THE IMPLEMENTATION POSSIBILITIES OF 5G TECHNOLOGY IN ROAD TRAFFIC

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Abstract

The paper discusses technological aspects of 5G technology and possibilities of its application in the field of road traffic as a baseline for various optimizations i.e., autonomous driving, traffic lights optimization, vehicle-2-vehicle (v2v) communication and eco-driving.

Keywords: *5G, optimization, implementation, road, traffic*

1. INTRODUCTION

The fifth generation (5G) of mobile networks was first introduced to the world in South Korea in April 2020. The leading world experts predict that 5G technology will cover 65% of the world's population by the end of 2025. Today's 4G (+) technology processes our requests, receives, and sends data between the smart devices and the Internet in a few tens of milliseconds, using high data transfer speeds. 5G technology will offer much faster data transfer speeds. They are expected to be up to a thousand times faster than in 4G technology, with higher efficiency and better network reliability. Apart from reducing communication time and increasing reliability, 5G technology will represent a platform for the development of many new technologies. It is predicted that its application will enable development of optimized systems that should greatly contribute to the progress of all areas of human activity, including the construction of smart road infrastructure. Thus, by using all this technology, vehicles will be able to communicate and exchange data on traffic conditions, which should have a positive effect on the optimization of the road traffic flows. The first part of the paper briefly describes the features of 5G technology, while the second part of the paper provides an overview of possible 5G technologies in the field of the road transportation.

2. AN OVERVIEW OF 5G TECHNOLOGY FEATURES

5G networks are digital cellular networks, in which the service area covered by providers is divided into small geographical areas called cells. Analog signals, representing sounds and images, are digitized in the mobile phone, converted by an analogue to digital converter and transmitted as a stream of binary bits. All 5G wireless devices in a cell communicate via radio waves with a local antenna array and low power automated receiver within the cell on frequencies allocated by the receiver from a set of frequencies reused by other stations. Local antennas are connected with the telephone network and the Internet by a high bandwidth optical fibres or wireless backhaul connection.

5G can support up to a million devices, while the existing 4G (+) supports up to 100,000 devices per square kilometre. In addition, it is possible to use millimetre waves to achieve additional capacity, as well as higher network throughput. Millimetre waves have a shorter range than microwaves, so cells are limited to a smaller size. The millimetre wave antennas are smaller than the large antennas used in the previous cell networks. MIMO (Multiple-Input, Multiple-Output) technology was first deployed in 4G in early 2016 and it relied on 32 to 128 small antennas in each cell. On the right frequencies and accurately configurated, it can improve performance 4 to 10 times**.** It is expected that 5G mobile technology will provide higher maximum data rates, minimum latency, greater reliability, high network capacity and increased availability. Better performance and improved efficiency will reinforce users' experiences and connect new industries.

2.1. 5G Architecture

The system model of the 5G network is completely based on the IP algorithm for both wireless and mobile network interoperability. The model contains a computer terminal (which plays a crucial role in the current structure) and a sum of independent radio access technologies. Any radio access technology is accessible/available on any terminal due to the IP hyperlink to the external Internet environment. However, radio access technology (RAT) must have a separate network interface within the mobile terminal. So, if we have access to four different RATs, we should have four different access specific interfaces to the mobile station (MS) in addition to simultaneous activation to all of them for the 5G architecture to be functionally operated.

2.2. Standards and properties of 5G network

2.2.1. Bandwidth (Speed)

The expected 5G network speed is 50 Mbps and will go up to 1 Gbps. The fastest 5G is known as mmWave. As of 3 July 2019, mmWave has had a top speed of 1.8 Gbps on AT&T's 5G network. Sub-6 GHz 5G (mid-band 5G) is by far the most common one and it usually delivers between 100 and 400 Mbps, having a much larger range than mmWave. Low-band spectrum may have slightly greater speeds than 4G with similar spectrum and number of antennas although some 3GPP 5G networks will be slower than some advanced 4G networks, such as T-Mobile's LTE/LAA network, which achieve 500+ Mbps in Manhattan and Chicago. The similarity in terms of bandwidth between 4G and 5G in the existing bands is due to the fact that 4G is already approaching the Shannon limit on data communication rates. 5G speeds in the less common millimetre wave spectrum, with its much more abundant bandwidth and shorter range, and thus greater frequency reuse, can be significantly higher.

