improve security, energy, and bandwidth in future networks. These cutting edge methods stem from the principles of quantum mechanics and present solutions for presenting with the increasing needs of Internet of Things and V2X communication.

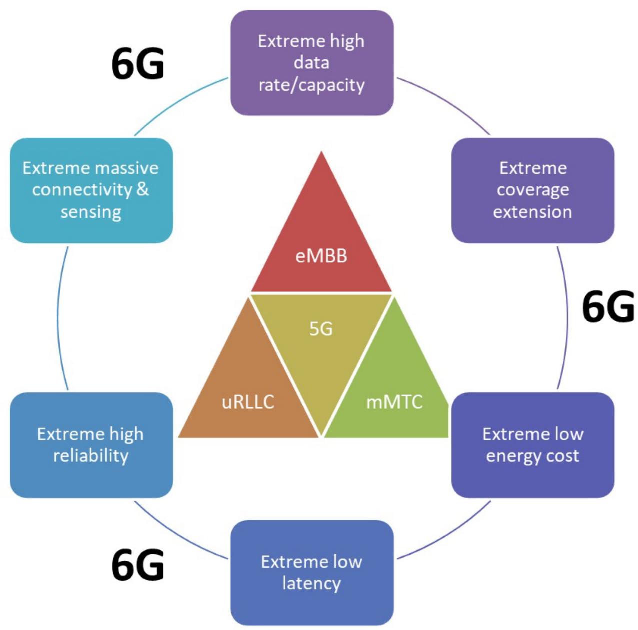

Fig. 2: Orbital Angular Momentum Modulation

Quantum Key Distribution

Quantum key distribution is a promising technique that helps in the establishment of the 6G communication network. It thus makes it possible for two distant parties to establish for themselves secure quantum keys whereby they are able to subsequently encrypt secure messages into what is known as cipher text. Based on the concepts of quantum mechanics, QKD remains a critical element through which 6G can achieve ultimate security. Unlike other types of cryptographic systems, QKD does not depend on mathematical computation complexities but rather uses principles derived from quantum theory as its basis of security.

This makes it almost impossible for third parties to tap or gain access to any sensitive information being relayed. Since 6G networks are designed to support more and more connected devices and manage greater amounts of data, QKD represents a secure method to counteract cyber threats and keep information secret. The question of applying QKD in 6G networks is challenged by some limitations especially in the coverage distances and the problem of the trusted nodes to encode/decode transmitting information over extended distances. However, these are seen as potential barriers to current QKD implementation which are thought to dissolve with the advancement of quantum communication technologies, toward achieving tap-proof communications through replacement of qubits with light encoding.

Superdense Coding

Superdense coding forms another novel prospect of a quantum-inspired heuristic that has potential for utilization in the 6G wireless networks. This method can be called the 'inverse of quantum teleportation', which will help the quantum node A to reach specific goals of communication more effectively than with the help of traditional techniques. Superdense code might just prove to be useful for 6G networks as a means of delivering more information over limited resources… enhancing spectral efficiency and conserving power. This corresponds with the objectives set for 6G technology in terms of the rate of data transfer and energy consumption. As primary ingredients of 6G systems, superdense coding could extend data transfer rates via applications with an unprecedented demand for bandwidth and latency. In the coming years this field will evolve mature and therein superdense coding is expected to help meet the stringent requirements of wireless communications.

Quantum Entanglement in Communication

Quantum entanglement is a property when particles are correlated in a way that the quantum state of each of the particles cannot be described by any single physical property. The entanglement holds great promise for 6G wireless networks. Using this property, it is possible to develop new quantum communication networks that would work with greater efficiency and security. In the case of 6G quantum entanglement may be used to protect the link between devices since it would be highly improbable for third parties to snoop into the data that has been transmitted or even change it. This has important consequences for the protection of V2X communications other applications where URLLC connections are critical.

Also, quantum entanglement can FT possibly improve the performance of 6G networks as it enables the sending of multiple copy streams. This capability is in sync with the vision of 6G focusing on the momentum of massive machine type communications and burgeoning IoT revolution. Although quantum communication exists only at the beginning stage of development, having demonstrated only the first proof of concepts and first-sided commercial application, and, thus, there already exists a significant influence on 6G wireless technology. In the course of more research, quantum-inspired modulation schemes are likely to be an integral enabler in achieving the vision for 6G networks in terms of security, efficiency and capacity.

Terahertz Band Modulation

Some important bands in the terahertz spectrum range from 0.1 THz to 10 THz have significant implication for 6G wireless technology. This spectrum range provides wide bandwidth required to deliver data transmission rates in the range of terabit per second. It is essential for housing data-hungry services like HD Holographic communications and Immersive Extended Reality that are likely to underpin the IoT architecture in the 6G world.

