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Highway 4.0: Digitalization of highways for vulnerable road safety development with intelligent IoT sensors and machine learning

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ABSTRACT

According to United Nations (UN) 2030 agenda, the transportation system needs to be enhanced for the establishment of access to safe, affordable, accessible, and sustainable transport systems along with enhanced road safety. The highway road transport system is one of the transport systems that enables to transits goods and humans from one location to another location. The agenda of UN 2030 for the transport system will be accomplished with the assistance of digital technologies like the internet of things (IoT) and artificial intelligence (AI). The implementation of these digital technologies on highways empowers to provide reliable, smarter, intelligent, and renewable energy sources experience to the users travelling along the highways. This study discusses the significance of the digitalization of highways that supporting and realizing a sustainable environment on the highways. To discuss the significance of digitalization, the study has categorized digitalization into five subcomponents namely smart highway lighting system, smart traffic and emergency management system, renewable energy sources on highways, smart display and AI in highways. An architecture-for smart highway lighting, smart traffic, and emergency management are proposed and discussed in the study. The significance of implementing smart display boards and renewable sources with real-time applications is also addressed in this study. Moreover, the integration of AI in highways is addressed with the perspective of enhancing road safety. The integration of deep learning (DL) in the edge-based vision node for predicting the patterns of traffic flow, highway road safety, and maintenance of quality roads have been addressed in the discussion section. Embedding the deep learning techniques in the vison node at the traffic junction and the highway lighting controller is able to deliver an intelligent system that provides sustained experience and management of the highways. Smart reflectors, adoption of renewable energy, developing vehicle-to-vehicle communication in vehicles, and smart lamppost are the few recommendations for the implementation of digitalizing highways.

1. Introduction

The UN 2030 Agenda states that “sustainable transport systems, along with universal access to affordable, reliable, sustainable and modern energy services, quality and resilient infrastructure, and other policies have increased productive capacities, that indeed build strong economic foundations for all countries” (Transport and the Sustainable Development Goals | UNECE, n.d.). Concerning this statement, the advancement in highways is the primary goal for establishing efficient transportation. Many initiatives have been initiated in developing countries for the establishment of efficient transportation, smooth traffic and also for enhancing the connectivity between the destinations. An efficient transportation infrastructure like International connectivity roads, Green-field expressways, development of Economic Corridors, Inter Corridors, Feeder Routes, Border and, Coastal and Port connectivity roads, and National Corridor Efficiency Improvement are the part of efficient transportation (Bharatmala Pariyojana). India is one of the fasting growing economies, where massive investments are executing in transport and technology for transforming the cities into world-class smart cities. In the northeast area of India, the government (Road Network in India: National Highways, Projects, Govt Initiatives | IBEF,

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Nomenclature

AI	Artificial Intelligence
ANN	Artificial Neural Network
AIMSUN	Adaptive Network-Based Fuzzy Inference System
BLE	Bluetooth Low Energy
CAGR	Compound annual growth rate
DL	Deep Learning
EPCs	Electronic Product Codes
EMS	Emergency Management System
EDAS	Eco Driving Advisory System
ETC	Electronic Toll Collection
XGboost	eXtreme Gradient Boosting
FPGA	Field-programmable gate array
FIS	Fuzzy Inference System
FCM	Fuzzy cognitive maps
ID	Identification
ITS	Intelligent Transport Systems
GPRS	Global packet for radio service
GSMA	Global System for Mobile Communications Association
GSM	Global System for Mobile Communications
IEEE	Institute of Electrical and Electronics Engineer
LED	Light Emitting Diode
LoRa	Long-range
6LoWPAN	Ipv6 over Low Power Wide Personal Area Network
LPWAN	Low Power Personal Area Network
PIR	Passive Infrared
LAN	Local Area Network
LDR	Light Dependent Resistor
LED	Light Emitting Diode
IoT	Internet of Things
IP	Internet Protocol
NFC	Near Field Communication
NB-IoT	Narrowband IoT
OWL	Web Ontology Language
OS	Operating System
RDF	Resource Description Framework
RF	Radio Frequency
R&D	Research & Development
RFID	Radio Frequency Identification
SFO	Sustainable Forest Operations
SoC	System on Chip
SVM	Support Vector Machine
UI	User Interface
UN	United Nations
VANET	Vehicular ad-hoc Network
VoBU	Vehicle on Board Unit
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
Wi-Fi	Wireless Fidelity
WPAN	Wireless Personal Area Network
ZB	Zetta Bytes
WAN	Wide Area network
PAN	Personal Area Network

n.d.) forecasts $350 billion investment in road networks from 2020 to 2025. Due to increasing government initiatives for enhancing transport infrastructure in the country, the roads and roads market are expected to display a Compound annual growth rate (CAGR) of 36.16% between 2016 and 2025. Data lake and project management software is a unique platform implementing by the national highway authority of India (NHAI) for implementation of real-time monitoring and complete digitalization in highways with the assistance of digital technologies namely cloud, AI, and big data analytics (NHAI goes fully digital, launches cloud based, AI powered Big Data Analytics platform, n.d.). The digitalization of highways encourages to meet the goal of sustainable cities and clean energy framed by the UN for accomplishing quality life with zero carbon emissions (sustainable development goals pdf). At present many companies are developing innovative solution in the highways for achieving safe journey, congestion-free, secure, time-efficient, and pollutant-free routes. Smart highways fulfill the gap of inconvenience caused on highways, in which innovative technology like highway lighting, Electronic Toll Collection (ETC), Variable Message Signs, Lane Exit Warning System, and Intelligent Transport Systems (ITS) (Growing Demand for Smart Highway to Significantly Increase Revenues Through 2026, n.d.). The sustainable and intelligent \ strategic infrastructure strategy relies on technology for improving the standard of living of people. Smart city management is an essential component of smart city programs to promote planning strategies for better decision-making (Camero and Alba, 2019; Broccardo et al., 2019). UN has set 17 sustainable development goals (SDGs) (sustainable development goals pdf) for implementing the sustainable cities and communities on which Government and different non-government organizations (NGOs) are working on different aspects such as smart traffic management, smart parking, smart health care, smart transport, etc.,. Moreover, it assists to provide the standard of living environment for public over the years, technology has further influenced society, raising our quality of life and living standards. Advances in telecom, IoT, cloud and edge computing, scalable storage, and data analytics have given fast computing, data-enabled insights, and connectivity always. Many countries have now launched national initiatives in the area of intelligent cities with the addition of the convergence of digital technologies to transform lives and boost the business operations and market competitiveness. Australia's Highway 1 is the longest national highway in the world at over 14,500 km. According to World Economic Forum's new Global Competitiveness Report, Singapore has the world's best road quality, followed by Switzerland and the Netherlands (Global Competitiveness Report 2020 | World Economic Forum, n.d.).

IoT is emerging technology that is capable of enhancing the smart city goals. Generally, in smart city infrastructure, the traffic management is the essential component, as mismanagement of traffic congestions causes a severe problem that goes along with the city development. There are different factors in smart traffic management such as smart highway lights, smart traffic and emergency management, Vulnerable Road Safety, renewable energy resources on highways, and smart information displays (Lee and Chiu, 2020). These systems collect traffic data in real-time to ensure that any social problem caused by road congestions is avoided or minimized (Gohar et al., 2018). For predicting real-time information about traffic congestion on roads some mobile applications are used like Google map or Apple Maps and the prediction is based on sensor data which are installed on different highways and urban roads (How Does Google Maps Predict Traffic? | HowStuffWorks, n.d.). The traffic management on highways and urban roads are different from the collecting road. On the collecting road, there are some pedestrian crossings, VIP visits, ambulance services, bicycles, and other vehicles. In order of implementing a real time system in traffic management, IoT plays a key role by integrating different physical devices to exchange information, tracking, and monitoring the movement of traffic (Li et al., 2017; Qian et al., 2019). Concerning the monitoring of traffic data, IoT devices are typically installed as roadside and automobile sensors (Bibri, 2018). The huge amount of data generating from the distinct IoT devices on the highways can be useful for establishing a prediction system. AI assists to establishes a prediction system on the highways related to traffic prediction, accident prediction, and weather prediction. The emergence of mobile edge computing (MEC) assisting the IoT devices to perform the prediction and analytics at the edge device itself. MEC provides an opportunity to embed the AI model for performing the prediction regarding traffic patterns, traffic prediction, etc.

The motivation of the study is to explore the possibilities of digitalization in highways. Digitalization is defined as providing intelligence to the system that is integrated on the highway with emerging technologies including IoT and AI.