2.2.2. Latency

The 5G network supports three categories of latency rate:

- Air Latency - Delay between the user device and the cell tower. For a 4G network, the latency added to the data download would be a variable greater than 10 ms. The variables will depend on the signal strength, the number of devices in the cell sector, distance, noise, and many other factors. There is a tendency to reduce the air latency to 1 - 5 ms in 5G mobile networks.
- End-to-End Mobile Latency – Total latency between the base station (eNodeB) and the internet gateway. This latency is a variable between 30 and 100 ms which depends on the number of network devices, RAN network distance, network load, load of each element in the network and the user activity. The goal for 5G is to achieve 5 ms end-to-end latency.
- End-to-End Internet Latency – Represents the time required to download a website to a mobile device. Although the fifth generation strives to keep the latency to a minimum, the internet latency from the mobile operator to the downloaded website is beyond the control of 5G.

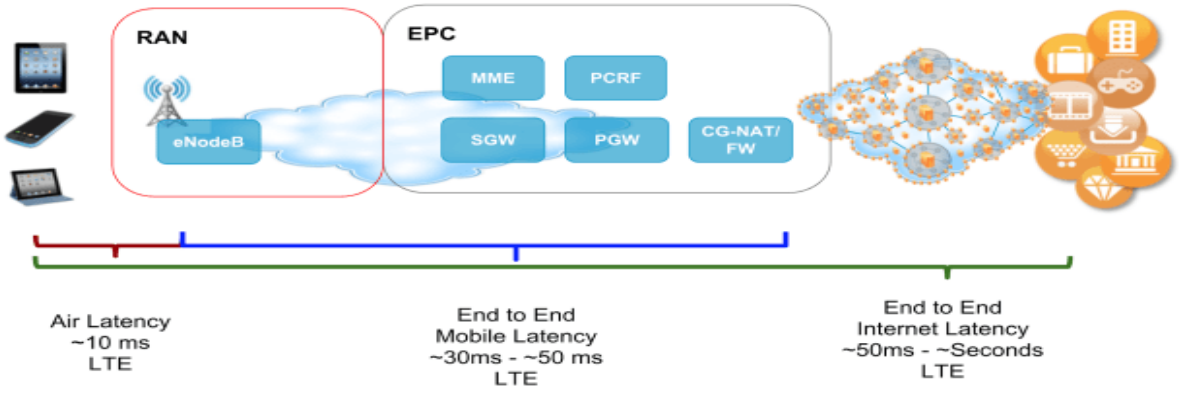


Fig. 1. 5G latency [7]

2.2.3. 5G New Radio (NR) Technology

The International Telecommunication Union (ITU) has defined the IMT-2020 standard that sets the conditions for the 5G network, which, among other requirements, define a theoretical maximum download speed of 20 Gbps and 10 Gbps data transfer speed. Therefore, the Third Generation Partnership Project (3GPP) – an organization that develops specifications and sets standards in mobile telecommunications – has selected 5G New Radio (NR) (Dahlman, Parkvall and Sköld, 2018) and Long-Term Evolution (LTE) as a proposal to be implemented in IMT-2020 standard. The 5G NR may include lower frequencies (FR1), those below 6 GHz, and higher frequencies (FR2), above 24 GHz. However, the speed and latency in early FR1 implementations, using 5G NR software on 4G hardware, are only slightly better than new 4G systems.

Frequency bands for 3GPP 5G NR are separated into two different frequency ranges. Frequency Range 1 (FR1) includes sub-6GHz frequency bands and frequency Range 2 (FR2) includes frequency bands in the mmWave. The maximum bandwidth may vary depending on the frequencies being used. The maximum channel bandwidth defined for FR1 is 100 MHz, due to the deficiency of continuous spectrum in this crowded frequency range. The minimum channel bandwidth defined for FR2 is 50 MHz and the maximum is 400 MHz, with dual connectivity and carrier aggregation supported in 3GPP Release 15. The higher the frequency, the greater is the ability to support high data rates. Some carrier distances (15, 30 kHz) can only be used in FR1, and some carrier distances (120 kHz) can only be used in the millimetre wave range, and there are carrier distances (60 kHz) that can be used in both FR1 and FR2.

