

5G Advanced Mobile Communication for Smart Cities and Connected Vehicles

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Abstract: The exponential growth of urban populations and the rapid evolution of mobility demand a communication infrastructure that is not only ultra-fast but also intelligent, reliable, and scalable. 5G Advanced, also referred to as 5.5G, is emerging as a critical enabler of smart cities and connected vehicles, extending the capabilities of traditional 5G networks. Unlike standard 5G, which primarily emphasized high data rates, 5G Advanced integrates enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC), and massive machine-type communication (mMTC) along with AI-native intelligence and energy-efficient architectures. These advancements enable seamless, context-aware, and highly adaptive digital ecosystems.

In the context of smart cities, 5G Advanced provides the backbone for millions of interconnected IoT devices including intelligent traffic management systems, high-resolution surveillance cameras, environmental monitoring sensors, smart grids, and connected healthcare solutions. By enabling real-time data exchange, predictive analytics, and autonomous decision-making, 5G Advanced transforms cities into sustainable, safe, and resilient urban ecosystems.

For connected vehicles, 5G Advanced is the cornerstone of Vehicle-to-Everything (V2X) communication—covering V2V (Vehicle-to-Vehicle), V2I (Vehicle-to-Infrastructure), V2P (Vehicle-to-Pedestrian), and V2N (Vehicle-to-Network). These capabilities support autonomous driving, cooperative collision avoidance, real-time navigation, intelligent fleet management, and immersive in-car experiences such as AR-assisted driving and cloud gaming. With sub-millisecond latency, 5G Advanced ensures end-to-end safety, reliability, and efficiency in transportation systems.

This paper explores the architecture, features, and applications of 5G Advanced in building intelligent cities and enabling autonomous mobility. We present block diagrams of system architectures, provide a comparison of 4G, 5G, and 5G Advanced, and discuss key challenges such as spectrum allocation, infrastructure costs, and cybersecurity threats. Furthermore, we review recent research trends and propose a roadmap for integrating 5G Advanced into smart city infrastructures and connected vehicle ecosystems, thereby laying the foundation for future 6G innovations.

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I. INTRODUCTION

The 21st century is witnessing a revolution where connectivity is no longer a luxury—it is the nervous system of modern life. As cities grow smarter and vehicles become more intelligent, the need for a communication backbone that is ultra-fast, highly reliable, and context-aware has become undeniable. This is where 5G Advanced, often called the bridge between 5G and 6G, emerges as the key enabler of the next wave of digital transformation.

Unlike traditional networks that were designed mainly for voice and internet access, 5G Advanced is built for an era of autonomous systems, real-time decision-making, and billions of connected devices. It brings together the power of enhanced mobile broadband (eMBB) for speed, ultra-reliable low-latency communication (URLLC) for safety, and massive machine-type communication (mMTC) for scale. Combined with AI-driven intelligence and energy-efficient architectures, it goes beyond connectivity—it creates living, breathing digital ecosystems.

In the context of smart cities, 5G Advanced acts as the invisible fabric that ties together intelligent traffic lights, surveillance systems, healthcare sensors, waste management, energy grids, and emergency response services. Imagine a city where traffic never clogs, ambulances reach patients faster because signals turn green automatically, power grids adjust to demand in real time, and security systems predict risks before they happen. This vision becomes reality with the massive device connectivity and ultra-low latency that 5G Advanced enables.

The automotive sector is undergoing a similar transformation. Connected and autonomous vehicles (CAVs) are no longer futuristic concepts—they are becoming everyday realities. Cars are evolving into data-driven machines on wheels, capable of communicating with each other (V2V), road infrastructure (V2I), pedestrians (V2P), and cloud platforms (V2N). With sub-millisecond response times, vehicles can predict accidents before they happen, coordinate lane changes seamlessly, and offer immersive in-car experiences such as AR navigation, cloud gaming, and AI-powered assistance. In this ecosystem, safety and intelligence converge, powered by 5G Advanced.

Therefore, 5G Advanced is not merely an upgrade of 5G—it is the foundation for digital societies and intelligent mobility. It enables sustainable cities, accident-free roads, efficient transportation, and better quality of life. As industries, governments, and researchers continue to integrate this technology into real-world systems, 5G Advanced will serve as a stepping stone toward fully autonomous cities and the dawn of 6G.

➤ 5G Advanced Technology Overview

5G Advanced is not just a minor upgrade of 5G—it is the next intelligent leap in connectivity. Think of it as the “brain upgrade” of networks, designed to handle the explosive growth of devices, data, and real-time interactions that our future cities and vehicles will demand.

➤ Key Features

• Enhanced Mobile Broadband (eMBB):

- ✓ Imagine downloading a full 8K movie in just a few seconds, or streaming VR/AR-based navigation inside a car without lag.
- ✓ 5G Advanced offers speeds up to 10 Gbps, meaning it can deliver internet that feels instant.
- ✓ In smart cities, this supports real-time surveillance, high-resolution video conferencing for governance, and digital classrooms.

• Ultra-Reliable Low-Latency Communication (URLLC):

- ✓ Latency is the “response time” of a network. 5G Advanced brings it below 1 millisecond.
- ✓ For humans, that’s faster than the blink of an eye.
- ✓ In vehicles, this means a car can detect and respond to an accident instantly, preventing crashes.

- ✓ In healthcare, doctors can perform remote robotic surgeries safely, with no delay.

• Massive Machine-Type Communication (mMTC):

- ✓ Smart cities rely on millions of IoT devices—streetlights, sensors, parking meters, smart grids, and emergency systems.
- ✓ 5G Advanced connects up to 1 million devices per square kilometer without crashing the network.
- ✓ This ensures every sensor in a smart city talks to each other in harmony, creating a truly connected ecosystem.

• AI-Native Networks:

Unlike older networks that simply transmitted data, 5G Advanced “thinks” using AI.

• For Example:

- ✓ It predicts traffic congestion and reroutes vehicles automatically.
- ✓ It learns energy consumption patterns and balances smart grids efficiently.
- ✓ It even protects itself by detecting and blocking cyberattacks in real time.
- ✓ In short, AI makes the network autonomous and self-healing.

• Energy Efficiency (Green Networking):

- ✓ Traditional networks consume huge amounts of power.
- ✓ 5G Advanced introduces energy-aware scheduling, sleep modes for IoT devices, and optimized base stations.
- ✓ This reduces carbon footprint, making smart cities eco-friendly and sustainable.