Challenges in THz Communication

However, in its current development state, THz communication has several obstacles. An important constraint is that THz waves are attenuated to a high extent due to path loss. Thus, with the increase in the carrier frequency, aperture area of the receiving antenna is small and it has a limited capture area for the radiation power. The total loss in these materials increases by 20dB per decade as carrier frequencies increase; in the THz spectrum it is especially large. The last of the major challenges is caused by gaseous attenuation. It is stated that atmospheric absorption normally remains invariant and insignificant in sub-6G bands; however, it becomes significantly substantial at the THz band. Main substances influencing THz wave propagation are oxygen and water vapor in the atmosphere; however, water vapor shall dominate in some spectral bands. The outdoor conditions pose challenges to the THz signal transmission due to effects resulting from weather situations. This is because the physical dimensions of liquid water droplets in clouds, fog and rain are of the same order as THz wavelength and can therefore absorb or scatter incident signals. It is weaker than path loss and atmospheric absorption but it is an essential component that has to be taken under consideration in 6G networks design.

Innovative THz Modulation Techniques

To overcome these challenges, THz researchers are working on the new modulation approaches that are suitable for the THz band. One is a combination technique in which parallel processing can handle the data rates efficiently. As for another very curious method, it does not use mixers at all, but injects information directly into the signal source. This technique is called pre-distortion to reverse the first signal distortion; thereby, eradicating one of the biggest hurdles that terahertz technology face during deployment. Progress in the technology of the devices used are also important. Research and development of various electronic, photonic, and plasmonic devices for THz communication and sensing are being developed. There are many approaches that are being worked on to provide multifunctional and compact Smart Antenna Systems for THz transmission by using array system, lens and metasurface. These improvements are directed towards improving energy efficiency of 6G networks which is paramount since THz frequency range is power hungry.

Potential Applications

Nevertheless, comprehensive applications of THz communication in 6G wireless networks include several use cases and are significant. THz links can provide viable prospects to generate fast wireless local area network (WLAN) connection and hence numerous services such as instant video transfer and live conduct of virtual reality activities. THz in connection to network infrastructure may change wireless backhauling as we know it tomorrow. THz technology if applied to interconnect base stations with the core network, eliminate the time and cost coupled to the trenching of optical fiber and would have a positive impact on the efficiency of 6G networks. The highly directional property of THz links also open up great solutions to improving security in the link in a way that making eavesdropping much more difficult. This feature nicely fits with the trends towards applying blockchain technology to 6G networks where data security and privacy are critical. Furthermore, THz links could express a realistic solution for ground - satellite connectivity since attenuation reduces with height. All of this could be instrumental in bringing 6G networks to the more peripheral regions and narrowing the so-called digital gap in this respect.

Cognitive Radio and Dynamic Spectrum Access in 6G

Therefore, for the spectrum operating environment of 6G wireless technology, demand for efficient spectrum utilization becomes an even more crucial issue than it was initially. CR and DSA have been considered as appropriate solutions for dealing with the existing spectrum scarcity and inefficient allocations in 6G networks. These technologies facilitate ways and means of using returned path frequencies in an intelligent and adaptive manner, to supply better connectivity and performance into the IoT (Table 2).

Table 2. Advanced Modulation Techniques for 6G

Modulation Technique	Modulation Type	Key Benefits	Potential 6G Applications	Complexity	Power Efficiency
QAM (Quadrature Amplitude Modulation)	Amplitude and phase modulation	High spectral efficiency	High-data-rate transmission, beamforming	High	Moderate
Lattice-Based Modulation	Space-time coded, uses lattice structures	Enhanced robustness in noisy environments	Ultra-reliable low-latency communication (URLLC)	Very high	High
SCMA (Sparse Code Multiple Access)	Code-domain modulation, sparse signals	Efficient for massive device communication	Massive IoT, mMTC (massive Machine-Type Communication)	Moderate	High
TeraHertz Modulation (THz)	Exploits very high-frequency bands	Extremely high bandwidth	High-speed data links, ultra-fast wireless	High	Power-hungry due to high frequencies

Spectrum Sensing Techniques

Spectrum sensing is the most crucial component of cognitive radio system by enabling the secondary users to detect spectrum holes, so that they can use the idle spectrum bands without causing any interference to the PU. For improving the detection accuracy and efficiency of spectrum sensing in 6G networks, new spectrum sensing algorithms are being designed. One of such strategies is known as hybrid spectrum sensing, which has multiple sensing methodologies and thus avoids the pitfalls of individual strategies. For instance, the integration of energy detection (ED) and cyclostationary (CS) analysis has demonstrated the enhancement of the time signal detection and minimization of false alarm. Especially for the healthcare use-cases in 6G, the proposed hybrid approach is favourable as it guarantees stable information transfer of vital medical data and efficient resource management. In addition, spectrum sensing is also combining with ML algorithms to distinguish the patterns of resources' allocation and future spectrum usage. This requested ML-based method contributes to measuring radio transmission activities in real-time so as to provide dynamic spectrum access in 6G systems.