5G NR is the new radio air interface that has been developed for 5G mobile communications. An air interface is the radio frequency portion of the circuit between the mobile device and the active base station. The active base station can change as the user is on the move, with each changeover known as a handoff. 5G will initially be available through improvements in LTE, LTE-Advanced and LTE Pro technologies as a Non-standalone 5G NR. But it will soon be followed by a major step-up with the introduction of a new air interface, Standalone 5G NR.

In short, the 5G NR has been designed to significantly improve the performance, flexibility, scalability, and efficiency of the current mobile networks and to get the most out of the available spectrum. Furthermore, the 5G NR air interface is only one of the components of the future 5G network, so it must be designed to work as a part of a broader flexible network architecture. 5G NR must meet the following requirements:

- Providing a large number of different services on different devices with different performance and latency requirements.
- Support a wide range of the implementation models, from traditional macro-cells to hotspot implementations.
- Enabling new ways of connecting devices.

2.3. Implementation

The initial 5G NR implementations depended on pairing with the existing LTE (4G) infrastructure in non-standalone mode (5G NR radio with 4G core), before reaching stand-alone mode with the 5G core network. The Global mobile Suppliers Association has identified 224 operators in 88 countries that have tested or have been licensed to conduct field trials of 5G technologies and are deploying 5G network or have announced the launch of services. The first country to adopt 5G on a large scale was South Korea, in April 2019. When South Korea launched its 5G network, all the operators used Samsung, Ericsson and Nokia base stations and equipment apart from LG U Plus, who was using the Huawei equipment.

2.3.1. Spectrum

Large quantities of new radio spectrum (5G NR frequency bands) have been allocated to 5G for the purpose of its deployment. For example, in April 2016, the FCC (the U.S. Federal Communications Commission) unplugged vast amounts of bandwidth in underused high-band spectrum for 5G. The Spectrum Frontiers Proposal (SFP) doubled the amount of unlicensed millimetre-wave spectrum to 14 GHz and created four times the amount of flexible, mobile-use spectrum that the FCC has licensed to

date. In March 2018, the European Union lawmakers agreed to make the 3.6 and 26 GHz bands available by 2020. The operators are increasingly using unlicensed spectrum in the 2.4 and 5 GHz frequency bands. 4G and 5G networks use these bands to facilitate traffic in congested areas and provide connectivity for the billions of devices. In these bands, mobile networks use LTE-U / LAA, MulteFire, LWA (LTE + Wi-Fi), CBRS and LSA technologies.

2.3.2. Edge Computing

Edge Computing is a distributed computing paradigm that brings budgeting and data storage closer to where it is needed, to improve response time and save bandwidth. In the early 2000s, these networks evolved to host applications at the edge servers, resulting in the first commercial edge computing services that hosted applications such as real-time data aggregators and ad insertion engines. Modern edge computing significantly expands this approach through virtualization technology that makes it easier to deploy and run a wider range of applications on edge servers. Edge computing is defined as off-cloud computing that occurs at the edge of a network, more specifically in applications where real-time data processing is required. According to this definition, cloud computing works on large data, while marginal computing acts on "current data", i.e., data that is being generated and whose processing is required in real time.

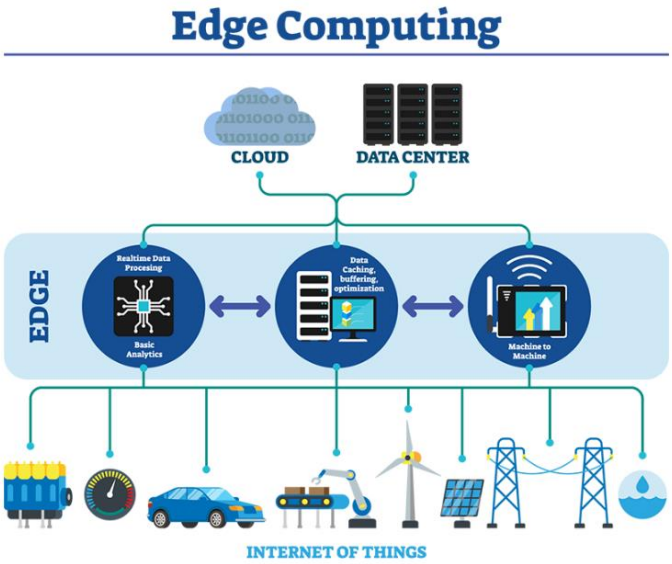


Fig. 2. Edge Computing infrastructure [8]