II. WHY 5G ADVANCED IS A GAME-CHANGER

➤ For Smart Cities:

Imagine a digital nervous system running through the city—traffic lights, hospitals, schools, homes, and transport systems are all connected. If a fire breaks out, the system:

- Instantly alerts firefighters.
- Clears the traffic route by changing signals.
- Sends live building data (exits, gas leaks) to rescue teams.
- Updates nearby citizens in real-time.
- This chain reaction of intelligence is only possible with 5G Advanced.

➤ For Connected Vehicles:

- Think of cars as smartphones on wheels, but smarter.
- They talk to each other: warning about sudden brakes, slippery roads, or accidents ahead.
- They talk to infrastructure: knowing when a signal will turn green, or where the nearest free parking is.
- They talk to pedestrians’ smartphones: preventing accidents by alerting drivers.
- This makes roads safer, smoother, and stress-free.

➤ *For Citizens:*

- Instead of wasting hours in traffic, you move freely.
- Instead of waiting for ambulances, help arrives faster.

- Instead of wasting electricity, cities auto-adjust power use.
- In short: 5G Advanced improves daily life in invisible but powerful ways.

III. 5G ADVANCED NETWORK ARCHITECTURE

The 5G Advanced architecture integrates cloud computing, edge intelligence, and distributed antennas.

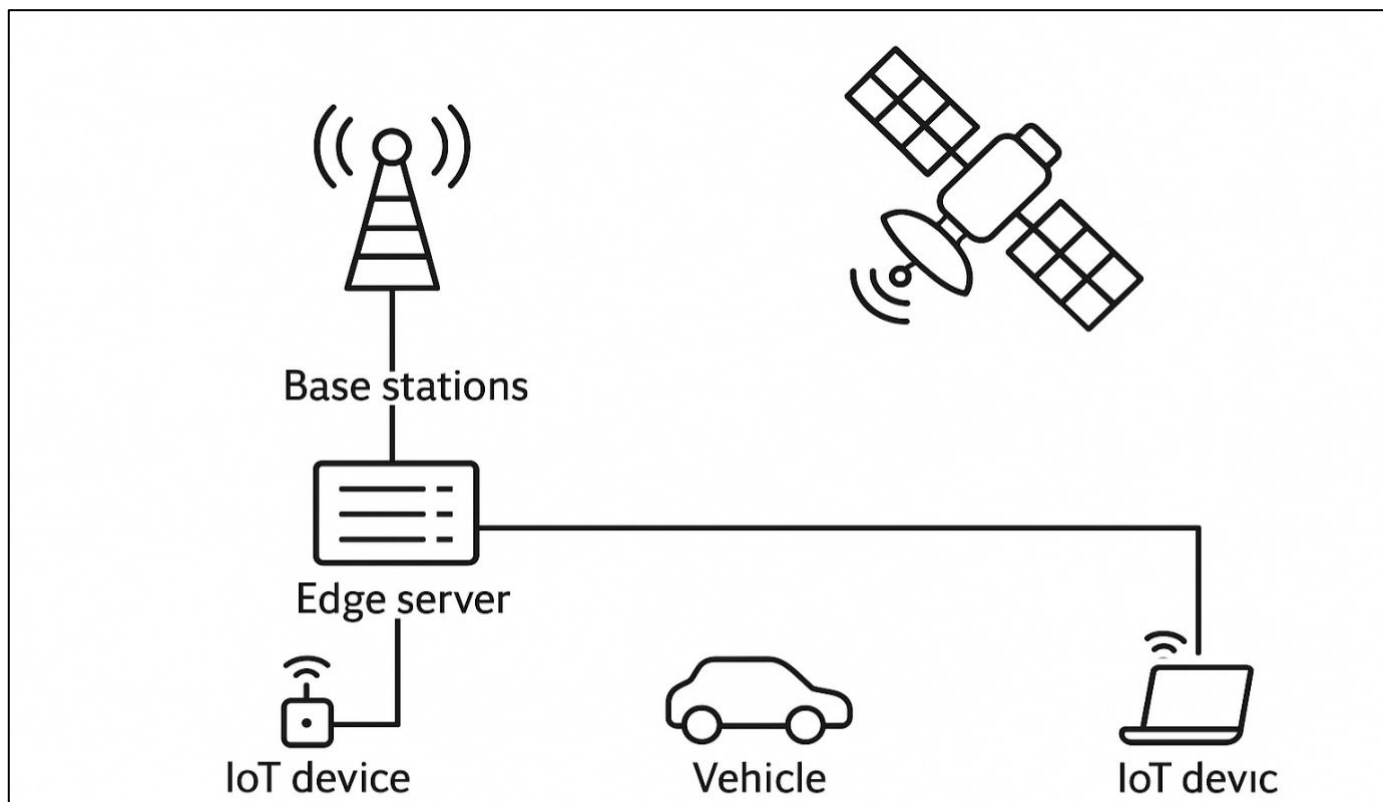


Fig 1 Block diagram of 5G Advanced Architecture (Base Stations, Edge Servers, IoT Devices, Vehicles, Satellites).

➤ *Features:*

- Core network with cloud-native design
- Edge computing for low latency
- Network slicing for different applications
- AI-driven traffic management

➤ *5G Advanced in Smart Cities*

The rise of smart cities marks a major step in the digital transformation of urban life. A smart city is not simply a city with Wi-Fi or digital services; rather, it is a highly connected and intelligent ecosystem where technology is used to improve governance, mobility, healthcare, safety, sustainability, and the overall quality of life for citizens. For such a city to function effectively, there must be a reliable, intelligent, and high-performance communication backbone. This is where 5G Advanced—the next evolution of 5G networks—comes into play.

5G Advanced (sometimes called 5.5G) is designed to support massive device connectivity, extremely low latency, ultra-fast speeds, and AI-driven automation. Unlike earlier generations of communication networks, which were mainly built for voice and mobile data, 5G Advanced has been

specifically optimized to power the Internet of Things (IoT), artificial intelligence (AI), and real-time communication systems. This makes it the perfect foundation for the creation and operation of smart cities.

➤ *IoT Integration for Smart Infrastructure*

One of the defining features of smart cities is the deployment of IoT devices across almost every sector of urban life. Smart streetlights, waste bins, water meters, parking sensors, environmental monitors, and energy grids constantly generate data that needs to be processed in real time. 5G Advanced supports massive machine-type communication (mMTC), which means it can connect millions of IoT devices per square kilometer without network congestion.