The contribution of the study is as follows:

a. The study discusses the significance of IoT including architecture, and components. Moreover, we have provided the technical specifications of distinct wireless communication protocols.
b. The significance of digitalization of highways is addressed and for the detailed explanation, it has been categorized into five subsections including smart highway lighting, smart traffic and emergency management, renewable energy sources on highways, smart display board, and AI in highways.
c. A novel architecture is proposed for smart highway lighting and smart traffic and emergency management and detailed discussed in this study.
d. In smart highway lighting, we have addressed the function of sensor nodes with edge-based vision nodes.
e. The real-time implementation of renewable energy sources like wind, solar and piezoelectric on the highways is well presented in this study.
f. The smart display board that provides real-time data like a weather report, speed limit road status, etc. based on IoT are discussed in this study.
g. AI on the highways assists to provide a reliable infrastructure for providing safe driving, prediction of traffic and accident events, weather prediction, Vulnerable Road Safety, etc.
h. Smart Reflector, Adoption of renewable energy in the highway, vehicle-to-vehicle (V2V) Communication, Smart lamp post on the highway, Edge-based Vision Node, Inclusion of deep learning are suggested recommendations for the future directions. Moreover, a hybrid architecture is proposed, where the amalgamation of every sub-component of digitalization is interconnected with a radio frequency (RF) antenna.

The organization of the article is as follows, Section 2 covers the role of IoT for digitalization with architecture, components, and technical specifications of wireless communication protocols. Section 3 covers the components of digitalization in highways including smart highway lighting, smart traffic and emergency management, renewable energy sources on highways, smart display board, and AI on highways. Section 4 covers the discussions and recommendations of the study.

2. Integration of IoT

In this section, we will discuss the overview of IoT including 3-layer based architecture and components of IoT. Moreover, the technical specifications of wireless communication protocols are also addressed in this section.

a) IoT

IoT is an integration of physical things with hardware, firmware, and sensor systems that enables these things to acquire necessary data from the environment (Archibong et al., 2020). IoT is a disruptive technology that will substantially facilitate most of those services around us to accomplish their ultimate efficiency (Rahman and Asyhari, 2019). *Digitalization* has encouraged "smart" to be the next apex of technological advancements currently undertaken (Zheng et al., 2020). In essence of IoT technology is now presumed to be one of the essential parts of the industrial 4.0 revolution for contributing to tremendous beneficial benefits for the population and generate breakthrough opportunities (Malik et al., 2020) (Nižetić et al., 274 (2020).).

A recent forecast by the International Data Corporation (IDC) predicts that there will exist 41.6 billion embedded IoT devices or "things," accumulating 79.4 zettabytes (ZB) of data in 2025 (The Growth in Connected IoT Devices Is Expected to Generate 79.4ZB of Data in 2025). According to Global system for mobile communication association (GSMA) intelligence forecasting, the number of IoT connections will reach 25 billion globally by 2025 (GSMA | IoT Connections Forecast: The Rise of Enterprise | Internet of Things, n.d.). The growth of IoT devices from 2015 to 2025 is presented in Fig. 1. IoT is designed to feature prominently in managing multiple energy sources to create a better environment over such a small application domain. As IoT is capable of connecting billions of physical devices over the internet, there is an essential requirement of flexible architecture. However, at present IoT-A is trying to establish the fundamental architecture of IoT concerning the requirement of industries and researchers (Internet of Things Architecture | IoT-A Project | FP7 | CORDIS | European Commission, n.d.).

b) 3-Layer IoT architecture

3-Layered basic IoT architecture is initiated in the studies for the establishment of IoT network (Yang et al., 2012; Khan et al., 2012; Wu et al., 2010) and the architecture is shown in the Fig. 2. The perception layer, network layer, and application layer are the layers of 3-layer architecture. The perception layer represents the physical sensors that aim to sense the variation of physical things and processing the sensor information. The functions like temperature, location tracking, identification of things, weight, vibration, level measurement, smoke, etc. are performed by the perception layer using sensors and actuators. The network layer enables the transmission of the data processed by the sensors. Distinct network technologies are available for the transmission of the data.

Global system for mobile communication (GSM)/ global packet for radio service (GPRS), Zigbee, Long Range (LoRa), Bluetooth, and wireless fidelity (Wi-Fi) are the network technologies. The significance of the application layer for IoT is that it can deliver high-quality smart services to fulfill the requirements of its clients. The application layer includes a range of vertical markets such as smart homes, manufacturing, smart health care, and food processing industry, etc.

c) components of IoT

The fundamental components of IoT enable us to gain a deeper insight for the actual requirement and usability of IoT. In the following section, we explore six fundamental components that accomplish the functionality of IoT, and it is shown in Fig. 3.

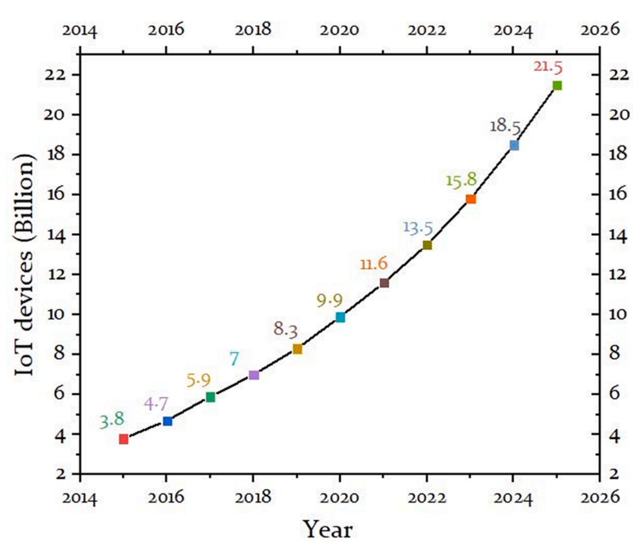

Fig. 1. Growth of IoT devices (2015–2025) (State of the IoT 2018: Number of IoT devices now at 7B – Market accelerating, n.d.).

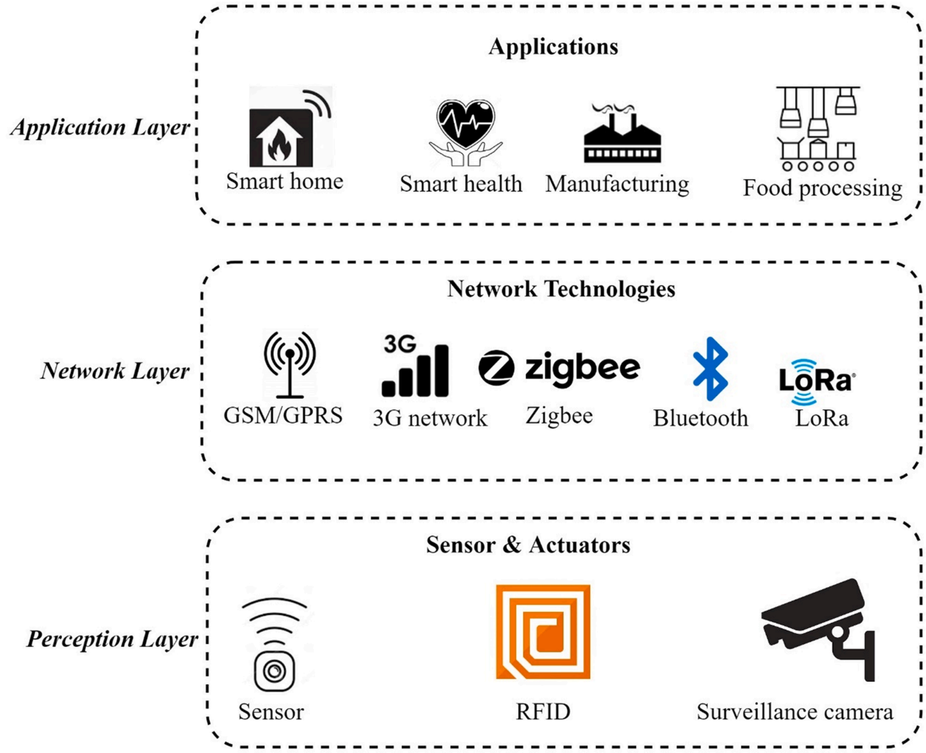

Fig. 2. 3-Layer based IoT architecture.

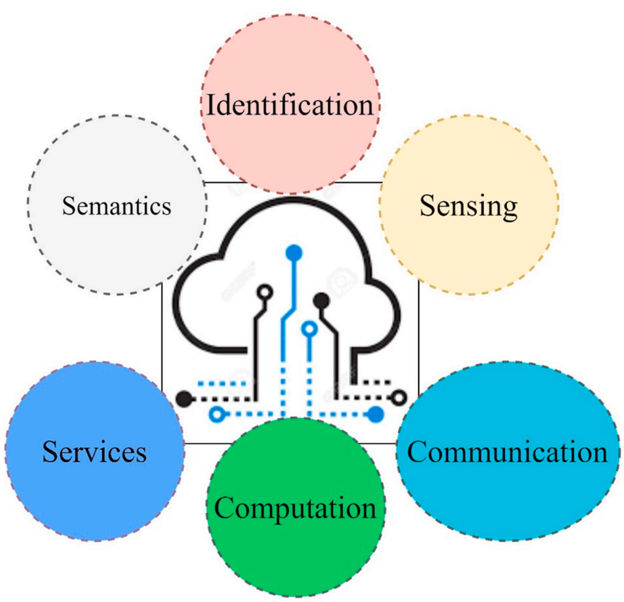

Fig. 3. Components of the IoT (Al-Fuqaha et al., 2015).

