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Research Article

Applications of artificial intelligence in 6G wireless communications

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Abstract

With the vision of "Ubiquitous Wireless Intelligence", 6G opens up numerous avenues of technological innovation, several of those supported by machine learning and artificial intelligence which form the focus of this work. However such a leap in the field of Information and Communication Technology (ICT) is taking place in a world increasingly motivated to bridge social and economic inequalities through digital inclusion, at the same time prioritising the UN Sustainable Development Goals (SDGs). The document has four parts, what 6G promises, the existing gaps and technical challenges, then the role of machine learning in various aspects, then the challenges of including AI/ML.

Keywords: *6G network, wireless communication, communication systems, artificial intelligence, machine learning.*

1. Introduction

The First Step: In March 2019, a summit organised in Finland, attended by 300 delegates from 29 countries, flagged off the development in the direction of 6G. It is an advancement over the existing mobile communication technologies glued by the vision of Ubiquitous Wireless Intelligence. 6G intends to keep people connected irrespective of geographical location, thus extending coverage to remote areas as well as in unexplored territories such underwater and underground. It plans to integrate computational intelligence into its infrastructure and devices to assist users in real time (Latva-aho *et al*.,2020)

The advent of 6G promises a host of new offerings for its users (Dang *et. al,* 2020). While visual and auditory forms of communication have been prevalent, 6G will extend the interaction to include other senses, starting off with haptic touch. Holographic presence and augmented reality will make this interaction more immersive. The relevance of these introductions can be envisioned in the context of the tourism industry. While travel is a great resource for entertainment and education, myriad factors like political instability, health concerns, vagaries of nature and xenophobia create situations which hamper the inflow of tourists. This severely affects the associated economic activities (Chirisa *et al*.,2020). (Akhtar *et al*.,2021) puts forth the advantages of virtual tourism as not just a marketing tool but also the product itself.

Location based services such as Global Positioning Systems have translated into transportation, public surveillance and rescue operations. Accurate indoor positioning is still lagging behind, which can be used in healthcare. User location and identification can be extended to autonomous or collaborative robots, which further are useful in medicine, elderly care, industrial automation et cetera. 6G envisions communication underwater to support marine operations. It boosts in-flight communications for aircraft navigation and safety which can be useful for unmanned aerial vehicles (UAVs)

Technological advancement in mobile communications has been a steady and continuous process which has been demarcated by generations- 1G, 2G, 3G, 4G and 5G. The applications supported by these technologies have expanded from voice and messaging to interactive gaming and wearable devices. In the span of these developments, the number of users availing these services has also increased. Yet over 3 billion of the world population remains unconnected, which when added to the existing infrastructure will pose new challenges.

At the time of composition of this document, the COVID pandemic has engulfed the world in 2020, and also recurred in several countries. It has led to restrictions on social gatherings, in-person meetings and physical movement amid public health concerns. As people are staying in and adopting the work-from-home model, they have turned to their internet-based devices (fixed/mobile) for entertainment, educational services, health-related consultations and livelihoods. The pandemic has led to a major surge in internet traffic. (Feldmann *et al*.,2021) analyses the internet traffic patterns in certain parts of Europe and America over the weeks following the lockdown and observes surges and shifts in peak hours, choice of application and daily consumption limits. Technology innovation has been

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deemed invaluable for businesses to stay in competition. The prolonged shutdown of markets during this pandemic has made social media platforms vital to the sustenance of several commercial activities. Thus, virtual tours, virtual classrooms and virtual social gatherings have become the norm.

The International Telecommunication Union (ITU), a United Nations specialized agency which facilitates and monitors connectivity in communication networks released aggregated telecom statistics in November, 2020 released a dataset available at their website in regarding the wireless communications as well as internet users. Figure 1 graphs the annual trends in the number of users of Internet in the period 2015-19. The plum bars show the absolute count of the Internet users. The lighter bars indicate the increase in number of users. It can be observed that the count increases by 6 to 8 percent every year.

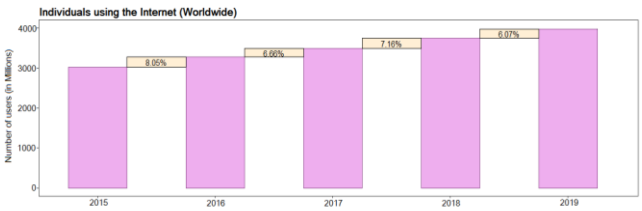

Fig 1. Individuals using the Internet (Worldwide)

As can be read from Figure 2, the International Bandwidth is on a steady rise through 2015 to 2019. The chart shows the rising bandwidth by the means of an upward arrow. The aquamarine bars to the right present the international bandwidth broken down by economic regions . The bandwidth per user in Europe stands at 211.2kbit/user, which is 7x the bandwidth per user in Africa.