Adaptive Modulation and Coding

The topic of Adaptive Modulation and Coding (AMC) is widely discussed in concern with the rates of data transmission and spectral efficiency of 6G networks. As such, AMC makes sure that a stable communication links are established even when it comes to sensitive wireless environments because it provides flexibility in changing the modulation scheme and coding rate in accordance with the channel condition. With reference to 6G, the idea of AMC is expanded and integrated with AI and ML to develop ML-centric transceiver chains. These enhanced protocols may also control signal processing dynamics in real-mode to enhance SNR and power specific fractional efficiency. Such flexibility is crucial to address the different needs of different 6G applications such as V2X and Blockchain.

Cooperative Spectrum Sharing

Cooperative spectrum sharing has been found to be important approaches for enhancing the usage of spectrum channels in 6G networks. This approach covers a strategy where several users or devices join in perceiving and distributing spectrum opportunity effectively. Cooperative spectrum sensing can be broadly classified into two categories: single-user and multi-user. Thus, multi-user cooperative spectrum sensing has drawn plenty of attention since it helps to overcome challenges like hidden terminal problems, signal fading, and shadowing problems. In this approach, several SUs work together to sense the spectrum and the outcomes are then combined to provide more accurate opportunities for spectrum sensing.

A new concept that has emerged recently and is recommended for use in cooperative spectrum sensing in 6G is called federated learning. FL hence enables the development of an aggregated ML model of FL without the need to reveal spectrum sensing data owned by wireless user devices. This approach goes further to improve spectrum sensing accuracy and at the same improve the privacy of communication in 6G network. Cognitive radio and dynamic spectrum access are expected to be enablers of 6G technology since they will provide the needed ultra-high-speed data transmission, most connectivity, and energy efficiency for next-generation wireless networks. These solutions shall help make the best use of deployed spectrum resources for servicing IoT devices, V2X, and other emerging solutions in the 6G era.

Security Considerations in 6G Modulation

Civil society's reliance on 6G wireless technology as it evolves makes it necessary to invest in a secure structure. As seen, the 6G networks bring more speed, capacity and connectivity which calls for advanced security threats. Such challenges also include physical layer security, quantum-safe cryptography, and inter alia secure modulation using blockchain system.

Physical Layer Security

Physical layer security has become the most important mechanism for protection in today's 6G network. PLS protocols have been proposed to reap the benefits of randomness in wireless channel and maintain the secrecy with less overhead and delay as cryptographic solution. It is most effective in the IoT domain because it offers security solutions for heavily constrained devices. A lot of research work has described PLS schemes based on a key mainly due to the fact that the wireless transmission medium itself can act as a source of randomness. These schemes bear common key that forms credential of sophisticated cryptographic frame work. The full secret key and also the symmetric key in a PLS system is made from the transmitter as well as the receivers private info making the system more secure. Although the PLS methodology has been used effectively in secondary research; enhancing its effectiveness is an ongoing pursuit, and with the help of AI/ML integration solutions being used for the current analytical tools, researchers are attempting to find out how to enhance it. These intelligent optimization techniques generate safer and more dependable air interfaces, requisite to the flexibility of 6G RAN. The inclusion of PLS with O-RAN interfaces allows for adaptable security architectures that can be applied throughout RAN.

Quantum-Safe Cryptography

Quantum computing as a new technology can be challenging for defenders of present cryptographic systems utilized in mobile networks. In an attempt to counter this challenge, 6G networks should incorporate quantum-safe cryptography since quantum computers pose the threat of posing an attack on the networks. Among these solutions, Quantum Key Distribution (QKD) has come out as the most suitable approach towards securing the sixth-generation networks or 6G networks. QKD enables two users to establish, without any risk and intermediaries, two shares of a private quantum key which can be subsequently used to encrypt-secret messages. Unlike other encryption techniques, security in QKD is anchored on principles of quantum mechanics meaning that any third party wanting to eavesdrop or access prohibited data is easily detected. With the advancement of the 6G technology standards and technologies, it is important to establish and adopt quantum resilience cryptosystem and protocols. Valuable quantum-resistant practices will be achieved through this approach globally making the 6G networks usable worldwide.

Blockchain-Based Secure Modulation

Blockchain holds certain advantages in terms of security in 6G networks, which will be described in this study. A decentralized, distributed ledger system is tightly secure and communication-peer to peer, which helps the 6G to manage data and transactions safely. Opinion that with the help of integration of blockchain technology in 6G networks, the message security, privacy and credibility can be enhanced. They can be applied in IoT system for use in automating and securing the exchanges that happen within devices in the system. These contracts allow fast and secure actions and they can be connected with AI in order to maintain and update the system. Furthermore, as a result of the immutability feature of the blockchain, misuse and other erroneous actions are controlled and prevented in 6G networks. Transparency and redundant nature of the technology because of public networks lay a strong foundation in secure data management and access control. As 6G wireless technology progresses, it is important that these security measures – physical layer security, quantum-safe cryptography, and blockchain secure modulation – will all be needed to address future security concerns of next-generation networks. Thus, by applying these concepts, 6G networks can guarantee the confidentiality and integrity of data, and its availability at a time when the world is becoming more connected.