1) *Identification:* Identification is a prerequisite for IoT to label and co-ordinates the services to their request. Numerous IoT identification methods are accessible, like ubiquitous codes and electronic product codes (EPCs). Besides, acknowledging IoT entities is essential to identify between the entity ID and its address. Entity ID refers to its names, such as “H1″ for a simple sensor and the address of the entity to refer to its address in a communication network.
2) *Sensor:* A sensor is a device that senses and responds to the input from the physical environment. Classical sensors work for measuring environmental variables, processing variables, and convert the analog signal into a digital signal. However smart sensors are capable of generating sensing data into digital data. Connectivity is necessary for the transmission of sensory data and they are different wireless protocols for establishing connectivity.
3) *Communication:* The distinct kinds of wireless communication technologies are existing in the Internet of Things. GSM/ GPRS, Zigbee, Bluetooth Low Energy (BLE), 6LoWPAN, radio frequency identification (RFID), LoRa, Sigfox, narrow band-IoT (NB-IoT), Long Term Evolution (LTE), IEEE 802.11 g Wi-Fi, near field communication (NFC), and Z-wave are the communication technologies. Zigbee, Z-wave, BLE, 6LoWPAN, and IEEE 802.11 g are the short-range wireless communication technologies.

Generally, the transmission range of these communication technologies like IEEE 802.11 Wi-Fi, IEEE 802.15.4 Zigbee, and IEEE 802.15.1 BLE are short-range, however, except IEEE 802.11 Wi-Fi remaining two wireless communication technologies consume low power for the data transmission. GSM / GPRS, LTE, LoRa, Sigfox, and NB-IoT are communication technologies for long-range distances. LoRa, NB-IoT, and Sigfox are emerging low power and long-range communication technologies that meet the goal of the IoT. Among the three Low power wide area network (LPWAN) technologies, LoRa is the optimal communication system with secure bi-directional communication and free licensed band capabilities. RFID and NFC are identification technologies that work on radio waves. Both technologies communicate up to a range of 4 cm–10 cm.

4) *Computation:* Microprocessors, microcontrollers, Field programmable gate array (FPGA), and system on chip (SoC) are the hardware-based computation unit of the IoT. Beagle Bone, Arduino, UDOO, Cubie board Friendly ARM, Raspberry PI, Gadgeteer, Z1, WiSense, Mulle, Intel Galileo, and T-Mote Sky are some hardware computational units.
5) *Services:* Tiny OS, Riot OS, and Lite OS are the few real-time development platforms for IoT applications. The cloud platform is a software-based computational platform of the IoT. In this platform is used the sensory data is converted to machine-readable form.

Classification, sorting, and calculations are performed on the data for getting meaningful information. Different tools are existing for data processing in the IoT. *Ubiquitous Services, Collaborative-Aware Services, Information Aggregation Services, and Identity-related Services* are the four services of IoT (Gigli and Koo, 2011).

Collaborative-aware services and ubiquitous services employ information templates to make accurate smart decisions, intending to provide services to their participants at anytime and anywhere. Identity-related services reveal that every application puts forward real-time objects into a virtual world, so there is a requirement of identifying those objects.

Information Aggregation Services acquire and quantify the raw sensory measures which must be evaluated and communicated to the IoT platform. Smart homes, industrial automation, smart agriculture, and smart agriculture are some applications that come under the four services of IoT. In order of providing services, semantics act as a medium for extracting the knowledge smartly. Semantic reflects the brain of the IoT by transmitting demands to the appropriate resource. Web Ontology Language (OWL) and Resource Description Framework (RDF) are the recommended platform for the implementation of semantics (Schneider et al., 2011).

The components of IoT delivers the benefits of implementing the IoT for establishing smart and digitalization in every field. IoT is capable of bringing the things of the physical environment into a virtual environment from anywhere through internet connectivity. Mobile edge computing (MEC) is a novel architecture that enables to provide of cloud computing services at the edge of the network (Abbas et al., 2018). It is a groundbreaking edge technology that can be extended to mobile, wireless, and wireline scenarios through software and hardware platforms situated at the network edge near end-users. It is a vital attribute in the 5G architecture that enables a wide range of potential applications and services that demand ultralow latency. MEC replaces the traditional client–server architecture in surveillance cameras where the network faces stress due to receiving a large amount of video streaming data (Mao et al., 2017). Here MEC will be favorable for realizing the intelligence at the edge device itself and programmed to communicate data to the network in the case of motion detection. Moreover, MEC enabled surveillance cameras providing distinct applications including detecting traffic jams, predicting accidents based on traffic patterns, and traffic management (Varghese et al., 2016).

In the case of IoT, connectivity plays a crucial role in reliable and robust communication between the nodes and cloud servers. Generally, GSM/GPRS, 3G/4G, and IEEE 802.11 g Wi-Fi communication protocols are employing to establish connectivity between end nodes and servers. The limitation of embedding these communication protocols at the end node demands more energy, connectivity interruption at a remote location and a subscription amount must also be required to use this communication protocol for data transmission. This limitation can be overcome by employing open-licensed band communication protocols like IEEE 802.15.4 Zigbee, Long Range, Ipv6 over low power wide area network (6LoWPAN) and Sigfox are free licensed band communication protocols for transmitting data from end nodes to the server without connectivity interruption. The visualization of the data in the cloud server assists the authorities of any field to monitor things from any location via internet connectivity. Low power consumption and long-range transmission are the features that are necessary for implementing robust IoT. The technical details of the communication protocols in the IoT are illustrated in Table 1.

3. Digitalization in highways

Digitalization highway is a robust and real-time embodiment of the physical and operational characteristics of highways that have a significant effect on the performance, protection, efficiency, safety, security, and convenience of drivers. Digitalization of highways strengthens the concept of establishing an intelligent transportation system infrastructure of the future. The data available in the digitalization database can be used for applying analytics for getting the desired result that can assist future researchers in a broad area of the intelligent transportation network. Fig. 4 illustrates the areas in which the digitalization of highways can be implemented for providing a reliable and effective ecosystem for vehicles and drivers. Smart lighting system, smart reflector, smart traffic and emergency system, renewable energy sources on the highway, electric charging point, smart display, smart traffic light, smart diversions leading to the destination, and smart bins are the applications in the highway for digitalizing.

a. Smart highway lighting

A smart city is a framework where the resources are utilized systematically for achieving the maximum throughput with minimum input and also for providing quality, efficient, and sustainable life to the

Table.1
Technical specification of wireless communication protocol.

Parameters	GSM/GPRS	LoRa	6LoWPAN	BLE	Sigfox	NB-IoT	Zigbee	Wi-Fi
IEEE Standard	NA	802.15.4 g	802.15.4	802.15. 1	802.15.4 g	NA	802.15.4	802.11a, b,g,n
Network Topology	Cellular system	Star of stars	Star, mesh	Star, bus	Star	NA	Star, P2P, mesh, tree,	Point-to-hub
Frequency Band	850–1900 MHz	433 MHz, 868 MHz, 915 MHz	868/915 MHz and 2.4 GHz	2.4 GHz	868/915 MHz	Licensed LTE bands	868/915 MHz and 2.4 GHz	2.4 / 5 GHz
Licensed/ Unlicensed band	Licensed	Unlicensed	Unlicensed	Unlicensed	Unlicensed	Licensed	Unlicensed	Licensed
Modulation	GMSK	CSS	NA	GFSK	BPSK	QPSK	BPSK, O-QPSK	BPSK, QPSK, COFDM, CCK, M−QAM
Network	LAN (Local)	WAN (Wide)	PAN (Personal)	PAN (Personal)	WAN (Wide)	WAN(Wide)	LAN (Local)	LAN (Local)
Nominal Range	(5–30) km	5 km (Urban), 20 km (Rural)	(10–50) meter	10 m	10 Km (Urban), 40 km (Rural	1 Km (Urban), 10 Km (Rural)	10–50) meter	100 m
Standardization	GSM Association.	Semtech alliance	Internet Engineering Task Force (IETF)	Bluetooth Special Interest Group	Sigfox company	3GPP	Zigbee Alliance	Wi-Fi Alliance
Power consumption	High	Low	Low	Low	Low	Low	Low	High
Throughput	48 kb/s	50 kb/s	250 kb/s	1 Mb/s	200 bp/s	200 kb/s	250 kb/s	54 Mb/s
Modem interface	RS 232 serial interface	RS 232 serial interface	RS 232 serial interface	RS 232 serial interface	RS 232 serial interface	RS 232 serial interface	RS 232 serial interface	RS 232 serial interface
Bi-directional	Yes (Full-duplex)	Yes (Half-duplex)	No	Yes (Full-duplex)	Limited (Half-duplex)	Yes (Half-duplex)	Yes (Full-duplex)	Yes (Full-duplex)