For example, smart streetlights equipped with sensors can adjust brightness depending on traffic or pedestrian activity, saving energy. Waste bins with sensors can signal collection trucks when full, reducing unnecessary trips and lowering fuel consumption. Smart parking sensors can notify drivers of available spots through a mobile app, reducing traffic caused by vehicles searching for parking. All these IoT

applications rely on the high reliability and scalability of 5G Advanced.

➤ *Smart Traffic Management and Mobility*

Traffic congestion is one of the biggest problems in urban areas. Traditional traffic light systems operate on fixed timers and often fail to respond to real-time traffic conditions. With 5G Advanced, AI-driven traffic management systems can monitor vehicle density through sensors and cameras, then adjust traffic signals dynamically to optimize flow.

In emergencies, 5G Advanced enables the creation of “green corridors” for ambulances, fire brigades, and police vehicles. Traffic lights along their route turn green automatically, ensuring faster response times and saving lives. In addition, connected public transport systems can coordinate routes and schedules in real time, reducing delays and improving efficiency.

➤ *Public Safety and Security*

Ensuring public safety is one of the most critical responsibilities of city authorities. 5G Advanced empowers AI-enabled surveillance systems to detect unusual activities or criminal incidents instantly. High-resolution CCTV cameras connected via 5G Advanced can stream live video feeds without lag, enabling real-time monitoring.

With facial recognition, license plate detection, and anomaly recognition algorithms, police can identify threats or suspects quickly. For example, if a suspicious bag is left in a crowded area, AI can detect it and send alerts to authorities immediately. Drones connected to the 5G Advanced network can also be deployed for crowd monitoring, traffic control, or disaster management.

➤ *Smart Healthcare and Emergency Services*

Healthcare in smart cities is not limited to hospitals; it extends into homes, ambulances, and even wearable devices. With 5G Advanced, remote healthcare (telemedicine) becomes more reliable due to ultra-low latency and high bandwidth. Doctors can diagnose patients virtually in real time using high-quality video or even AR/VR tools.

In emergencies, connected ambulances play a vital role. Patient vitals such as heart rate, blood pressure, and oxygen levels can be transmitted to hospitals while the ambulance is en route. This allows doctors to prepare emergency rooms in advance, reducing treatment delays and saving lives. For chronic patients, wearable medical devices continuously monitor health and send updates to healthcare providers via the 5G Advanced network.

➤ *Sustainability and Smart Grids*

A sustainable city is one that uses resources efficiently while minimizing its environmental impact. 5G Advanced

supports this through smart energy and smart water systems. Smart grids powered by IoT sensors monitor electricity demand in real time, distribute energy more efficiently, and integrate renewable energy sources like solar and wind.

Smart meters in households and industries allow citizens to track their energy consumption and optimize usage. Water distribution systems equipped with sensors can detect leaks, ensuring minimal wastage. Even waste management systems become smarter when trucks follow optimized routes based on real-time bin data. This not only saves costs but also reduces carbon emissions, making cities greener and more sustainable.

➤ *Citizen Services and Governance*

Another important aspect of smart cities is technology-driven governance. With 5G Advanced, governments can create digital platforms for services like bill payments, grievance redressal, and online permits. These services become faster, more efficient, and more accessible. Citizens can also use smart city apps to access transport schedules, pollution data, healthcare facilities, and safety alerts in real time.

This creates a citizen-centric governance model, where data-driven decisions improve efficiency and transparency. For example, if air pollution levels rise above a threshold, the system can automatically send alerts to residents, while also activating restrictions on industrial activity or traffic in specific zones.

➤ *Why 5G Advanced is Essential for Smart Cities*

Compared to earlier technologies, 5G Advanced offers several unique advantages:

- **Massive Connectivity:** Ability to connect millions of IoT devices.
- **Ultra-Low Latency:** Less than 1 ms delay for real-time decision-making.
- **High Reliability:** Essential for safety-critical services like healthcare and traffic management.
- **AI Integration:** Networks can self-optimize and predict issues.
- **Energy Efficiency:** More sustainable than older networks, supporting green city goals.
- These features ensure that smart cities are not just technologically advanced but also safer, greener, and more efficient for their citizens.

➤ *Smart City IoT Ecosystem with 5G Advanced*

Smart cities rely on massive IoT networks for traffic, healthcare, utilities, and governance.