Conclusion

An analysis of modulation techniques for increasing the efficiency of 6G wireless has implications for the future of telecommunication. Such staking concepts like index modulation, orbital angular momentum modulation, and holographic MIMO are promising in heralding beyond Gigabit speed data transfer alongside enormous connectivity. Another interesting development that can help to improve the network parameters and security, is the quantum-inspired methods to be applied, as well as the modulation in the terahertz band. This progress in 6G technology is expected to enhance multiple fields such as Io T and V2X communications. In conclusion, the paper identifies the opportunities and challenges arising with the 6G wireless network development. The importance of cognitive radio and dynamic spectrum access is derived from attempts to fully utilize available system resources as much as possible, whereas physical layer security and quantum cryptography safety is critical for these types of networks. While future studies in this area are ongoing, it will be more than just a progression from the 5G – it will be 6G. This new generation technology has far higher potential to revolutionize applications in our inter-connected space.

References:

1. Adoum, B.A., Zoukalne, K., Idriss, M.S., Ali, A.M., Moungache, A. and Khayal, M.Y., 2023. A comprehensive survey of candidate waveforms for 5G, beyond 5G and 6G wireless communication systems. Open Journal of Applied Sciences, 13(1), pp.136-161.
2. Iyer, S., Patil, A., Bhairanatti, S., Halagatti, S. and Pandya, R.J., 2022. A survey on technological trends to enhance spectrum-efficiency in 6g communications. Trans-

actions of the Indian National Academy of Engineering, 7(4), pp.1093-1120.

3. Hamamreh, J.M., Hajar, A. and Abewa, M., 2020. Orthogonal frequency division multiplexing with subcarrier power modulation for doubling the spectral efficiency of 6G and beyond networks. Transactions on Emerging Telecommunications Technologies, 31(4), p.e3921.
4. Gustavsson, U., Frenger, P., Fager, C., Eriksson, T., Zirath, H., Dielacher, F., Studer, C., Pärssinen, A., Correia, R., Matos, J.N. and Belo, D., 2021. Implementation challenges and opportunities in beyond-5G and 6G communication. IEEE Journal of Microwaves, 1(1), pp.86-100.
5. Sharma, T., Chehri, A. and Fortier, P., 2021. Review of optical and wireless backhaul networks and emerging trends of next generation 5G and 6G technologies. Transactions on Emerging Telecommunications Technologies, 32(3), p.e4155.
6. Sivapriya, N., Vanteru, M.K., Vaigandla, K.K. and Balakrishna, G., 2023. Evaluation of PAPR, PSD, Spectral Efficiency, BER and SNR Performance of Multi-Carrier Modulation Schemes for 5G and Beyond. SSRG International Journal of Electrical and Electronics Engineering, 10(11), pp.100-114.
7. Imoize, Agbotiname Lucky, Hope Ikoghene Obakhena, Francis Ifeanyi Anyasi, and Samarendra Nath Sur. “A review of energy efficiency and power control schemes in ultra-dense cell-free massive MIMO systems for sustainable 6G wireless communication.” Sustainability 14, no. 17 (2022): 11100.
8. Han, S., Xie, T. and Chih-Lin, I., 2021. Greener physical layer technologies for 6G mobile communications. IEEE Communications Magazine, 59(4), pp.68-74.
9. Chowdhury, M.Z., Shahjalal, M., Hasan, M.K. and Jang, Y.M., 2019. The role of optical wireless communication technologies in 5G/6G and IoT solutions: Prospects, directions, and challenges. Applied Sciences, 9(20), p.4367.
10. Rajatheva, N., Atzeni, I., Bjornson, E., Bourdoux, A., Buzzi, S., Dore, J.B., Erkucuk, S., Fuentes, M., Guan, K., Hu, Y. and Huang, X., 2020. White paper on broadband connectivity in 6G. arXiv preprint arXiv:2004.14247.
11. Chen, J., Li, S., Xing, J., Wang, J. and Fu, S., 2020. Multiple nodes access of wireless beam modulation for 6G-enabled Internet of Things. IEEE Internet of Things Journal, 8(20), pp.15191-15204.
12. Raj, R. and Dixit, A., 2022. An energy-efficient power allocation scheme for NOMA-based IoT sensor networks in 6G. IEEE Sensors Journal, 22(7), pp.7371-7384.