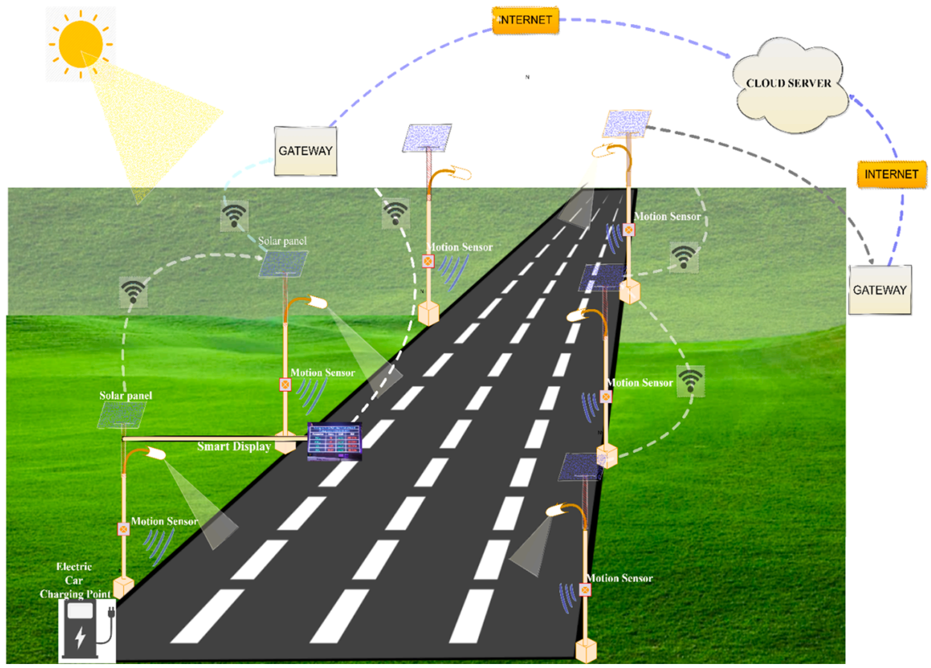

Fig. 4. Digitalization of highway.

citizen (Boosting smart cities with smart street lighting, n.d.). Highway lighting of the area where the energy resources need to be utilized sufficiently according to requirement. Energy-saving is a key aspect of utilizing the energy when it is required and on the highway, a considerable amount of energy is consumed due to continuous illumination of light even no vehicle entering during the operation time (Mukta et al., 2020). The optimization of highway lighting is achieved with smart highway lighting for boosting the potential utilization of electrical energy resources. Smart highway lighting is a strategy for managing and controlling the lighting through sensory and wireless communication technology. Smart highway lighting is an intelligent lighting system that reduces the energy consumption of light by switching on/off the light according to the traffic on the lane (Mustafa et al., 2017). Generally, in a smart highway lighting system, the function of the relay network is crucial because it provides consistent illumination according to the brightness and motion of the vehicles on the road lane. The sensory technology in the smart highway lighting adjusts the intensity of illumination by sensing outdoor brightness and it also capable of adjusting the intensity of illumination during the night by sensing the motion of vehicles (Garg et al., 2020). Light Dependent Resistor (LDR) sensor and Passive Infrared (PIR) sensor are the two different sensors that are embedding with a relay network for controlling the illumination on the

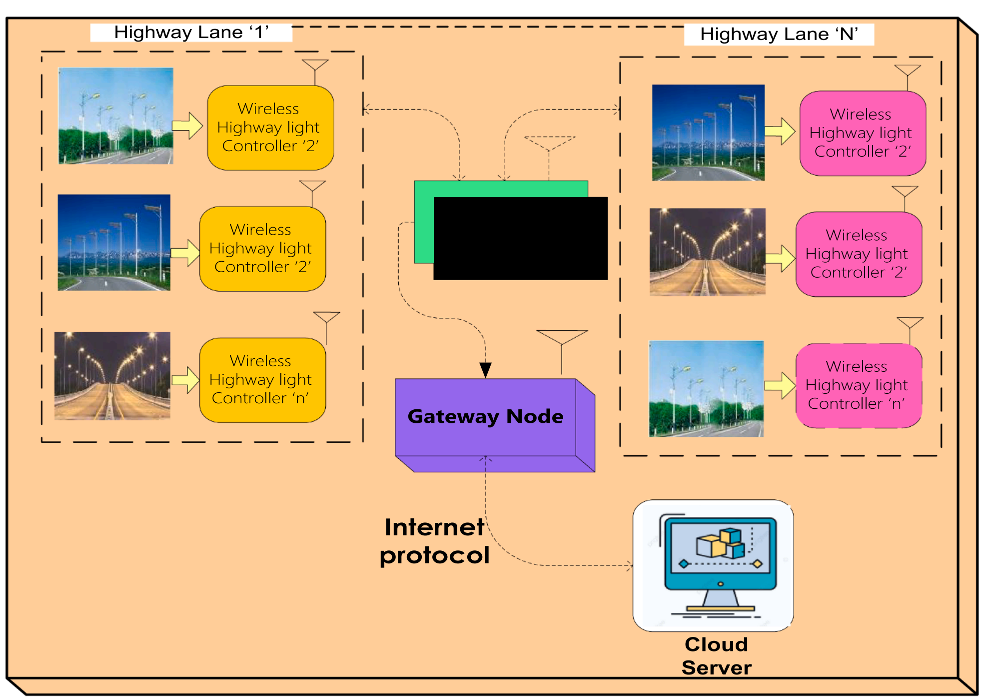

Fig. 5. Architecture of IoT-based smart highway lighting system.

highway road lane (Singh et al., 2019). However, in some cases, the highway passes through the tunnel road, where the factors like traffic flow, speed factor, and visibility of vehicles need to be considered because the tunnel highway is longer than 100 m, is broadly categorized into entrance zone, transition zone, middle zone, and exit zone. As the lighting system is unique in a different zone, a customized data acquisition and communication system needs to be designed for monitoring and controlling the light concerning the aforementioned factors of the tunnel highway. For sensing the intensity of light outside the tunnel, multiple light sensors can be embedded and for monitoring the speed & traffic flow, a 77- GHz radar module is embedded for the tunnel lighting system (Lu et al., 2020). Integrating a communication system enables the transmission of the data to the controller unit. At present IoT is the digital network that transforms the physical environment into a virtual environment for visualizing things from anywhere through internet connectivity (Chimata et al., 2018).

Fig. 5. illustrates the IoT-based architecture that has been implemented for monitoring and controlling highway light. A wireless highway light unit is a sensor node that senses the intensity of light and motion of a vehicle through a sensory module embedded in it. A Long RF wireless communication is embedded for transmitting the data to the cloud server via gateway node and the gateway node is integrating with IEEE 802.11 g Wi-Fi module for logging the data into the cloud server through internet protocol (IP). The Sensor Node will be customized along for inculcating various capabilities using the integration of various sensors including motion sensor, light-dependent resistor sensor, light dimmer, and long-range RF module as shown in Fig. 6.

The node will be powered by solar power and it uses long-range RF for communication with other gateways. Motion and LDR sensors are integrated for sensing the motion and intensity of light from the vehicle. Edge device-based vision node will be integrated with the sensor node and this vision node is capable of processing the inputs received from the sensor and camera. This vision node will use onboard DL algorithms to process the picture frames of its environment and process them to extract meaningful data from the gathered information.

As the proposed system is integrated with a vision node, it can detect the over the speed of vehicles, and it processes the information via LoRa RF communication and internet to the nearby authorities to inspect the vehicles for over speeding and it will help to improve the Vulnerable Road User model. In few instances, the sensor node can identify the exact motion and light intensity of the vehicle however with the availability of sensor inputs and vision data, the edge-based vision node processes the data and provides necessary insights to the computing unit of the sensor node to mechanism accurately to provide a perfect light intensity to the vehicles.

From the studies, the lack of implementing the fault detection and diagnosis system is addressed for highway lighting. This is one of the major areas to be focused on in avoiding the failure of the lighting system due to fault. Timely fault detection and diagnosis system should be implemented in the scenario of a highway road. Table.2 illustrates the recent studies on a highway lighting system.

b. Smart traffic and emergency management

Nowadays quick mobility is a fundamental requirement to humans for traveling and transporting goods from one destination to another. In smart cities, the goal is to provide quality and smooth facilities with the assistance of digital technology. Smart traffic and emergency management is the cornerstone of smart city infrastructures, for which wireless sensors are employed to monitor traffic flow, accidents, highway road conditions, and providing smart emergency services. Real-time traffic

Table 2
Recent studies on a highway lighting system.