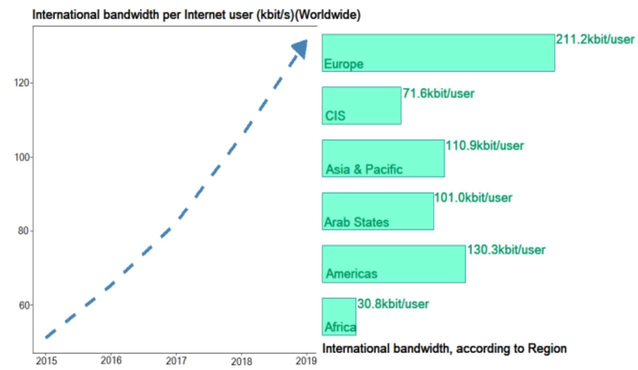

Fig 2. International bandwidth per Internet user (kbit/s)

Figure 3 presents the percentage of individuals using the Internet, broken down both by economic region (depicted by grouping) and sex of the user (depicted by colour). The gender divide is noticeable in Africa, Asia & Pacific, and the Arab States.

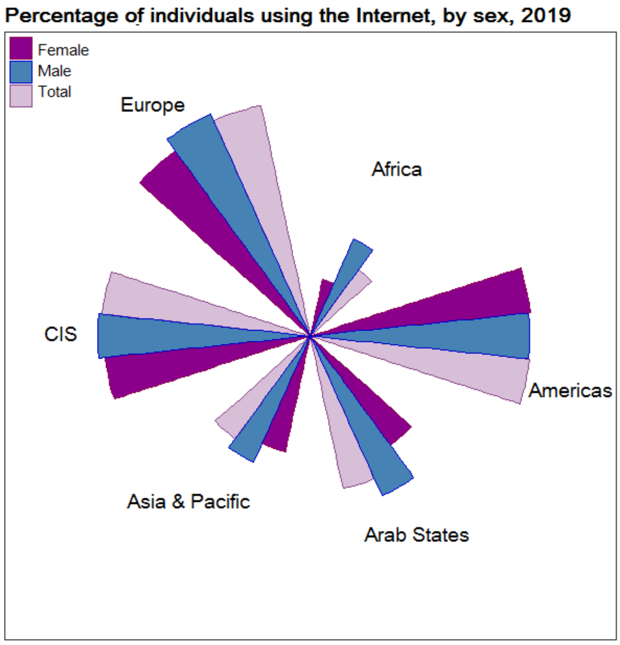

Fig 3. Percentage of individuals using the Internet, by sex, 2019

Figure 4 presents the percentage of individuals using the Internet, broken down both by economic region (depicted by grouping) and rural/urban setting (depicted by colour). No region is devoid of the urban rural divide, although in Europe, the gap seems to be narrower.

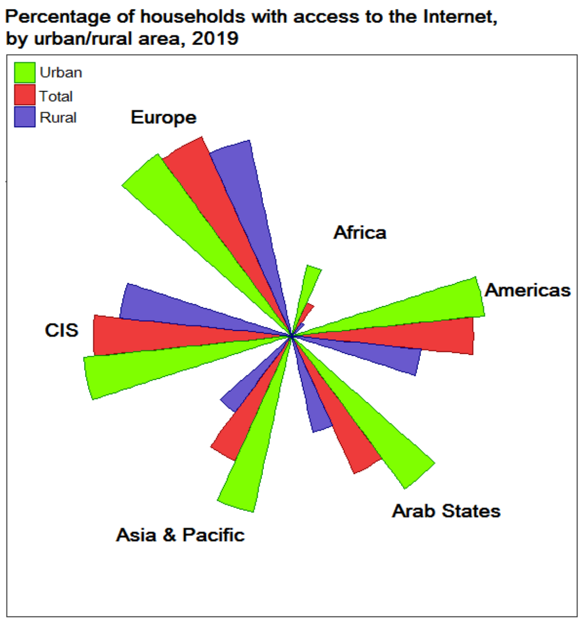

Fig 4. Percentage of households with access to the Internet, by urban/rural area, 2019

Every hurdle opens up new opportunities. Mobility analysis to study population behaviour using mobile technologies has been discussed in (Grantz *et al.*,2020), making connectivity a critical aspect in epidemiology research, government policies and public welfare.

These new applications will need research in technical, conceptual and legal perspectives to make the systems secure, economic forethought to take them to remote lesser developed parts of the world with a cost effective model, avail communication devices to people still unconnected, extend lifetime of battery operated devices and improve the overall mobile experience.