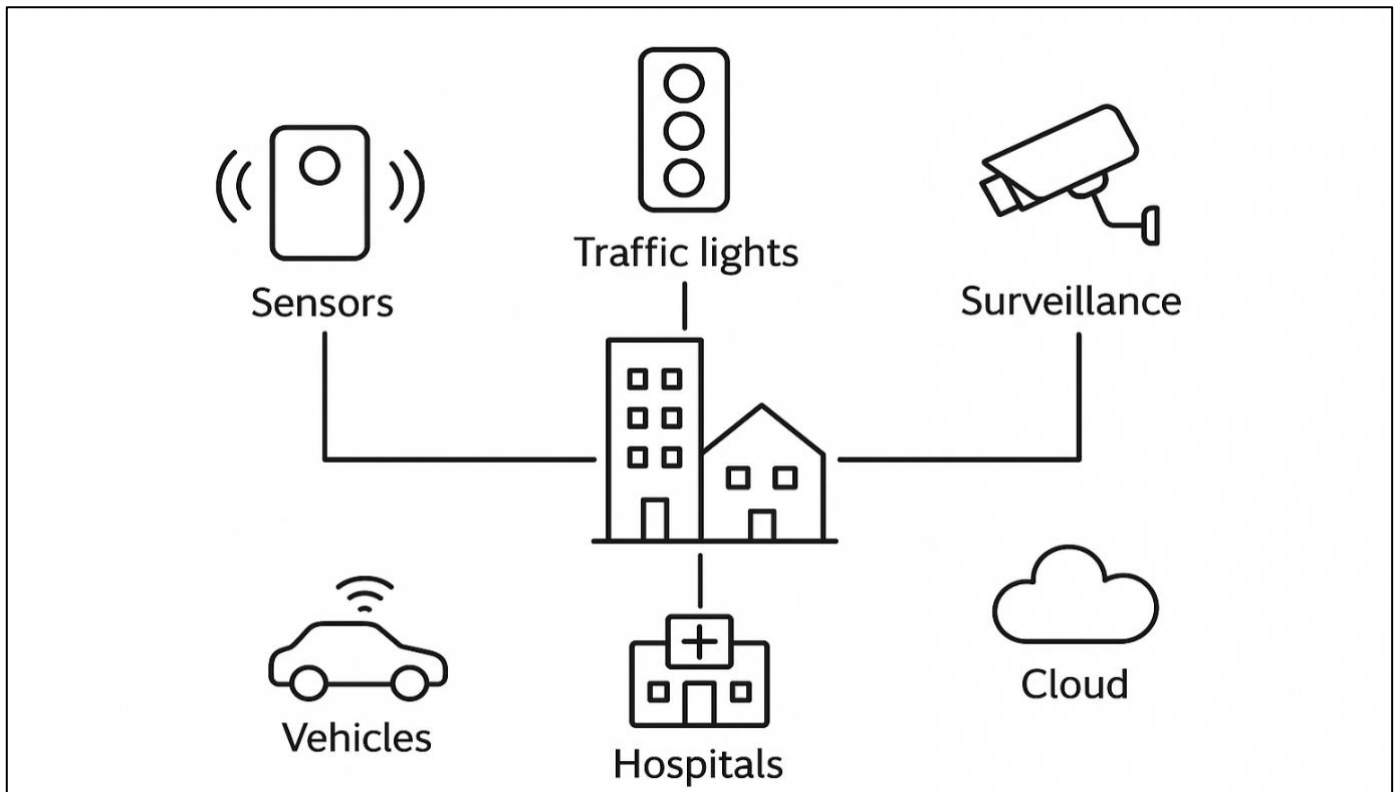


Fig 2 Smart City Ecosystem Diagram (Sensors, Traffic Lights, Surveillance, Vehicles, Hospitals, Cloud).

- *Applications:*

- ✓ Smart traffic lights reducing congestion
- ✓ Remote healthcare monitoring
- ✓ Smart grids and energy distribution
- ✓ Real-time surveillance and emergency alerts

IV. 5G ADVANCED IN CONNECTED VEHICLES

The automobile industry is undergoing its greatest transformation in history. Cars are no longer just machines for transportation; they are evolving into intelligent computers on wheels. This transformation is powered by 5G Advanced, the next generation of wireless communication technology that goes beyond traditional 5G to deliver ultra-fast speeds, almost zero latency, and unmatched reliability. For connected vehicles, 5G Advanced is not just an upgrade in connectivity—it is the very backbone of safe driving, smart navigation, predictive decision-making, and autonomous mobility.

➤ *Vehicle-to-Everything (V2X) Communication*

One of the most revolutionary concepts enabled by 5G Advanced is V2X (Vehicle-to-Everything) communication. It ensures that vehicles are not isolated on the road, but continuously share and receive information with all surrounding entities in real-time.

➤ *V2X has Several Dimensions:*

- *Vehicle-to-Vehicle (V2V):*

Cars can exchange information about speed, location, road conditions, and sudden braking. For example, if a car

ahead encounters a pothole or emergency braking, it can instantly alert the following cars, preventing chain collisions. This level of predictive awareness was not possible with earlier networks.

- *Vehicle-to-Infrastructure (V2I):*

Cars communicate directly with traffic signals, toll booths, smart parking systems, and road sensors. Imagine a scenario where a traffic light sends information to approaching vehicles about its countdown, allowing them to adjust speed and reduce unnecessary stops. Similarly, parking systems can guide drivers to empty slots, saving time and fuel.

- *Vehicle-to-Pedestrian (V2P):*

Using smartphone signals, wearables, or connected sensors, vehicles can detect pedestrians or cyclists crossing roads—even when they are not visible to the driver. This reduces the risk of accidents, particularly in crowded urban areas or at night.

- *Vehicle-to-Network (V2N):*

Cars are always connected to the cloud, receiving real-time updates on traffic conditions, weather forecasts, or alternative routes. V2N also allows over-the-air (OTA) software updates, ensuring vehicles are always running the latest safety algorithms.

With 5G Advanced, V2X communication happens with ultra-low latency (less than 1 millisecond), which is critical for life-saving decisions on the road.

➤ *Autonomous Driving*

The dream of self-driving cars is becoming a reality, and 5G Advanced is the key enabler. Autonomous vehicles rely on sensors, radars, cameras, and LiDAR to detect their surroundings, but they also need a high-speed communication backbone to process this data in real time.

With 5G Advanced, cars can process information from both their own sensors and surrounding vehicles, creating a 360-degree awareness of the road environment.

Lane changes, overtaking, and merging into traffic require split-second decisions, and ultra-reliable low-latency communication (URLLC) ensures these actions are safe.

In complex scenarios, such as traffic intersections, multiple autonomous cars can coordinate with each other using V2V and V2I communication, reducing accidents.

Autonomous cars can also “learn” from shared experiences. For instance, if one car detects a slippery road, this information is uploaded to the cloud and instantly shared with other vehicles approaching the same route.

Thus, 5G Advanced makes self-driving cars not only possible but also safer, smarter, and more efficient.

➤ *In-Vehicle Entertainment and Navigation*

Driving is no longer just about getting from one point to another. With 5G Advanced, vehicles are turning into mobile entertainment hubs and intelligent assistants.

Passengers can enjoy ultra-HD video streaming, cloud gaming, and AR/VR experiences while on the move. The high speed and massive bandwidth of 5G Advanced make lag-free entertainment possible. Navigation becomes smarter with real-time 3D mapping. Augmented Reality (AR) navigation can project directions directly on the windshield, helping drivers take the correct turns without distraction.

Cloud connectivity also enables personalized experiences, such as automatic adjustment of seat positions, music playlists, or temperature preferences based on user profiles stored in the cloud.

Future connected cars may even support immersive metaverse-based interactions, where passengers can attend virtual meetings or socialize while traveling. This not only enhances comfort but also redefines the entire concept of mobility.

➤ *Safety Applications*

Safety is the most critical benefit of 5G Advanced in connected vehicles. Unlike human drivers, who may have delayed reactions, connected vehicles powered by 5G Advanced can respond almost instantly to threats.

- *Automatic Braking:*

If the car in front suddenly stops, the following car is immediately alerted and applies brakes automatically, avoiding collisions.