Author	Aim of the study	Highway	Acquisition	Communication
(Wang et al., 2020)	Controlling light-emitting diode (LED) lamps	Tunnel	Surveillance camera for detecting movement of vehicles	RFID-based low-power WAN communication
(Lu et al., 2020)	Implementing an intelligent light control system at the entrance of a tunnel.	Tunnel	Light sensors for the intensity of light, Radar for traffic flow.	Gateway node
(Rahman et al., 2020)	Controlling light intensity	Toll plaza	Ultrasonic, light sensitivity sensor	XBee, GSM communication
(Santhosh Reddy et al., 2019)	Adjusting the intensity of light	Highway	LDR, proximity sensor	IEEE 802.11 g Wi-Fi inbuilt in the raspberry pic
(Wadi et al., 2018)	Personalized lighting	Streetlight	Light sensor	fuzzy-based control approach
(Khalil et al., 2017)	Establishes smart streetlight concerning to smart grid	Streetlight	Light sensor and pressure sensor	Zigbee communication
(De Paz et al., 2016)	Controlling the public lighting and optimizing the maintenance of lighting.	Cities	Light sensor	Wi-Fi (Wireless Fidelity)

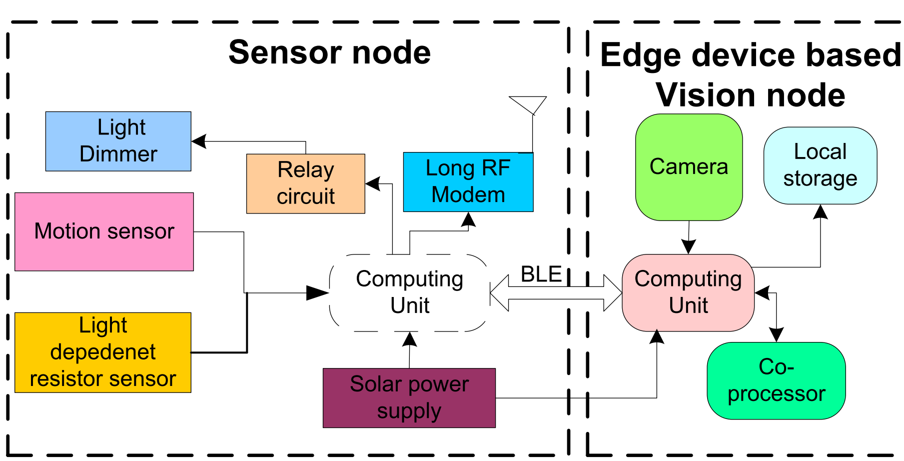

Fig. 6. Wireless highway light controller with edge device.

and emergency services play an integral role in transforming smart cities and also enable them to provide efficient & reliable services to humans. According to (1.2 Billion Vehicles On World's Roads Now, 2 Billion By 2035: Report, n.d.), by 2050 the total number of vehicles will be double to 2.5 billion and high population density is leading to traffic congestion. 25% of vehicle accidents, 15% of bad weather, 10% of work zones & poor road signals, and 5% of poor traffic lighting are the key causes for occurring traffic congestion (de Souza et al., 2017). The aforementioned statistics of vehicle accidents bring importance to the emergency response that plays a vital role in reducing losses of life and it is also an essential component to interconnect with the nearby emergency management. However, conventional approaches to traffic control have proven hard to deal with the complex circumstances and demands in such cases. With the advancement of wireless sensors, communication protocols and digital technology, smart traffic, and emergency management can be established for providing real-time data of the traffic and emergency events for enhancing the traffic efficiency of the highway. V2V communication and Vehicle-to-Infrastructure (V2I) communication establishes smart traffic and emergency. V2V communication is the potential to wirelessly obtain knowledge about the speed and location of nearby cars that shows considerable potential in helping to alleviate road congestion, prevent collisions and enhance the environment (Vehicle-to-Vehicle Communication | NHTSA, n.d.). V2I communication is bi-directional wireless communication between vehicles and road infrastructure (What is Vehicle-to-Infrastructure (V2I) Communication and why do we need it, n.d.).

Smart traffic and emergency management system is illustrated in Fig. 7. Smart traffic and emergency management system is an integration of distinct modules for continuously communicate the data from heterogeneous sources like vehicles, roadside sensors, and roads.

In vehicle-to-vehicle communication, the advanced and reliable wireless communication protocol like IEEE 802.11 g Wi-Fi, BLE, IEEE

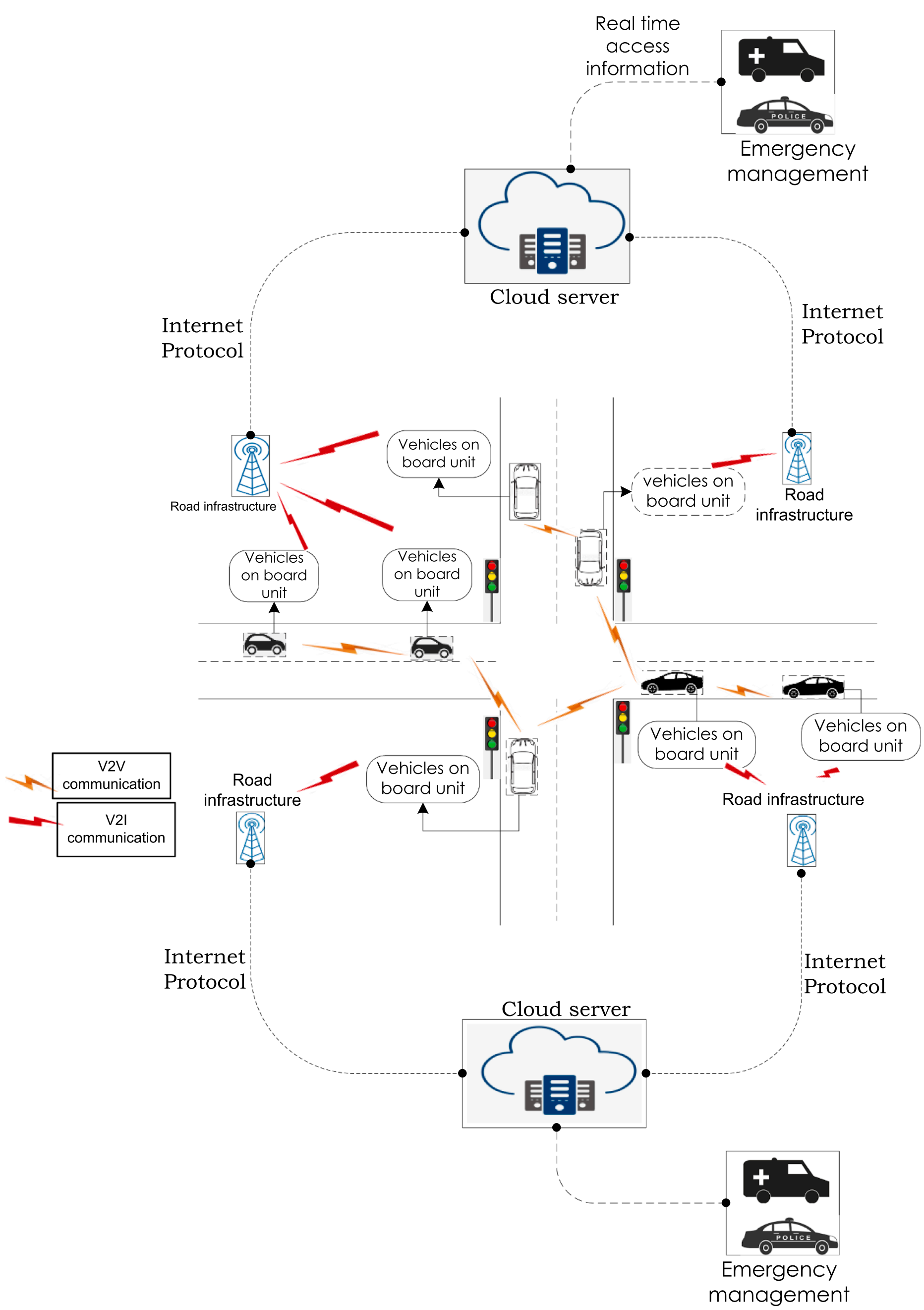

Fig. 7. Smart traffic and emergency management system for Vulnerable Road User model.

802.15.4ZigBee, LPWAN like LoRa and Sigfox, 5G network can be integrated with Vehicle onboard unit (VoBU) of the vehicles for transmits the traffic-related data in between them. Road infrastructure is also embedding with these communication protocols for receiving the data from vehicles and also transmits the data over internet protocol to the cloud server. Roadside sensors are also integrated with a similar communication protocol for transmitting the traffic data to the road infrastructure unit. As the real-time traffic data logs in the cloud server, the traffic authority can monitor the traffic patterns of distinct locations, and in case of congestion; the authorities provide an optimal route to the vehicles for avoiding the congestion within a short interval of time. The emergency management system (EMS) is under the control of nearby hospitals and police authority, EMS access the information through a cloud server for checking the traffic accidents and also check the requirement of emergency services for saving the life as an immediate response to the emergency saves the life. New generation wireless communication technology 5G provides features like ultra-high reliability, ultra-large bandwidth, and ultra-low delay that meet the requirements of a vehicle to vehicle and vehicle to infrastructure communication (Duan et al., 2020). The complete architecture illustrates that the implementation of smart traffic and emergency system.