2.3.3. Multi-user MIMO

Multi-user MIMO is a set of multiple-input and multiple-output (MIMO) technologies for multiple wireless communication in which multiple users or terminals transmit radio signals via one or more antennas thus communicating with one another. In contrast to MU-MIMO, a single-user MIMO (SU-MIMO) involves a single user or terminal that has multiple antennas and communicates with only one similarly equipped node. Pursuant to the way OFDMA (orthogonal frequency division multiple access) allows the possibility of multiple access to OFDM in the cellular communication, multi-user MIMO provides MIMO the ability to have multiple users in the wireless area. MIMO technology also allows multiple users to share the same network resources, simultaneously. Multi-User MIMO allows messages for different users to travel securely along the same data pipelines, then be sorted to individual users when the data arrives at their mobile devices. Think of it as similar to your online shopping order traveling in a delivery van together with other orders. Your order shares space in the van, but it is delivered directly to you — the intended recipient. Serving multiple users with same transmission increases capacity and allows for better utilization of resources. That adds up to the ability to download or stream with an improved experience for the user even in crowded area.

2.3.4. Beamforming

Beamforming is a technique that focuses a wireless signal towards a specific receiving device, rather than having the signal spread in all directions from a broadcast antenna. A direct connection is faster and more reliable than it would be without beamforming. Although the principles of beamforming have been known since the 1940s, in recent years beamforming technologies have introduced additional improvements in Wi-Fi networking. Today, beamforming is crucial to the 5G networks. A single antenna broadcasting a wireless signal radiates that signal in all directions, which is the natural way electromagnetic waves work. One of the techniquse for focusing a signal in the particular direction involves having multiple antennas in close proximity, all broadcasting the same signal at slightly different times. The overlapping waves will produce interference that in some areas is constructive (it makes the signal stronger) and in other areas is destructive (it makes the signal weaker).

If performed correctly, this beamforming process can focus the signal on a specific location or receiving device. By focusing a signal on a specific direction, beamforming allows delivering of higher signal quality to your receiver which means faster data transfer and fewer errors — without need for boosting the transmission power. This is the goal of the most techniques for improving wireless communication. The limitations of beamforming mostly involve the computing resources it requires. There are many scenarios where the time and power resources required by beamforming calculations end up negating its advantages. But continuing improvements of the processor power and efficiency have made beamforming techniques affordable enough to be built into consumer networking equipment.

2.4. Security issues

The European Commission and the European Agency for Cybersecurity have published a detailed report on security issues related to 5G. The report advises against employing solely one supplier for 5G infrastructure, especially those based outside the European Union.

A team of researchers from ETH Zurich, Lorraine University and Dundee University published a research article under the title "A Formal Analysis of 5G Authentication" (Basin et al., 2018), identifying security issues regarding the 5G technology. The article describes the technology as underdeveloped and insufficiently tested, allowing the transfer and access to significantly larger amounts of data, and thus expanding the attack areas. At the same time, network security companies such as Fortinet, Arbor Networks, A10 Networks and Voxility have advised on personalized and mixed security deployments against the massive DDoS attacks anticipated after the 5G deployment. Driven by 5G technology standards development, the IoT Analytics has estimated an increase in the number of connected IoT devices, from 7 billion in 2018 to 21.5 billion by 2025. This could significantly elevate the extent of attacks on these devices as well as DDoS, crypto and other cyber-attacks. Fearing the potential espionage by users of the Chinese equipment suppliers, several countries including the United States, Australia and the United Kingdom have taken actions to limit or eliminate the use of Chinese equipment in their 5G networks since the beginning of 2019. Chinese suppliers and the Chinese government have denied these claims and allegations.

On October 7, 2020 the British parliament's defence committee released a report claiming there had been clear evidence of Huawei collusion with the PRC and the Chinese Communist Party apparatus. Valdi recommended considering removing all Huawei equipment from the national 5G networks earlier than planned.

There are five reasons why 5G networks are more vulnerable to hacker attacks than their predecessors:

- This network has moved away from centralized, hardware-based switching to distributed, software-defined digital routing. Previous hub-and-spoke networks were vulnerable to congestion effects thus being convenient for cyber-protection implementation practice. In the 5G software-defined network, however, that activity is pushed outward to a web of digital routers throughout the network, thus denying the potential for chokepoint inspection and control.
- 5G further complicates this cyber vulnerability by virtualizing in software higher-level network functions formerly performed by physical appliances. These activities are based on the common language of the Internet Protocol and well-known operating systems. Whether used by nation-states

or criminal actors, these standardized building block protocols and systems have proven to be valuable tools for those seeking to commit fraud.