- *Accident Alerts:*

When an accident occurs, alerts are broadcast to nearby vehicles, helping them reroute or slow down to avoid secondary accidents.

- *Weather Warnings:*

Vehicles can receive real-time updates about fog, heavy rain, or icy roads, allowing drivers and autonomous systems to take precautions.

- *Emergency Services Integration:*

In case of crashes, vehicles can automatically send the exact location, passenger health data, and crash severity to nearby hospitals and emergency services, improving survival chances.

By shifting from reactive to proactive safety, 5G Advanced ensures that connected vehicles protect not only their passengers but also pedestrians, cyclists, and other road users.

➤ *Future Scope of 5G Advanced in Connected Vehicles*

The potential of 5G Advanced in the automotive industry is vast. Some of the future possibilities include:

- Fully Autonomous Fleets: Robotaxis and delivery vehicles operating without human intervention.
- Smart Highways: Roads embedded with sensors and communication nodes to guide vehicles efficiently.
- Zero-Accident Vision: With predictive and cooperative driving, accidents could be reduced to near zero.
- Green Mobility: 5G-enabled vehicles can optimize fuel consumption and support electric vehicle (EV) charging coordination, reducing environmental impact.
- Integration with 6G: 5G Advanced serves as a stepping stone toward 6G, which will bring holographic communication, even faster speeds, and advanced AI-driven mobility.

➤ *5G Advanced for Connected Vehicles*

Connected vehicles use V2X communication:

- V2V (Vehicle-to-Vehicle)
- V2I (Vehicle-to-Infrastructure)
- V2P (Vehicle-to-Pedestrian)
- V2C (Vehicle-to-Cloud)

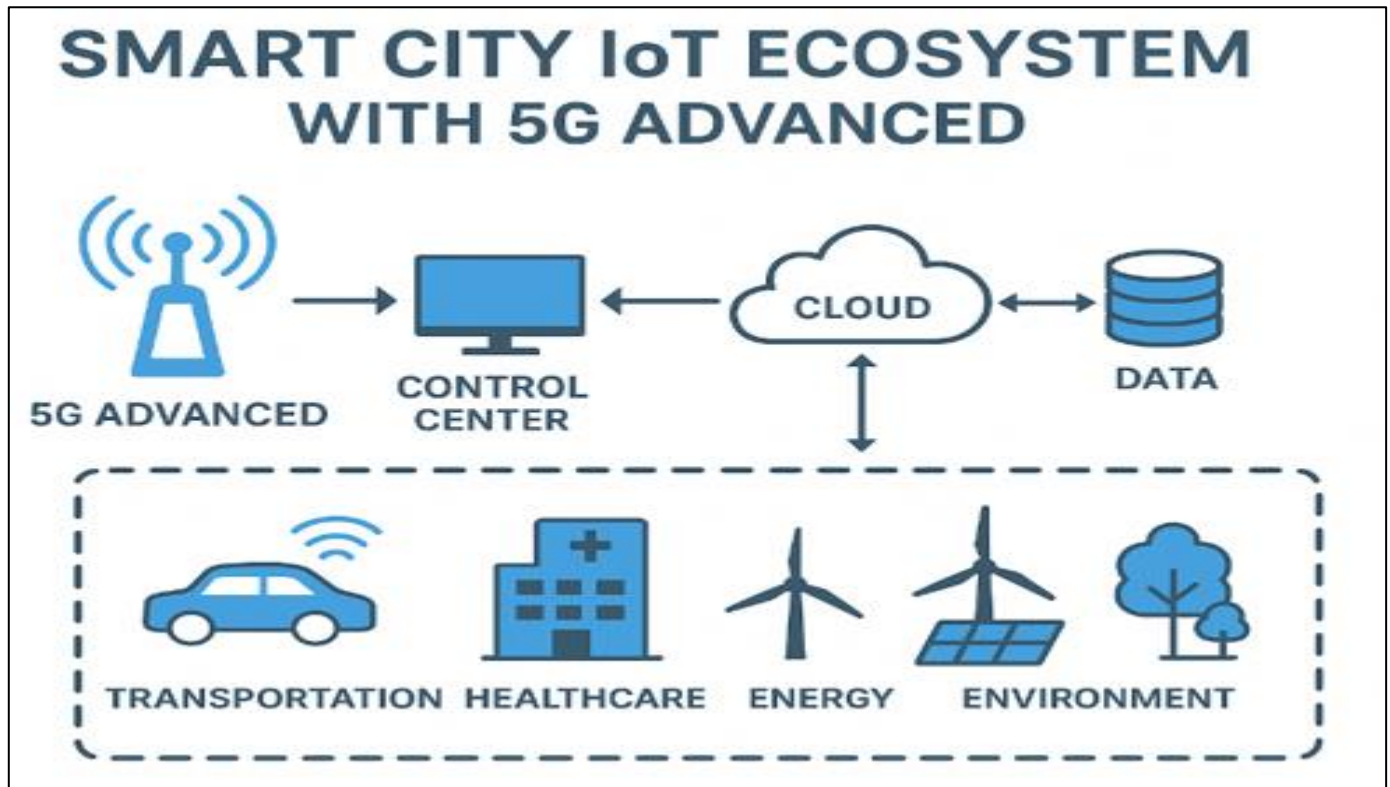


Fig 3 Connected vehicle ecosystem block diagram.

- *Benefits:*

- ✓ Collision avoidance
- ✓ Cooperative driving
- ✓ Smart navigation
- ✓ Logistics optimization

V. APPLICATIONS OF 5G ADVANCED IN SMART CITIES

➤ *Smart Traffic Management*

Traffic jams are a big problem in modern cities. With 5G Advanced, traffic lights can communicate with vehicles and adjust in real time based on traffic flow. For example, if an ambulance or fire truck is approaching, signals automatically turn green to clear the way. This reduces congestion, improves emergency response time, and saves fuel.

➤ *Smart Energy Grids*

Electricity demand in cities keeps rising. 5G Advanced enables smart energy grids, where power supply and demand are monitored in real time. Smart meters in homes and offices communicate directly with energy providers, helping to balance loads and reduce wastage. This creates more sustainable and eco-friendly cities.

➤ *Waste Management*

Smart bins connected via 5G Advanced send alerts when they are full. Garbage trucks then take optimized routes, saving time and fuel. This makes cities cleaner, reduces pollution, and lowers operational costs for municipal corporations.