An emergency management system enhances the traffic efficiency on the highway by identifying the exact reason for traffic congestion in real-time. the traffic emergency response system can timely and accurately control the following information of personnel and vehicles, quickly and conveniently resettle personnel and vehicles, effectively carry out follow-up rescue work, effectively improve rescue efficiency and improve the level of urban management. Table 3 illustrates the recent studies that discuss the smart traffic and emergency management system.

c. Renewable energy resources on highways

The goal of smart cities is to establish an ecosystem that is easily accessible to the citizen by integrating advanced technology and sustainable energy. At present increase in the number of vehicles on the highways spikes the pollutants level in the environment, it is a serious concern to be focused on as it is combating the goal of establishing an eco-friendly environment. An electric vehicle is a promising step towards highway sustainability which replaces internal combustion engine-based transportation (Kumar and Alok, 2020). Many automobile industries are working towards developing electric transportation systems for meeting the requirement of smart cities in the nearby future. Generally, electric vehicles are 75% efficient for switching the input energy into kinetic energy (Why are Electric Cars Important to Society (Benefits of Electric Vehicles), n.d.). Charging station infrastructure for an electric vehicle is the major concern of deploying the electric vehicles as the energy sources are solely dependent upon electricity (The five major challenges facing electric vehicles - BBC News, n.d.). With the assistance of renewable energy sources, the charging station point can be deployed at a distinct point on the highways in order of implementing a sustainable energy source for charging the vehicles. The utilization of sustainable energy and ensuring access to sustainable, accessible, and modern energy for citizens leads to sustainable development. The world focuses on renewable sources of energy for its economy and the sustainability of the climate. Renewable energies such as solar, wind, pieselectric, and hydroelectric resources are widely acknowledged as sustainable energy (Bani-Hani et al., 2018). Except hydroelectric, the remaining energy sources can generate energy for powering the highway side applications like sensor node, gateway node, traffic lights, LED lights, and smart display board for a multitude of data collection. The integration of renewable energy on the highways reduces the installation cost of deploying electric transmission lines for powering the highway side applications and these renewable energy sources produce zero eco-friendly carbon emissions. Renewable energy sources like sun and wind may vary according to the location, in hilly areas the amount of sunlight is less when compared with other areas, so the optimal renewable energy source should be implemented in such areas. Solar energy is harvested by deploying the photovoltaic panels on the roads or the top of the lights. The photovoltaic panel absorbs the radiant energy and the power generation unit transforms radiant energy into electrical energy (Liu et al., 2019; Singh et al., 2018). The significant reason behind implementing the solar panels is, as around 2%–5% of the surface of the Earth is covered by highways. By 2050, this proportion could rise by 60% and it reveals that amount of land taken out of nature that produces a strong effect on the environment.

Current technical advances concerning the new photovoltaic panels now stand up to heavy-duty loads with hyper-resistant structures. Using these advanced solar panels, our conventional asphalt roads might become massive power generators.

Fig. 8 illustrates the solar Roadways or photovoltaic roads are developed by the USA for harvesting solar energy and these roadways will be available in the future for walking and driving on it (Solar roadways: the future of renewable energy - BibLus, n.d.). The sustainable city relies on renewable energy, which promotes the development of electric vehicles.

Table 3
Recent studies discuss the smart traffic and emergency management system.

Research	Research focus	Findings
(Afrin and Yodo, 2020)	A summarization of present traffic congestion measures	Enhancement in smart traffic management resilient management system for implementing a sustainable driving ecosystem
(Liu and Wang, 2019)	Implementing traffic response system with IoT	Enhancement of rescue and response system with quick response.
(Sarrab et al., 2020)	Employing roadside units for receiving traffic-related data like congestion and unusual incidents.	Better accuracy is an outcome for vehicle detection with low relative error in the estimation of road occupancy.
(Lee and Chiu, 2020)	Hybrid traffic control is proposed for establishing a driver eco-friendly transportation system.	Emergency Vehicle Signal Preemption EVSP) provides real-time information at an intersection about the status of an emergency vehicle.
(Sumi and Ranga, 2018)	Vehicular ad-hoc network (VANET) to deliver priority to emergency vehicles for smooth movement through traffic congestion.	Eliminates the delay in an emergency.
(Lee and Li, 2018)	An eco-driving advisory system (EDAS) is implemented for smooth driving at the intersection.	Open traffic light control model (OTLCM) gives 25.1%~81.2% in intersection scenario.
(Ahn and Choi, 2019)	Vehicular communication-based approach for traffic control.	The approach achieves the reduction of message transmission overload without losing the accuracy of vehicle queue length estimation.
(Javaid et al., 2018)	Smart traffic management system achieved with IoT	The system intelligently controls the signal timing based on traffic density on a specific roadside
(De Oliveira et al., 2021)	Enhancing the traffic signals by implementing a wireless communication network based centralized light control system	Effective communication is established between the network coordinating device and traffic lights.
(Biswal et al., 2021)	A voice-controlled smart traffic-based system is implemented for controlling LED lights through voice commands	Arduino Uno and Bluetooth communication are utilized for realizing voice command systems.
(Dhingra et al., 2020)	A traffic monitoring system is implemented for monitoring the congestion and traffic light management	Moreover, the proposed fog and cloud-based system are interfaced with Twitter for sending alerts regarding traffic congestion.
(Beg et al., 2020)	Implemented intelligent traffic policing and emergency system	The unmanned aerial vehicle is integrated for realizing the intelligent traffic policing and emergency management system

Fig. 8. Pilot based solar panel deployment on the road (Solar roadways: the future of renewable energy - BibLus, n.d.).

Another renewable source that can be generated on highways is wind energy. Generally, wind energy is harvested by windmills depending on the intensity of the wind. As the number of vehicles is traveling on the highways, the wind blowing from the vehicles can be used for capturing the energy by deploying the wind turbine in the center and side of the highway. Fig. 9 illustrates the wind turbines that are designed by TAK studio for capturing wind energy (Top Article from 2019 - Traffic Powered Wind Turbines | AltEnergyMag, n.d.). Here the wind draft force from the vehicles is converted into electrical energy by electrical power generation. The wind energy generates through wind turbines is utilized for powering the light of the highway during the night and in the day-time, the energy is stored in the grid.

Piezoelectric energy is another renewable energy that can be produced on highways through vehicles. The conversion of the mechanical force of the vehicles into electrical energy is called piezoelectric energy (Yang et al., 2018). Here piezoelectric crystals are inserted underneath the asphalt layer of the road for capturing the energy generating from the vehicle motion. The force or pressure exerts on the crystals deformed and force consumed from the deformation is converted into electrical energy (Hickson, 2013). A lever-type piezoelectric energy harvester is designed which is having features of electrical output and low durability for utilizing the piezoelectric energy harvesters as a future charging station on the highways (Jeon et al., 2021). The energy-producing from the piezoelectric harvesting is capable of powering the sensors and wireless devices for enhancing the power efficiency of the sensor nodes of the highways (Subbaramaiah et al., 2020). The piezoelectric road is successfully implemented in the country of Israel by innowatech for capturing the electricity from the pressure exerted by the vehicles on a road (Roads that generate clean energy - On The Road Treds – Together we move the world, n.d.). Hence these are renewable energy sources that can be generated on the highways for powering the lighting and other wireless devices. Implementation of the different energy resources enhances energy efficiency and also achieves the goal of smart cities i.e clean energy with zero carbon emissions.

d. Smart display board for Vulnerable Road User model

Generally, to protect and provide security to the pedestrians and cyclists on the road, they are vulnerable road user (VRU) models. VRU model is the law that supports the VRU laws deliver valuable legal

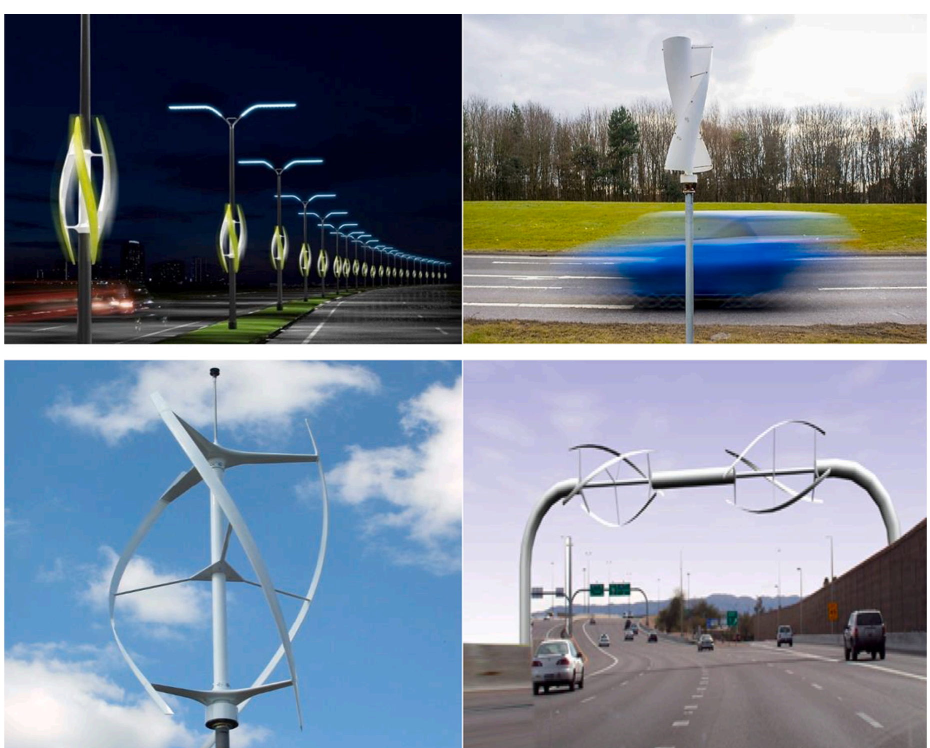

Fig. 9. Wind turbines deployed on the highways in Scotland (Top Article from 2019 - Traffic Powered Wind Turbines | AltEnergyMag, n.d.).