- Even if it were possible to lock down the software vulnerabilities within the network, the network is also being managed by software—often early generation artificial intelligence—that itself can be vulnerable. An attacker who gains control of the software managing the networks will also control the network.
- The dramatic expansion of bandwidth itself makes 5G more vulnerable. Physically, low-cost, short-range, small-cell antennas deployed in urban areas are becoming targets. Functionally, these cell sites will use 5G's Dynamic Spectrum Sharing capability in which multiple streams of information share the bandwidth in so-called "slices"— each slice with its own varying degree of cyber risk. When software allows the functions of the network to shift dynamically, the cyber protection must also be dynamic rather than relying on a uniform, lowest common denominator solution.
- Vulnerability has been created by attaching tens of billions of hackable smart devices to the network colloquially referred to as IoT (the Internet of Things). Therefore, plans for a diverse and seemingly inexhaustible list of IoT-enabled activities, ranging from public safety devices, to household chore, to medical devices and road traffic have been underway. In July, for example, Microsoft reported that Russian hackers had used the IoT devices to gain access to networks. From there, the hackers discovered further compromised IoT devices into which they could plant software exploitation program.

The key item for the safe implementation of the 5G network is that companies must recognize and take responsibility for new cyber vulnerabilities. Traditionally, common law has established that those who provide products and services have a duty of care to identify and mitigate potential harms that could result. Such a cyber security is based on:

- Greater investment in reducing the cyber risk.
- Implementation of machine learning and artificial intelligence protection.
- Focusing on security in the development and operational cycle.

2.5. Advantages and disadvantages of 5G technology

5G technology offers a wide range of features that are useful to all groups of people, including students, professionals (doctors, engineers, teachers, governing bodies, etc.), and even to common men. There are several advantages of 5G technology:

- It gathers all networks on one platform.
- High resolution and bi-directional large bandwidth shaping.
- More effective and efficient.
- Easily manageable with the previous generations.
- It facilitates subscriber supervision tools for the quick action.
- Possibility to provide uniform, uninterrupted, and consistent connectivity across the world.
- Education will become easier − A student sitting in any part of the world can attend the class.
- Medical Treatment will become easier and more economical − doctor will be able to treat the patient in the remote part of the world.
- Possible natural disasters including tsunami, earthquake etc. can be detected faster.

Although 5G technology has been researched and developed to solve all the problems with radio signals and the difficulties of the mobile world, due to some security reasons and lack of technological progress in most geographical regions, it has the following shortcomings:

- The technology is still under development although it has started to be implemented and its sustainability is being investigated.
- The speed at which this technology aspires seems difficult to achieve (could be achieved in the future) due to insufficient technological support in most parts of the world.
- Many old devices are not compatible with 5G, so they all need to be replaced with the new ones which requires a large infrastructure investment.

3. THE INFLUENCE OF 5G TECHNOLOGY ON DEVELOPMENT OF SMART TRAFFIC

As the wider implementation of 5G technology approaches, companies in all industries are preparing for the upcoming changes. Carriers, from those providing public passenger transport services to those transporting goods, could benefit greatly from the introduction of the next-generation mobile networks. 5G technology can provide increased visibility and control over transportation systems. Low latency, high capacity and reliability will improve the flow and tracking of people and goods, providing complete connectivity. The three most important types of supported communications include:

• Vehicle-to-vehicle (V2V) - for communication between vehicles.

• Vehicle-to-infrastructure (V2I) - for vehicle communication with the road infrastructure.

• Vehicle-to-everything (V2X) - for vehicle communication with any traffic entity or any other system.

