# Abstract

Intelligent transport systems (ITS) yield fruitful solutions to manage traffic problems. ITS includes all approaches of transportation likewise air, rail, road, and water. Interrelation and collaboration of various components of each mode ensure the successful implementation of ITS. The research work in the thesis is performed in accordance with the objective of implementing a well-developed ITS, with adequate capacities to handle the transport demand. Modern ITS are being propelled by the development and adoption of wireless telecommunications and computing technologies, thereby allowing that our roads and highways can be both safer and more efficient transportation platforms. This has motivated me towards performing an exhaustive survey of the existing works in the domain of ITS during the period. Generally, ITS uses stationary infrastructures called roadside units (RSU) to communicate with the traffic management centre for data collection, analysis, and control operations. RSUs contribute to data dissemination, traffic predictions, and management. However, RSU deployment requires huge installation and additional maintenance cost that trigger a significant research domain that deals with optimal placement of RSUs. Identifying the placement positions that provide maximum coverage and network performance so that we can cover the transportation region with the reduced number of RSUs are one of our primary areas of this research. A novel optimal RSU deployment framework (IIA-ORD) is proposed based on complex network analysis of considered transportation network. IIA-ORD follows the idea of deploying RSUs in the crucial road intersections that are significant in terms of commercial and educational uses. Different criteria and their evaluated values are used to identify the deployment positions like degree centrality, betweenness centrality, eigen vector centrality, derived cumulative traffic connection and modified K-shell index. Then multi-criteria decision-making formulation TOPSIS is used to build the final candidate list of positions used for RSU deployment. After a set of simulations and comparisons to recent existing RSU deployment schemes, the outcomes exhibit the significance of the proposed IIA-ORD in terms of average area coverage, average connectivity, contacts per trip, end-to-end delay, PDR, and number of RSUs. Finally, the effectiveness of the system is established by implementing a traffic prediction framework by placing RSUs in every intersection with our proposed scheme based on the accuracy and loss analysis. After the execution of traffic