The germination of 6G is taking place at a time when nations are working towards meeting the UN Sustainable Development Goals (SDGs) for a better environment and better life. These 17 goals with 169 targets deal with broad ideas like mitigation of poverty, managing climate change, social justice, restoration of natural resources and the like. As (Matinmikko-Blue *et al*.,2020) observes, the digital inclusion that 6G intends to bring about can be instrumental towards the empowerment of marginalised communities. Through increased access to information, people can create new sources of employment, take initiatives to preserve their ecosystems and bridge social inequalities. With this vision, 6G infrastructure needs to be environment friendly and energy efficient. Sustainable supply chains and economic practices can boost agriculture, healthcare, educational services and industry, which can all lead to a better tomorrow.

2. Artificial intelligent and machine learning applications in 6G

Machine learning refers to the family of tools and algorithms which can design computational systems that can adapt their response to different environments/situations. Machine learning has been part of communication systems for decades (Letaief *et al*.,2019) and has been applied to a host of applications, such as monitoring the channel conditions and network performance, autonomous detection and management of faults and service impairments, forecasting of the user behaviour, traffic and resource utilization, and providing decision support for resource allocation, edge computing et cetera. ML supports monetary concerns like dynamic pricing, as well as the detection and curbing of cybercrimes. In 6G, it will be one of the pillars of the technology.

There are three learning models: unsupervised, supervised and reinforcement. Unsupervised learning can be used for exploratory clustering. Supervised learning is akin to a student training with an instructor, however, obtaining large labelled datasets relevant to the field of wireless communications is hard to assemble. The dynamism and non-stationarity of wireless networks made offline training less efficient. Reinforcement learning is analogous to a student learning from his/her mistakes. On interacting with the environment, the student receives penalties and rewards, which guide him in making future decisions. The reinforcement model is identified as suitable in the dynamic wireless environment.

Deep learning is a subset of ML that deals with the artificial neural networks with many hidden layers and many nodes. ANNs mimic the neurons in the human brain, thus although a black box in many ways, recent applications have established their supremacy in machine learning. Four primary architectures: unsupervised pre-trained networks, convolutional neural networks, recurrent neural networks and recursive neural networks, which can be used in all three aforementioned learning models: unsupervised, supervised and reinforcement, have been found useful in the majority of applications (She *et al*,2020; Ahmed, Tabassum & Hossain,2019).

(Santos *et al*.,2020) maps the desired improvements in 6G to various problems, the majority of those in the physical layer. Deep learning solutions are available for a host of those issues, a few examples trailing. Channel State Information (CSI) refers to the channel properties of a communication link, which are decisive in the selection of signal modulation, coding-decoding et cetera in order to maintain a good Quality of Service.(Le Ha *et al*,2021.;Ma & Gao,2020) propose their DNN based solutions for channel estimation. For this the works employ fully connected DNN. (Kim, Lee & Cho,2017) utilises the DNN to optimise the power requirement of existing OFDM systems. The proposed scheme reduces the Peak to Average Power Ratio (PAPR) while sustaining the required bit error rate (BER) required for commercial applications. Optimising power consumption can make the use of battery operated devices such as UAVs as intermediate communication terminals viable. Device location estimation, tracking and prediction are considered critical to mobility based services. The introduction of millimetre wavelengths for communication has enabled the detection and tracing of objects in an outdoor setting, without the necessity of line-of-sight, as demonstrated using the fingerprint positioning technique in (Gante, Falcao & Sousa,2020). To effectively manage allocation of resources such as power and sub-band in a heterogeneous multi-cell network, various supervised and reinforcement learning based resource allocation systems have been researched. (Ahmed, Tabassum & Hossain,2019) adds to these solutions an integration of a genetic algorithm with an unsupervised pre-trained DNN.

Federated learning: Wireless communication networks are interconnected subnetworks, each serving different demands under different constraints. Federated Learning (FL) (Aledhari, *et al*.,2020) is a decentralized/ distributed form of machine learning, wherein the training data doesn't reside in the central server/cloud. As (Liu *et al*.,2020) elaborates, devices register with the cloud where they receive pre-trained models, which are further trained with the locally available data. These new models are periodically aggregated and synchronized with the cloud. Thus, while the learned models are shared with the other entities, the data used for training remains at the local server, enhancing security and privacy.(Tang *et al*.,2021) demonstrates FL for UAV based IoT systems. Being battery run power constrained devices, the application of FL minimizes the power consumption.

With this procedure, FL reduces the computational load on the central data storage, enhances latency related metrics and enforces security measures.

Rapid advancements in semiconductor fabrication technologies has made quantum computing commercially feasible, which has infinite potential for wireless communications. Quantum bits, or qubits, have inherent parallelization capabilities. Several algorithms which exploit these properties have been demonstrated to speed up critical processes (Botsinis *et al*.,2018). Quantum computing has been widely researched in cryptography, thus the security and privacy issues anticipated with the data based computing in 6G might find it useful (Chen,2021). (Manzalini, 2020) describes the underlying concepts of quantum optical communication which uses photons as qubits, which can ensure high data speeds even during peak usage. The coexistence of machine learning and quantum computing in research has led to certain naming conventions, as found in (Nawaz *et al*.,2019). Communication systems which are purely based on the concepts of quantum mechanics are referred to as quantum communications, whereas QC-assisted communications refers to the conventional communications exploiting quantum speedups. The inclusion of quantum computing could be a big leap forward for communication in the 6G era.