defense to bicyclists and other individuals who are not protected by steel fences. VRU laws function underneath the principle of basic prevention by expanding the penalties for certain road activities that result in serious injury or death of certain road users, people would be hindered from engaging in such behaviors in the presence of those users. The model law imposes severe penalties on those who seriously hurt or kill bicyclists and other vulnerable road users. However, with the advancement in technologies, it is feasible to find the individual who violates the law on the road and causing severe damage to vulnerable users. The traffic in developing countries has now become a huge issue. As a result, time, fuel, and energy are lost. IoT is a network of electrical apparatuses, automobiles, physical apparatus, other electronics, sensors, and software that allow all such objects to communicate and exchange information (Nord et al., 2019). Intelligent traffic management is a vital part of smart city projects, as traffic congestion and city growth are serious problems (El Mokaddem et al., 2019). The smart road comprises different intelligent management systems such as adaptive traffic control system (Liu and Wang, 2019), renewable energy resources (Solar roadways: the future of renewable energy - BibLus, n.d.) smart road light system (Wang et al., 2020), smart Vulnerable Road User model, smart emergency management system (Sumi and Ranga, 2018), smart information display system. Smart information display is a key component for transforming highways and urban roads into a smart environment (Gomez et al., 2019). The smart display is used to display real-time information about different routes, weather information, car charging points, emergency. Fig. 10 illustrates the smart information display that visualizes the traffic update and road congestion on the highways of India and Britain. The information available on smart display is valuable for a diver to access the real-time information which assists them to save time and effort. Displaying multiple digital information on a single smart display addressing the smart highway environment (Smart motorways – our current position - GOV.UK, n.d.). Such a system is integrated with some local metrological departments for gathering and displaying real-time information about current weather over the smart display (Roadside Pollution Monitoring: An Essential for Smart Roadways - Oizom, n.d.). The pattern of urban roads and highways are different from the local roads. On local roads, there are some pedestrian crossing, bicycle, and other vehicles, but in the case of the highway is different. Besides, displaying information about the different routes on a smart display will improve the mobility of the smart roads. The real-time traffic congestion information and accident alert will help the driver for choosing the most suitable route from his current position. The other information which is available on this display is a car charging station and emergency services which are most important for a driver to know the information about the next car charging point and the emergency services such as hospital, car mechanics, etc. (see Fig. 11).

e. AI in highways for Safety on Road:

Currently, the issue of road accident rates is a major concern for countries' health and social policy. Now on average every 50 s, a fatal road incident happens, and traffic accidents happen every 2 s (Goniewicz et al., 2012). Concerning the World health organization (WHO) report, every year approximately 1.3 million dies on roads globally and 20–50 million sustain severe injuries and most of them need treatment for a long time (WHO, 2014). The lack of supervision and implementation of road traffic rules are the major cause of road accidents (Casado-Sanz et al., 2020). Additionally, lack of driver skills combined with an incorrect assessment of the road situation, lack of proper road infrastructure, and poor technical conditions of vehicles are also the causes of road accidents (Puvanachandra et al., 2012; Hussain and Redmond, 1994). The road safety strategies were intended to minimize risk exposure are evaluated by the following parameters: minimize the intensity of motor vehicle traffic, establishment of reliable wireless communication networks, planning the new roads with more safety, implementing limitations of vehicle users, use smart Vulnerable Road User model and enhancing the road infrastructure (Maurice and Lavoie, 2004). The establishment of modern technology contributes to a plethora of road infrastructure safety systems that strengthen the safety of drivers, pedestrians, and other road users. Modern technologies are capable of identifying those participants in road traffic who breach laws through speed cameras and sensors obtaining the information regarding the number of vehicles violating the red light (Horrey et al., 2012). Modern technologies ensure consistent data collection through camera networks, and onboard monitoring systems, and wireless sensor networks (Battiato et al., 2018). Camera network and sensor data of the road traffic integrating with AI techniques for predicting the events regarding the cause of accidents and occurrence of accidents in a short period. With the available data, AI analyzes the traffic monitoring and also count & classification of vehicles that are traveling on the highway environment. AI-based analytics tools are applied to digital data on the cloud server that predicts the traffic flows (Boukerche et al., 2020) by analyzing the vehicles passing through the intersection. DL algorithm model employed for predictive maintenance of the highway roads from the real-time video data (Machine learning tool predicts maintenance for highways - intellegens, n.d.). This algorithm optimizes the maintenance cost of the road by forecasting the damage on the highways. Road predict is a machine learning-based specialized tool that anticipates the accidents for limiting consequences in a short interval of time (How to use Artificial Intelligence Data Science to improve safety on motorways | by Qucit | Medium, n.d.). Table 4 illustrates the studies about the role of AI on highways.

4. Discussion

The digitalization of highways is having a significant role in achieving sustainable and resilient infrastructure. This indeed delivers a digital, smooth, and safer experience to the vehicles traveling across the highways. In this study, we have discussed the important elements of digitalization of highways, and we have presented the distinct architecture of distinct elements like smart highway lighting, smart traffic & emergency, renewable energy sources, smart display board, and AI. The

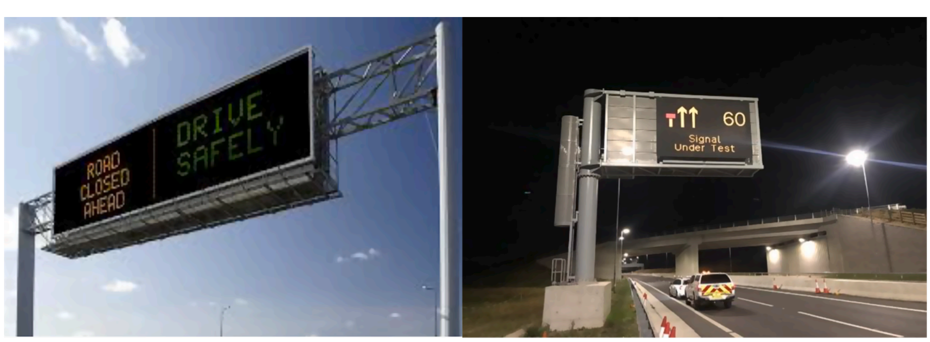

Fig. 10. Smart display board on highways of India and Britain (UK installs next-generation digital signage on its roads - Smart Cities World, n.d.); (Variable Message Signs, Speed Signs, and Lane Control Signal – MassTrans, n.d.).

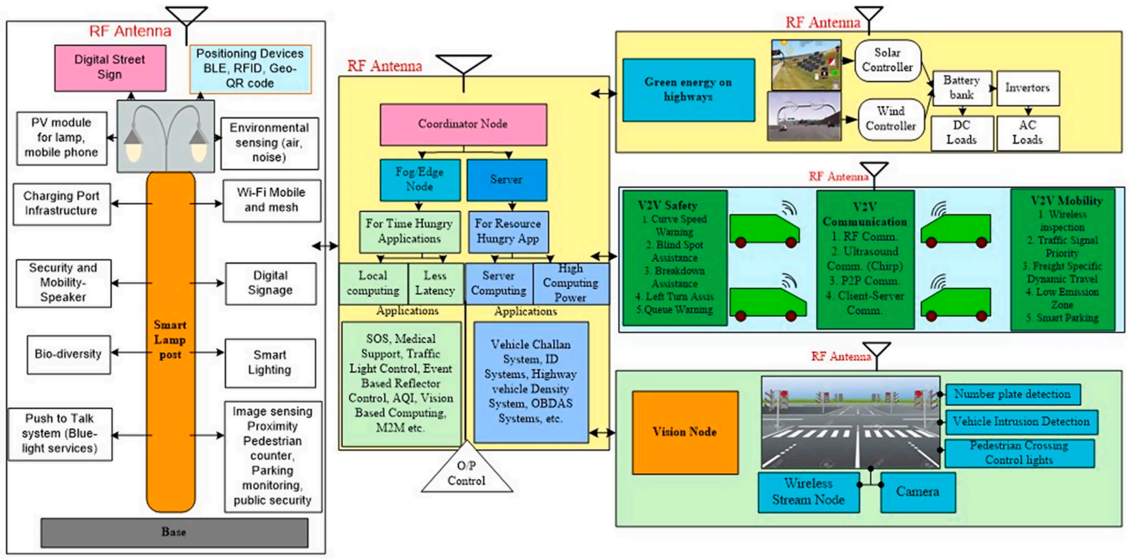

Fig. 11. Hybrid architecture for realizing the digitalization in highways.