prediction application in the RSUs, the next important objective is to control them in accordance with the estimated traffic. To this end, in this thesis, we develop an energy efficient RSU scheduling formulation where RSUs active or standby status are handled by the central controller based on the predicted traffic. To support high data rate requirement of VANET millimeter wave based RSUs are used for this formulation. It is evident that efficient VANET routing protocol plays crucial role in the accomplishment of applications like emergency message awareness, dynamic route planning using 802.11p standard dedicated for wireless access in vehicular environments (WAVE). Traditional mobile ad hoc network (MANET) routing and forwarding protocols have failed to provide standard performance for VANET and suffered from rapid link failures. In the thesis, it is shown that routing protocols that incorporates location specific functionalities and mobility constraints in their designs deliver better quality of service (QoS) performance. Bio-inspired algorithms are advanced emerging paradigm used in VANET routing due to their remarkable advantages. They are useful in addressing VANET optimization problems in searching accurate solutions to enhance vehicular networks performance. In the initial phase of VANET routing protocol designing, we propose an advanced version of ant colony optimization (ACO) based routing protocol named as reduced route overhead by ACO (RRO-ACO). It is influenced by the information distribution process of ants through their pheromones distribution process for discovering most stable route for data transmission. Vehicular nodes broadcast forward ant packets and link stability is accounted for identifying most stable route. Once the control packet is received at present hop, acknowledgement packets are used to minimize the further broadcasting of control packets by the previous hop. Performance evaluations of RRO-ACO with state-of-the-art routing protocols gives improved results in terms of PDR, overhead and latency. In the next phase, we propose a new bio-inspired VANET routing protocol called canine olfactory route-finding algorithm (CORFA). CORFA is inspired from the canines' unique message passing capability through barking where distance is inversely related to loudness of barking. Moreover, CORFA motivates by canines' distinctive behaviour of remembering past discovered environment. At the time of packet forwarding, vehicles request previously discovered routes from RSUs for avoiding route discovery process that ensures reduced network overhead. Here QoS parameters are compared for different scenarios like varying source to destination distance, packet size, vehicular speed and density to establish the effectiveness of proposed algorithm. Convergence analysis is also done in comparison with the existing bio-inspired VANET routing protocols. After the incorporation of optimal infrastructure placement and QoS aware routing, the further prime objectives of this dissertation are to alleviate traffic congestion and minimize environmental pollution, which directly improve passenger safety and comfort. To this end, we propose a RSU assisted variable speed limiting (VSL) system to alleviate the gathering of vehicles at the intersection. Static speed limiting systems are futile to manage traffic congestion, so our formulated VSL model is capable to ease congestion at intersections. For passenger benefit, existing navigation systems like Google provide shortest and fastest route for users. Nevertheless, the suggested route is not tailored to users' requirements. Considering this, we have developed a users' criteria-based path planning for finding appropriate healthcare destination that avoids unnecessary wastage of time. At the time of emergency, our developed application recommends exact destination for patients, which can be lifesaving. When compared to the baseline path-planning algorithm Dijkstra, our proposed system outperforms in terms of travel time and computational time. While VSL systems control vehicular speed to handle traffic congestion another worthwhile way to manage traffic congestion is to re-route the vehicles in multiple routes. As road resources and options for re-routing are fixed, so we cannot re-route to a particular road in a repetitive manner. Besides that, public vehicle follows pre-determined route so only private vehicles can change their route according to the traffic situation. Post pandemic era enforces physical distancing which increases the inclination of using private cars, which creates more congestion. To resolve aforementioned issues, we have proposed enhanced A* algorithm that differentiate private vehicles, re-routes them according to road condition and stops recurrent usage of a road. Reduction of travel time and waiting time generate less acceleration and deceleration, which save carbon emission and fuel consumption. Supremacy of this proposed algorithm is established by comparing it with conventional Dijkstra and A* algorithms. With the envisioned era of machine learning, ITS have evolved as more impactful tool for traffic and pollution management. Finally, by leveraging our already implemented optimal RSU deployment scheme we develop a traffic management system called RSU assisted federated learning-based traffic management (RATM-FL) that works in collaboration with a central cloud server. It is enriched with a federated learning framework to ensure enhanced system performance and safety. Distributive RSUs handle local traffic using BiD-LSTM model and federated learning is used to manage global traffic through a central cloud server. We validate our proposed model with extensive simulation study in comparison with the existing traffic management systems. Our results indicate that RATM-FL outperforms in terms of carbon emission, fuel consumption, travel time, waiting time and vehicular speed. So far, we have explored the requirement of optimal infrastructure deployment and smart functionalities for cost-efficient and energy-efficient VANET.

The evolution of autonomous driving and next-generation vehicular applications demands communication systems capable of handling high traffic loads with ultra-low latency and high reliability. Vehicle-to-everything (V2X) communication has emerged as a vital paradigm, with Cellular V2X (C-V2X) becoming increasingly prominent due to advancements in 5G and forthcoming 6G networks. C-V2X enables autonomous resource allocation in a distributed manner, it faces significant challenges such as resource conflicts, collisions, and Quality of Service (QoS) degradation in dense traffic scenarios. To encounter these discrepancies a novel Cluster Head assisted Q-learning-based Resource Allocation (CHQ-RA) framework is proposed. To coordinate resource distribution, Cluster Head Vehicles (CHVs) are selected based on stability metrics such as speed, acceleration, and probability of successful packet delivery. A Q-learning algorithm dynamically adjusts the sensing window for CHVs which optimizes network performance by adapting to real-time traffic conditions. Additionally, a fitness function is employed to prioritize vehicles for balanced and efficient resource allocation. Simulation results demonstrate that CHQ-RA significantly outperforms traditional Mode 4, and existing relevant methods in key metrics, including Packet Reception Ratio (PRR), Collision Ratio (CR), and Update Delay (UD). The proposed approach effectively enhances performance and reduces collisions in dense traffic environments offering a promising solution for improving resource allocation in vehicular networks.

Considering the challenges of vehicular networks including the rapid topology changes and highly mobile environment, bio-inspired VANET routing algorithms are developed to increase QoS performance. Finally, the thesis addresses transportation network shortcomings including congestion and pollution to achieve smooth, safer, and cleaner traffic.