2. Challenges in 6G

Considering the vision of 6G, inclusion of machine learning and artificial intelligence poses myriad challenges. On one hand are the traditional time-tested methods, and on the other the new promising technologies, both with pros and cons. These need to be addressed with foresight and sustainability in mind (Kato *et al*., 2020).

People come first. (Nguyen *et al*.,2020) surveys Americans on their usage of digital devices during the pandemic induced lockdown to find age, digital literacy, living conditions et cetera lead to inequalities even in a developed nation. (Comini,2020) explores internet traffic and speeds due to the pandemic in African countries. Several public and private service providers had to cut down some services or allocate extra spectrum to keep the speeds at a reasonable quality. While a surge was recorded at the beginning of the COVID lockdowns, the traffic stayed way above the pre-COVID statistics even after the lockdown-like restrictions subsided. Thus

Following the "garbage in, garbage out" philosophy, the performance of machine learning systems depends heavily on the data used for training. 6G has a vision of ubiquitous wireless intelligence. The aspect of ubiquity needs the communication systems to provide/ensure reliable and uniform performance across regions which might need the interfacing of heterogeneous networks /technologies /devices, in terms of both hardware and software. Thus a massive training dataset which covers all possible scenarios will be required. Alternatively, the existing infrastructure can be replaced. While the first has computational costs, the latter is economically infeasible. Thus implementing seamless wireless communication over a large geographic region can be a challenge. In contrast to a centralised model, federated or distributed learning allows for multiple models trained on local data. This reduces the computational load at the core and decreases latency, but runs the risk of inaccurate results on account of incomplete local information and/or cold start in highly dynamic environments. Thus, the decision between centralised and distributed will be tricky. In the communication systems not overall performance rather, performance of every transmitter-receiver pair needs to be optimised. Thus several Key Performance Indicators (KPI) like latency, throughput and packet loss rate, computational capacity and storage will be needed for a multi-objective optimisation. Applications involving autonomous robots, industrial automation et cetera need highly reliable performance. Though ample training of a machine learning system can generate good outputs, these are probabilistic in nature and their performance cannot be guaranteed in dynamic environments. This leaves much room for thought. The existing OSI model isolates all layers. However, several machine learning models work across layers. Thus, the OSI model might have to undergo some modifications, and so will be the algorithms which have been designed as per the OSI model.

As (PricewaterhouseCoopers, 2020) observes that mobile connectivity has become imperative for availing essential services, like education and healthcare. With millions of users and high data usage, the introduction of 6G will need restructuring of economic aspects like mobile tariff plans and investments towards infrastructure upgrades.

Artificial Intelligence (AI) refers to computer systems that can perform tasks or make predictions, recommendations or decisions that usually require human intelligence, but without explicit human instructions (Gillespie, Lockey & Curtis, 2021). However, the logic behind those decisions are poorly understood by the layman and the decisions are not entirely predictable (Glikson & Woolley,2020). Trust is essential for the existence, sustenance and deepening of relationships, even if it is between human and technology (Siau & Wang, 2018). AI in its current state is exaggerated and presented in a poor light by several sci-fi movies, and widely publicised reports of AI technologies giving unethical responses, some aspects of which are not covered by existing legal frameworks in several countries (Gillespie, Lockey & Curtis, 2021). The lack of understanding feeds into this fear and distrust, which has been observed to lead to intentional or playful abuse of technology (Glikson & Woolley, 2020).

AI will form a key player in making 6G vision come true. But as (Dang *et al*., 2020) discusses, inclusion of artificial intelligence will be a tightrope walk. To better understand this situation, (Gillespie, Lockey & Curtis,

2021) surveys over 6k people on their take on AI. What people need is greater confidence in those who built and use AI, better regulatory frameworks, and opportunities to know more about it.

The world is accepting artificial intelligence with a pinch of salt. (Bird *et al*.,2020) details the issues and initiatives different countries are taking to improve the acceptance of AI. A common observation reported is that a short positive interaction with autonomous or partially autonomous devices results in a positive change in attitude.

Conclusions

This research presented an overview of the advancement of artificial intelligence applications towards the 6G wireless communication network. The document has four parts, what 6G promises, the existing gaps and technical challenges, then the role of machine learning in various aspects, then the challenges of including AI/ML.An overview of the applications has been presented along with the literature review. In addition, the challenges and barriers were reported.

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