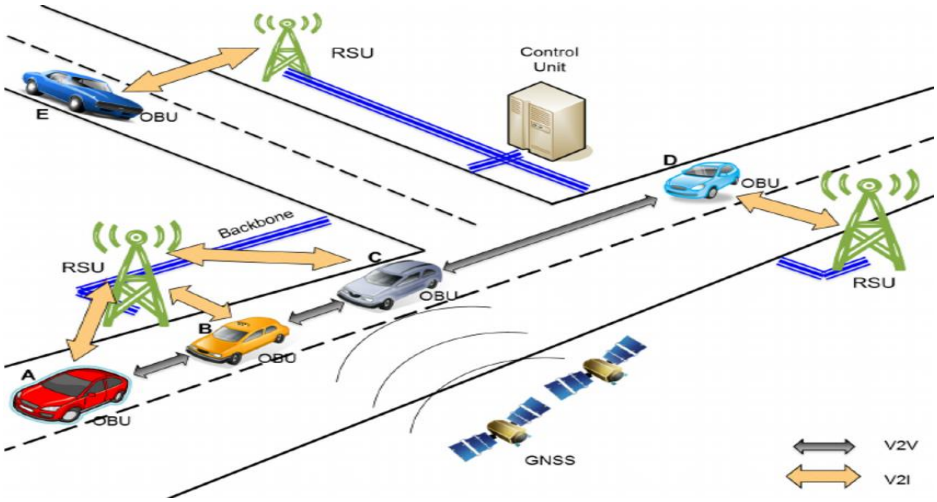


Fig. 3. V2V and V2I infrastructure [6]

Today, it is still a common case of complete lack of integration of the existing communication networks that use 5G technology or integration gateways to unify all short-range communication technologies. It is possible to create a single network governed by a common set of rules or policies. Unifying network protocols in this way allow uninterrupted communication with the connected vehicle as it travels between different access points. As 5G networks spread across the cities and connect the existing wireless networks, they can provide end-to-end visibility in real time in our transportation systems.

The increased network capacity will enable better integration of the various transportation modes, as well as their better connection with the users, enabling the planning and management of daily traffic flows, and more efficient prediction of the transportation capacity in real time. Similarly, ubiquitous city-wide 5G networks will make it easier for private fleet owners to get consistent telemetry data from their field service vehicles and delivery trucks. This data, delivered in real time, will help them track everything from the vehicle location and speed to idle time and fuel consumption. Analytics systems can use this information to optimize long-term vehicle usage and short-term routing.

Well-connected transportation infrastructure in both urban and rural areas and vehicles exchanging data in real time, help avoiding the creation of unnecessary oscillations in traffic flow by maintaining a specific distance between vehicles, i.e., their speed. With the growing presence of autonomous vehicles, V2V, V2I and V2X communications can help make autonomous driving algorithms safer and more reliable.

3.1. Autonomous driving

There are several intermediate levels that involve the way we communicate with vehicles. According to the Society of Automotive Engineers, there are six levels of driving automation, from no automation to full automation.

- No Automation (level 0): The driver is continuously in control.
- Assisted Driving Automation (Level 1): A minor driving task is performed by the system.
- Partial Automation (level 2): The driver must monitor dynamic driving tasks.
- Conditional Automation (level 3): Driver does not need to monitor driving tasks but must be able to resume control.
- High Automation (level 4): The driver is not required during a defined use case.
- Full Automation (level 5): The highest level refers to a fully autonomous system, no driver required.

In principle, autonomous driving is possible without V2X communication, for levels 1 and 2, where the driver monitors the driving environment. However, level 5 without any support from a wireless communication system, i.e., based only on embedded sensing and processing systems, is not practical. Without vehicular communication, uncertainty must be considered since one cannot know what another vehicle or pedestrian will do in the next few seconds. If vehicles share their available information, then other vehicles could use them to reduce uncertainties. Thus, autonomous driving can be benefited from the local communication V2V, and react faster to manoeuvres, and prevent collisions. A prominent use case of autonomous driving is Cooperative Collision Avoidance. According to the European Union community road accident database (CARE), intersection related fatalities accounted for more than 20% during the last decade. After all other traffic control mechanisms have failed, the communication between autonomous vehicles is required to take actions and prevent collisions. In such a dynamic and complex environment, upon identification of a collision risk, vehicles cannot decide individually, since different individual actions applied without prior coordination might cause additional collisions or uncontrolled situations. Therefore, all involved vehicles should work in a cooperative manner to compute the optimal collision avoidance actions.