➤ *Public Safety and Security*

High-resolution CCTV cameras with AI and 5G Advanced connectivity send live video streams instantly to police control rooms. Face recognition and crowd monitoring can help detect crimes or emergencies in real time. In case of accidents, authorities can be alerted immediately.

➤ *Smart Healthcare*

Connected ambulances equipped with 5G send patient health data to hospitals even before arrival, so doctors can prepare for treatment in advance. Telemedicine also becomes easier, where doctors can diagnose and treat patients remotely using AR/VR and high-speed video consultation.

➤ *Smart Buildings and Infrastructure*

Skyscrapers, malls, and housing complexes can be managed intelligently with IoT devices powered by 5G Advanced. Sensors monitor air conditioning, lighting, and security systems, reducing energy usage and improving comfort for residents.

➤ *Environmental Monitoring*

5G Advanced supports millions of connected sensors in a city. These sensors measure air quality, pollution, temperature, and water levels. Real-time data helps authorities take quick action, like issuing alerts during floods or reducing industrial emissions.

➤ *Smart Transportation & Mobility*

Public transport systems like buses, metros, and trains become smarter with 5G. Passengers can track vehicles in real time, while transport authorities can optimize schedules

based on demand. Combined with connected vehicles, this creates seamless and safer travel.

➤ *Smart Parking Systems*

Finding parking is a headache in big cities. With 5G-powered smart parking, sensors detect available slots and guide drivers directly to them. Payments can also be made

➤ *Application in Smart Cities*

digitally through connected apps, reducing time, traffic, and stress.

➤ *Disaster Management and Emergency Response*

In case of earthquakes, floods, or fires, connected sensors and drones powered by 5G Advanced can provide live updates to authorities. Rescue operations can be coordinated more effectively, saving lives and resources.

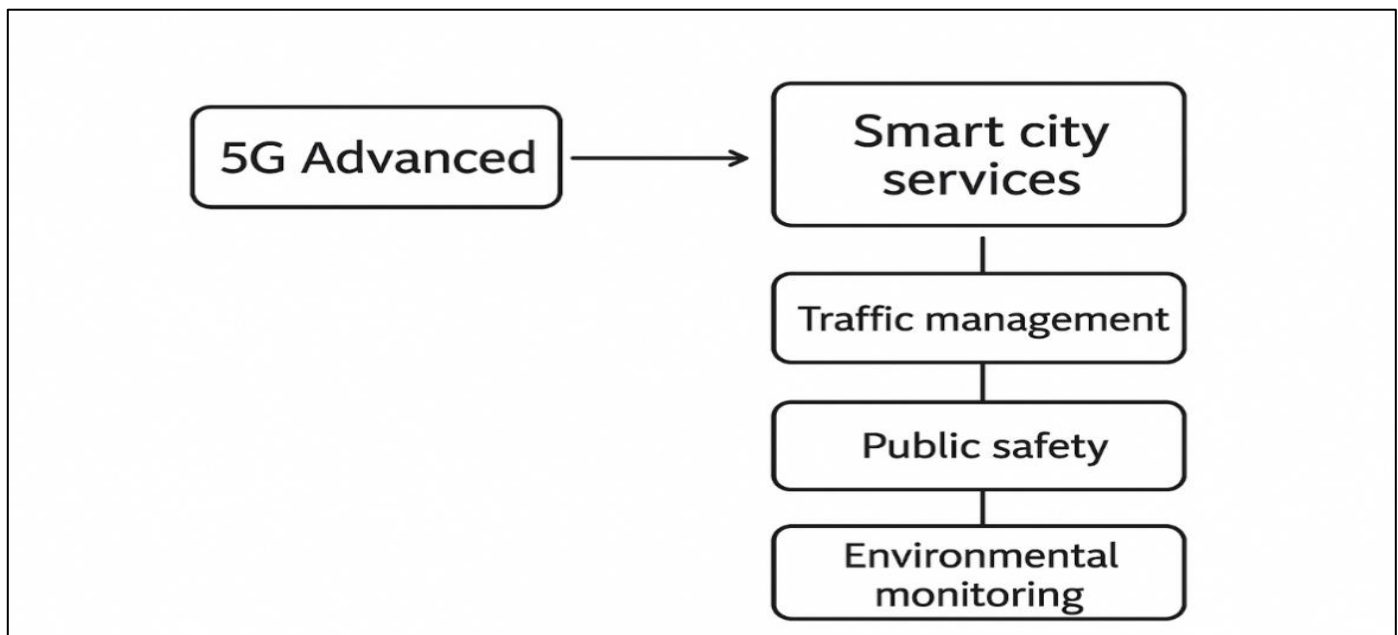


Fig 4 Application mapping diagram (5G Advanced → Smart city services).

VI. APPLICATIONS OF 5G ADVANCED IN CONNECTED VEHICLES

➤ *Vehicle-to-Everything (V2X) Communication*

5G Advanced is the backbone of V2X (Vehicle-to-Everything) systems, allowing vehicles to interact with their surroundings.

- V2V (Vehicle-to-Vehicle): Cars exchange data about speed, location, sudden braking, and accidents to avoid collisions.
- V2I (Vehicle-to-Infrastructure): Vehicles communicate with traffic lights, toll booths, parking systems, and road sensors for better route planning.
- V2P (Vehicle-to-Pedestrian): Cars detect pedestrians crossing the road and alert drivers or automatically apply brakes.
- V2N (Vehicle-to-Network): Vehicles get live cloud updates for maps, AI learning, and weather conditions.

➤ *Autonomous Driving Support*

Self-driving cars require real-time decision-making. 5G Advanced ensures ultra-low latency (<1 ms) communication so vehicles can safely handle:

- Lane changes
- Accident avoidance

- Detecting obstacles (fog, animals, sudden vehicles)
- Adaptive cruise control for smoother rides
- This makes autonomous driving safer and more reliable.

➤ *Advanced Safety Applications*

Safety is the top priority in connected vehicles, and 5G Advanced enables:

- Automatic Emergency Braking: If the car in front stops suddenly, your vehicle reacts instantly.
- Accident Alerts: Vehicles in a region share accident info in real time to avoid pileups.
- Weather Warnings: Fog, icy roads, or storms are detected and sent to vehicles in advance.
- This can reduce road accidents drastically.