significance of edge-based vision nodes, renewable energy sources from the highways are presented in the study. However, there are few possibilities for enhancing and realizing the digitalization of highways. To address the possibilities, we have proposed a hybrid architecture that clearly presents the interconnection of a different system of the highways and additionally, we have presented recommendations concerning each component of the hybrid architecture. The hybrid architecture is having five main components that are embedded on the highways. Smart lamp post, coordinator node, green energy on highways, V2V safety, V2V mobility, and vision node. Every component in the architecture is interconnected with a radio frequency (RF) antenna. Smart lampposts are a combination of independent features that are integrated for providing smart and effective features to urban city residents. Smart lamppost offers features like smart lighting, digital signage, environmental sensing, push-to-talk system, charging port infrastructure, wi-fi mobile & mesh, image sensing pedestrian counting, parking monitoring & public security, and digital street sign

Green energy on highways relates to the utilization of renewable energy sources for providing energy to the IoT-based devices on the highways. V2V safety components address the curve Speed warning, blind-spot assistance, breakdown assistance, left turn assistance, and queue warning. V2V mobility in the highways empowers to achieve the following applications namely Wireless inspection, Traffic Signal Priority, Freight Specific Dynamic Travel, Low Emission Zone, and Smart Parking. Vision node in the architecture enables to detection of vehicle intrusion, monitoring the Pedestrian Crossing Control lights, number plate detection, and wireless streaming of highway data through camera. The following are the recommendations for future directions in digitalizing the highways.

a. Smart Reflector:

Road reflectors, sometimes called raised pavement markers, are designed to help control traffic while encouraging safer driving conditions. A common but successful system is the automatic road reflector, which helps us automate the conventional road reflectors. A raised pavement marker is an on-road safety instrument used throughout the night to navigate the vehicles along the way. This automatic road reflector is developed just to replace the old method of navigating the vehicles at night. When the light intensity is low at night it starts blinking automatically and once the light goes bright it converts itself to power saver mode. To show the right track to a vehicle at night road reflector plays an important role. It is also used to divide the road into two parts with the help of a blinking LED light. Smart reflector also provides a warning system in the event of road accidents for the safety of the citizens; the reflector triggers all other reflectors in a designated vicinity for avoiding congestion on the highways.

b. Adoption of renewable energy on the highways:

Renewable power is growing, with the progress of lowering costs and promising the future of clean energy. The integration of renewable energy sources in highways enables to establish zero carbon emission and enhance energy efficiency. Solar energy, wind energy, and piezoelectric energy are the possible renewable energy sources that can generate electricity on the highways for powering wireless devices and lighting. US (United States) is developing solar-based road can harvesting solar energy and digital visualization of the marking. Israel country is generating power from the piezoelectric energy harvesting on the highways. Scotland is generating power from wind turbines that transforms wind energy into electrical energy. These countries are utilizing renewable energy efficiently for providing clean energy and a sustainable environment to the citizens. Adoption of renewable energy resources in the highways achieves the target of establishing a sustainable driver ecosystem.

c. V2V Communication:

V2V communication is necessary to implement in the present vehicles generates alerts about the upcoming traffic congestion, avoiding accidents, and boosting the safety of the vehicle uses. Traffic jams status is propagated and recommends cars to take the pre-exit and search for alternative roads, to prevent more congestion. V2V utilizes short-range communication for broadcasting and receiving messages between the vehicles in 360 degrees. The automotive industry needs to focus on implementing V2V communication for achieving the vision of implementing the digital network on the highways.

d. Smart lamp post on highway:

The smart lamppost is an innovative lamppost that can provide multiple applications at a single point. Smart lamppost will strengthen citizen safety by the digital display of real-time highway data such as meteorological data, air quality data, and traffic flow. Emergency button, wi-fi hot spots, solar energy powered, are smart applications are integrated into the smart lamp post. Digital signs and automatic controlling of the luminance of light are also embedded in the smart lamppost.

e. Edge-based vision node

Edge computing is providing an opportunity to process the data and provide necessary insights at the edge device (Satyanarayanan, 2017). At present AI on edge is an emerging area, where useful insights are extracted from the massive and distributed edge data (Deng et al., 2020). Edge computing establishes a system that can deliver computing power

Table 4
Studies of AI for highways.

Research	Objective	Technique	Findings
(Bahador et al., 2020)	Detecting real-time accidents	(XGBoost) and SHAP	Accuracy 99%, detection Rate: 79%, and false alarm rate: 0.16%.
(Afework and Sipos, 2020)	Identifying the key accident variables for the prediction of an accident.	Artificial Neural Network (ANN)	R^2 value 0.873 in model development and R^2 value 0.852 in model validation are optimal for accident detection.
(Behbahani et al., 2020)	Detecting and recording dangerous situations for each vehicle based on microscopic traffic data	Artificial Neural Network (ANN) and fuzzy inference system (FIS)	Efficiency is enhanced for avoiding rear-end collisions.
(Inkoom et al., 2019)	Predicting cracks on highway pavement	Artificial Neural Network (ANN)	Age of Pavement, Average, Daily Traffic, and Truck Factor are attributes for crack detection.
(Avila and Mezić, 2020)	Analyzing and forecasting traffic dynamics with a data-driven approach	Koopman mode decomposition	Time-ordered data arising from observation of linear/non-linear dynamical system is assumed for forecasting traffic dynamics
(Tian et al., 2018)	Analysis of safety in tunnel highway traffic	Fuzzy cognitive maps (FCM) algorithm	Enhanced FCM can identify the accurate region of the tunnel and fault data.
(Maghsoudi and Moshiri, 2017)	Predicting the traveling time on the highway	ANN and AIMSUN (Adaptive Network-Based Fuzzy Inference System)	NA
(by Mirza Ahammad Sharif, Real-time crash prediction of urban highways using machine learning algorithms, AN ABSTRACT OF A DISSERTATION, 2011)	Real-time prediction of accident highways	Support Vector Machine (SVM) and Random forest	In terms of sensitivity, the SVM model performed better, and in terms of accuracy random forest performed better.
(Huang et al., 2020)	Predicting crash occurrence and crash risk	Deep learning models	The deep model has better crash detection performance than the shallow model.
(Soleimani et al., 2019)	Identifying the risk of rail-roadway crossing.	eXtreme Gradient Boosting (XGboost) algorithm.	The overall accuracy of 0.9991 is achieved with the proposed model.

with less power consumption to ensure the safety of vehicles at high speed (Liu et al., 2019). 5G communication integration with edge computing boosts the vision-based edge device to perform and communicate the events in short intervals. Here the edge computing in the vision node process executes the necessary insights for the safety and quality of the highways.

f. Inclusion of deep learning:

The vision node provides the images and video data to edge computing; however, it is found that object detection is the challenging in vision node (Barba-Guaman et al., 2020). Here the deep learning models are very efficient in detecting the anomaly on the roads by processing the image and video data. DL neural networks such as sdd-mobile net v2 and SSD-inception v2 are better for object detection (Zhao et al., 2019). DL can accurately detect vehicles from video and audio data. So, the inclusion of deep learning in the edge-based vision node delivers an intelligent monitoring system for establishing highway safety.

5. Conclusion

Sustainable, affordable, and safe transportation are the goals of the UN agenda 2030. Concerning this context, highways are one of the key transportation systems that enable transits from one destination to a location. Digitalization of highways is the prominent solution for achieving the goals of the UN 2030 agenda. IoT and AI are digital technologies that empower the establishment of a smart, intelligent, and renewable energy sources-based eco-system on the highways for delivering a safe and smoother experience to users traveling on the highways. Digitalization in highways enables monitoring and access to traffic events, route guidance, air quality, weather forecast, and emergency facilities in real-time. Renewable energy-based lighting with a robust communication protocol establishes eco-friendly, cost-efficient, and energy-efficient lighting in highways. As digitalization in highways generates enormous data from heterogeneous sources like sensors, vehicle-to-vehicle communication, and road infrastructure so it can be employed with AI for predicting the traffic flow, crash accidents, and traveling time is attainable by integrating deep learning and vision node. The inclusion of edge-based vision nodes and deep learning techniques in the highways enables to delivery of intelligent and digitalized highways. Deep learning in the vision node enables to provide safety in risky traffic situations and also enhances the safety solution through prediction. A hybrid architecture for the digitalization of highways is addressed in the study.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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