3.2. Traffic light control

An individual traffic light controls the flow of traffic at one intersection and does so by not communicating with the traffic lights at adjacent intersections. On an isolated intersection, time cycle variables, consisting of phases, cycle lengths, offset parameters, and separation intervals, play a crucial role in the effective control of the vehicle flow:

- Phase - the part of the cycle that distributes the movement of traffic from different (conflicting) directions.
- Cycle - time to complete one sequence of signal phases.
- Offset - time ratio calculated by the difference between a certain point and a reference point in the traffic system.

The main goal of optimizing traffic signal control system is to minimize the waiting time for vehicles to pass through the intersection, i.e., to maximize the number of vehicles passing through the intersection. The stated variables are usually inversely proportional, depending on the given traffic conditions, i.e., they are mutually exclusive. Therefore, to optimize traffic flows, traffic control strategies that include

detectors or sensors have been used. Regarding the movement of the vehicle and the traffic density at each part of the intersection, the actual green interval, and its preconditions are determined, while the maximum and minimum green parameters are predetermined in the controller. Optimization of (road) traffic in urban areas is usually carried out in one of the following ways:

- At the intersection of the main and side streets (main and secondary traffic routes) in terms of traffic volume. The detector may request a green light for the side direction as well as an extension of the green light time to the maximum value due to the increased presence of the vehicles on the side direction. The main road vehicle sensor may revert to green until vehicles (or a number of vehicles) appear on the secondary route.
- At the intersection of the two equal traffic density directions. In this situation, the efficiency of the detectors is reduced, but they become effective when there is a change in load on a particular traffic route.

The use of detectors to control the operation of traffic lights, i.e., the constant optimization of the cycle in real time is a key component that affects the increase in road capacity.

3.3. Decentralized route choice

Instead of optimizing traffic flow based on average latency and travel time, the eco-driving is another option that intelligent traffic management can improve. The goal of eco-driving is to minimize fuel consumption and emissions from the starting point to the destination point by providing and exchanging information on the state of traffic flow between the vehicle and all the elements of the transportation system. Among the most common and easily manageable factors/variables that drivers have a direct impact on, and which can directly affect the environmental performance improvement are vehicle speed, acceleration, deceleration (braking), and the choice of the travel route. Information collected through the real-time traffic system via the 5G network can directly influence the drivers' decisions on choosing their routes' optimal values to achieve the optimal environmental effects and reduce the waiting time and total travel time from the starting point to destination.

The advantages of 5G technology have been manifested through the possibility of data transfer between the large number of vehicles on the road in a short period of time thus enabling the decentralization of data processing. This decentralization is visible through the selection of optimal factors - driving variables at the level of each vehicle which has led to optimization of the system load and much greater flexibility in making optimal decisions and optimization of traffic flows and increased environmental efficiency.

As the future technology brings reduced response times, enhanced connectivity speeds, and increased reliability to improve some of the most essential processes in our societies, 5G has the ability to make commuting quicker, easier, and more efficient than ever before. Networked cars running on 5G networks will be able to communicate effectively and instantly with each other as well as the environment, giving drivers information and alerts about what is happening around them. Using technologies such as Light detection and ranging (LiDAR; 3-D laser scanning), or various detector systems to collect and share important traffic infrastructure data with other vehicles (for example, braking data to warn nearby vehicles to possible unexpected events and hazards, information on the availability of parking spaces along the route along which the vehicle is moving), will be able to provide real-time updates on everything in its surroundings, from weather and road conditions to the potential traffic hazards.



Fig. 4. Illustration of more efficient route finding for vehicles running on 5G networks [10]

5G networks will enable V2V communication even when cars are outside the line of sight, utilizing 5G sensors to complement their LiDAR and radar capabilities to detect and communicate with the other vehicles. Some of these features, already in use, are running on 3G or 4G technology. However, they're limited to a small-scale applications. To enable this to happen at a larger scale the capabilities of the vehicles running on 5G networks will have to be increased to transmit information and make intelligent decisions faster than humans and the centralized traffic control system. As with any new technology, there will be a learning curve. The car manufacturers will have to acquire new capabilities to successfully connect vehicles and will have to face some challenges as they increase their connectivity management strategies.