➤ *In-Vehicle Entertainment & Navigation*

Passengers experience next-level connectivity:

- Ultra-fast streaming (4K/8K video, cloud gaming).
- AR/VR-based navigation for drivers, showing real-time directions and hazards.
- Seamless Wi-Fi hotspots inside vehicles.
- Entertainment + safety together make travel more enjoyable.

➤ *Fleet & Logistics Management*

For transport companies, 5G Advanced enables real-time fleet tracking. Trucks and delivery vehicles can:

- Share their live location
- Get optimized routes
- Monitor fuel efficiency
- Enable predictive maintenance (AI detects issues before breakdowns)
- This improves supply chain efficiency and reduces costs.

➤ *Smart Parking & Charging for EVs*

- Electric Vehicles (EVs) connected with 5G Advanced can:
- Automatically find available charging stations and reserve slots.

• *Applications in Connected Vehicle*

- Guide drivers to nearest parking spots with real-time updates.
- Enable automatic payment via connected apps.

➤ *Remote Vehicle Control*

In emergencies, 5G Advanced allows vehicles to be remotely operated by control centers. This is useful in:

- Moving a broken-down vehicle safely.
- Assisting autonomous vehicles stuck in unusual conditions.
- Military and rescue operations.

➤ *Enhanced Map & Cloud Updates*

Cars continuously update maps and navigation systems from the cloud using V2N. For example, if a new roadblock appears, all nearby vehicles are informed instantly.

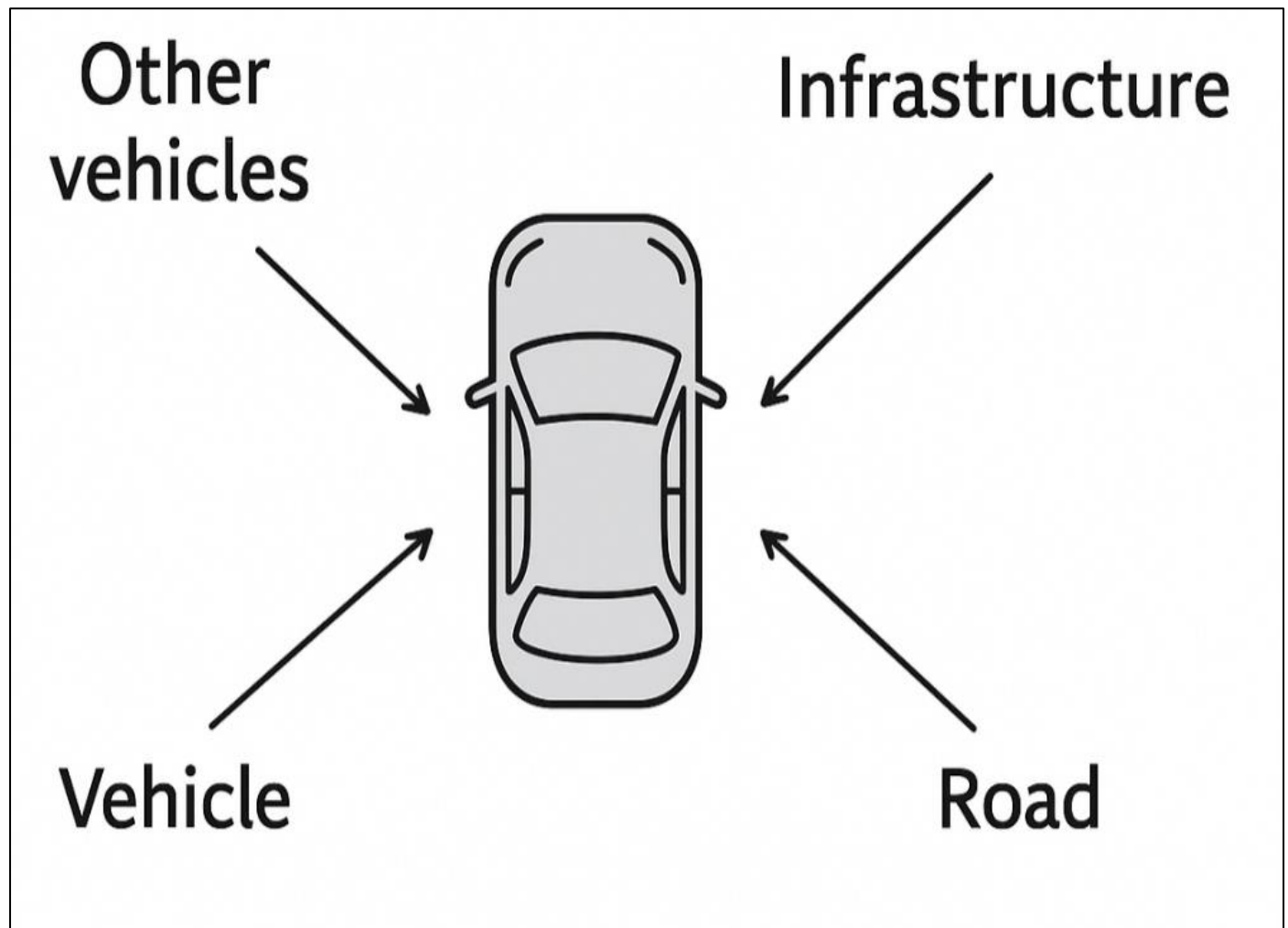


Fig 5 V2X communication model illustration.

➤ *Comparison of 4G, 5G, and 5G Advanced*

A side-by-side comparison shows:

- Data rate: 4G (~100 Mbps), 5G (~10 Gbps), 5G Advanced (>20 Gbps).
- Latency: 4G (30–50 ms), 5G (~1 ms), 5G Advanced (<1 ms).
- Applications: 4G (broadband), 5G (IoT, AR/VR), 5G Advanced (autonomous driving, smart cities).