3.3.1. Moving to 5G with edge computing

A popular use case for connected vehicles is sharing braking data. Let's say you are driving a connected vehicle, and connected cars ahead of you are unexpectedly coming to a stop. Being able to have your car anticipate a sudden stop would be a tremendous safety feature, and car manufacturers want to share that braking information with you. However, if the data need to travel too great a distance from where your car is located, the latency could prevent attaining this data in time. To avoid this, the car manufacturers need to not only explore 5G, but edge computing, as well. However, tackling the transition to 5G and edge computing can be challenging without connectivity expertise. Many car manufacturers are lacking sufficiently deep expertise in how LTE/5G network works, which can cause delays in innovation. In addition to knowing how 5G is becoming the future of autonomous vehicles, car manufacturers will benefit from learning how:

- Artificial Intelligence (AI) is impacting the automotive industry
- Combined technologies will transform the auto industry into a digital services business
- Spare part manufacturers are reducing warranties and launching new business models by collecting and analysing the car sensor data.

3.3.2. The impact of 5G technology on road traffic/transportation

The wider introduction and acceptance of 5G technology will undoubtedly have a great impact on many industries and activities. One of the biggest impacts will be on the automotive industry. In addition to the traffic system optimizations, 5G will certainly facilitate the use of infrastructure designed to support the introduction of electric vehicles, such as charging stations. The ability to find charging stations and identify effective routes more quickly could significantly improve the EV experience. Apart from EVs, autonomous vehicles will also come to the fore. Autonomous vehicles deploy machine learning. The more they are driven, the greater is the possibility to understand patterns that will help them shape the appropriate driving reactions. But all this processing of information is possible only if there is a possibility of collecting, processing, and storing of data in real time. The goal is to turn the concept of "vehicle-to-everything" into reality. Basically, the V2X is for a vehicle to wirelessly connect to multiple

sources of information in its surrounding environment, be it other vehicles or traffic lights. In 2016, eight corporations including car manufacturers (AUDI AG, Daimler AG, BMW), and telecoms (Ericsson, Huawei, Intel, Nokia, Qualcomm) created the 5G Automotive Association (5GAA), designed to support the development of the V2X technologies. Autonomous cars will bring new forms of shared services. One example is the way Tesla upgrades and maintains vehicles. One of the most famous upgrades happened in 2018, when the company updated the braking for the Tesla Model 3 just with a software upgrade. Tesla should have found this bug in its software before releasing the car on the market. Still, the way it was fixed was impressive. Volkswagen had software problems ahead of the launch of its new full electric vehicle, the VW iD3. It is obvious that the car industry needs to improve its way of working with software. It is one thing to release a safe and reliable car with the working software, and quite another to send new upgrades wirelessly to implement new functions and fix the problems.

4. CONCLUSION

Today, mobile networks have a big impact on the world we live in. The first generation of mobile networks was launched in Tokyo. Its development resulted in the deployment of the first commercial mobile phone. However, the first generation had a lot of shortcomings and could not meet all the demands of the market. The second generation offered solutions to some problems, calls were encrypted and a transition from analog to digital signal was introduced. The GPRS system was presented as a bridge to the third generation, which was up to 4 times faster than the previous one. Thanks to its systems, the world today is focused on the development of the broadband internet access. The transition from 3G to 4G is referred to as evolution because the fourth generation is based on the third one with the addition of the improved LTE technology. Unimaginable speeds have been achieved and response times have been greatly reduced. The fifth generation of mobile networks was created at the request of the market since 4G technology could no longer effectively meet the needs of users. The 5G system should provide much higher data transfer speeds, up to 10 times higher network capacity, minimum response time and increased availability, which will greatly affect the road traffic as we know it today. It will provide the increased visibility and control over the transportation systems, vehicles will be able to communicate with each other and with the infrastructure, i.e., they will be able to communicate with any "smart" traffic entity. There are already vehicles with a high level of autonomy, but after the full implementation of 5G technology, the traffic safety will increase significantly. The cars will communicate with each other and warn each other about the situation on the road, and other possible, unexpected events such as a collision. Cars will exchange this information in real time, with low or no latency at all. 5G will enable a detailed control of the traffic flow to minimize the waiting time and increase the number of vehicles passing through the intersection. All the improvements in the traffic will lead to the development of the eco-friendly driving, where cars will be able to assess the road network loading and automatically select the shortest possible path. However, apart from the introduction of 5G technology, the full implementation of V2V, V2I and V2X communication, will require the infrastructure investments. Furthermore, the artificial intelligence and machine learning software should be developed in order for cars to use and interpret the received data. Tesla and Volkswagen have been developing electric cars with a high level of autonomy for several years now. So far, their cars have demonstrated excellent results.

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