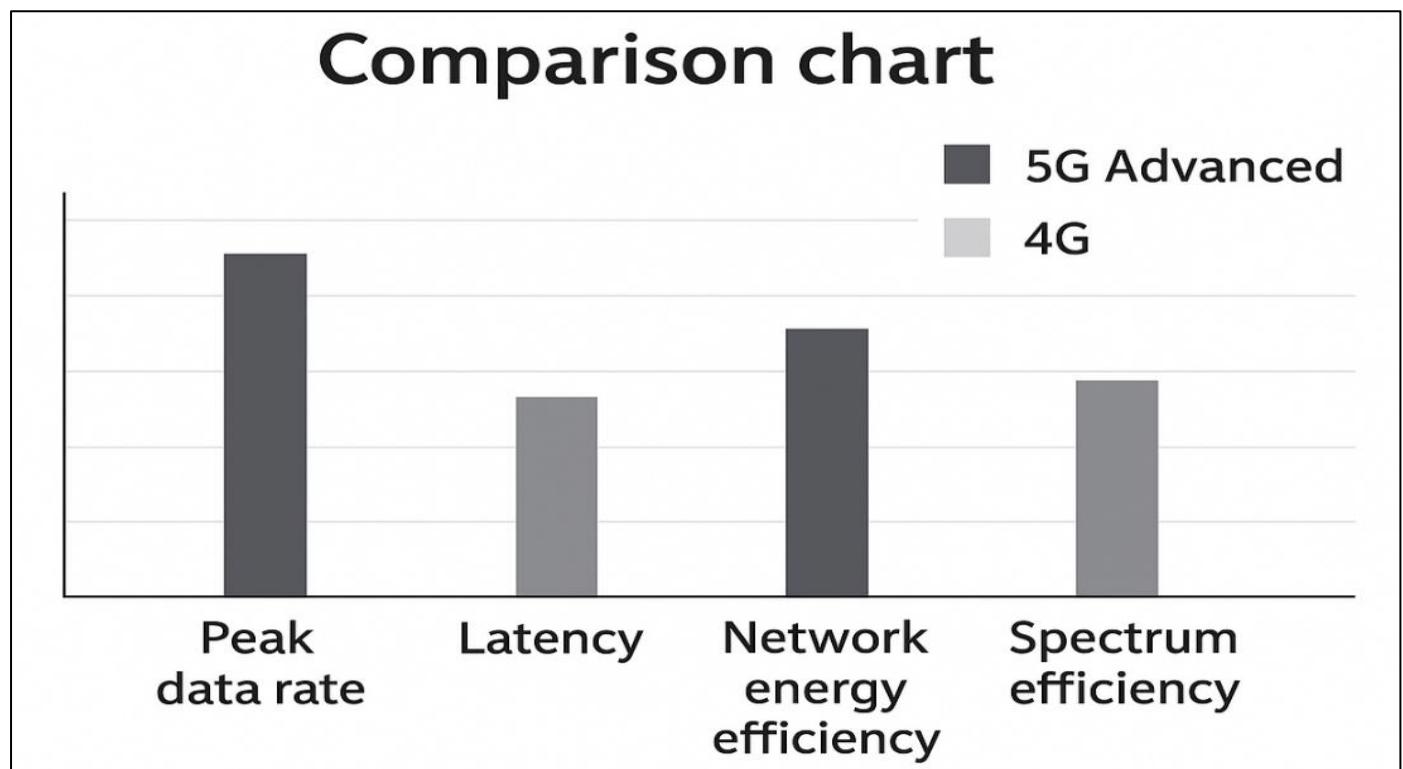


Fig 6 Comparison chart diagram.

VII. CHALLENGES AND LIMITATIONS OF 5G ADVANCED

➤ High Infrastructure Cost

Deploying 5G Advanced requires dense network of base stations, fiber optics, and upgraded antennas. Cities and highways need billions of dollars in investment, which many developing countries cannot afford immediately.

➤ Spectrum Availability

- 5G Advanced needs high-frequency spectrum (mmWave, sub-THz).
- Spectrum allocation is limited and often expensive due to auctions.
- Rural areas may struggle due to lack of coverage.

➤ Energy Consumption

- Despite being more efficient, the huge number of IoT devices and base stations increases total energy demand.
- This creates a sustainability challenge unless powered by renewable energy.

➤ Security & Privacy Issues

- With millions of connected devices, cars, and city sensors, cyberattacks are a major risk.
- Hackers could target traffic signals, vehicles, or healthcare systems, leading to dangerous outcomes.
- Strong encryption, AI-based threat detection, and cybersecurity policies are required.

➤ Interoperability Problems

Not all vehicles, sensors, or city systems are designed to work with 5G Advanced. Different manufacturers may use different standards, making it hard to achieve seamless communication worldwide.

➤ Latency & Reliability in Extreme Conditions*

While 5G Advanced promises <1 ms latency, real-world conditions (mountains, tunnels, weather) can increase delays. For autonomous cars, even a small delay can cause accidents.

➤ Social & Ethical Challenges

Autonomous vehicles raise questions about responsibility in accidents. Citizens may fear surveillance in smart cities due to constant monitoring via cameras and IoT devices.

➤ Future Research Directions

- AI-native networks
- 6G evolution with terahertz spectrum
- Quantum communication integration
- Edge intelligence for IoT

VIII. CONCLUSION

5G Advanced is more than just an upgrade to existing networks — it is a transformative technology that reshapes how cities and vehicles operate.

In smart cities, it serves as the nervous system that connects millions of IoT devices, sensors, and control systems. This allows real-time traffic control, efficient energy

use, improved waste management, and faster emergency responses. Healthcare systems benefit from connected ambulances, remote monitoring, and telemedicine powered by ultra-low latency communication. Public safety improves with AI-enabled CCTV and instant data transmission to control centers.

In connected vehicles, 5G Advanced enables V2X communication — cars talk to each other, to infrastructure, to pedestrians, and to networks. This makes roads safer, reduces accidents, and ensures smooth traffic flow. For autonomous driving, real-time updates from 5G Advanced are essential. Safe lane changes, collision avoidance, and smoother rides all depend on ultra-reliable low-latency communication. Passengers also enjoy advanced in-vehicle experiences — from ultra-fast streaming to AR/VR navigation and cloud gaming. Thus, vehicles transform into mobile digital hubs. However, challenges exist. Deploying dense 5G infrastructure requires high investment. Cybersecurity risks, privacy concerns, energy demands, and interoperability issues must be addressed carefully. Despite these limitations, the benefits are far greater. Smarter traffic systems, cleaner energy usage, safer vehicles, and efficient urban services make 5G Advanced a critical step toward sustainable living. Looking ahead, 5G Advanced is the bridge to In conclusion, 5G Advanced is not just about speed. It is the foundation of intelligent cities and safe, cooperative vehicles. It will create urban spaces that are responsive, transport systems that are autonomous, and societies that are sustainable. The future of human life will be shaped by this technology — making it the true backbone of tomorrow's connected world.

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