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High-efficiency Urban-traffic Management in Context-aware Computing and 5G Communication

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Abstract: With the increasing number of vehicle and traffic jams, the urban-traffic management is becoming a serious issue. In this article, we propose novel four-tier architecture for urban-traffic management with the convergence of vehicle ad hoc networks (VANETs), 5G wireless network, software-defined network (SDN), and mobile-edge computing (MEC) technologies. The proposed architecture provides better communication and rapider responsive speed in a more distributed and dynamic manner. The practical case of rapid accident rescue can significantly cut down the time for rescue. Key technologies with respect to vehicle localization, data pre-fetching, traffic lights control, and traffic prediction are also discussed. Obviously, the novel architecture shows noteworthy potential for alleviating the traffic congestion and improving the efficiency of urban-traffic management.

Keywords: Traffic congestion, Urban-traffic management, 5G, Mobile-edge computing, Traffic prediction.

1. Introduction

With the growth of urbanization in the recent years, the problem of urban-traffic congestion has become a more serious concern. In 2014, urban commuters in the USA collectively lost 6.9 billion hours, and 3.1 billion gallons of fuel to traffic delay, and the excess fuel and lost productivity cost $160 billion. Similarly, as nearly a third of the world's 50 most congested cities are in China, the traffic problem is worse than USA. Commuters lose precious time and burn away money in fuel costs, whilst the transportation agencies spend abundant cost to maintain the traffic. Researchers have addressed to add extra transportation infrastructure to reduce the congestion such as building a dedicated lane for bus rapid transit [1]. However the effect is limited because the construction speed of extra road is far less than the increasing speed of new vehicles. Therefore, the new urban-traffic management solution is expected to explore strategies to take emerging technologies to mitigate urban-traffic congestion [2]. In order to achieve high-efficiency urban-traffic management, there are at least three key issues that need to be addressed.

- **Perception of the real-time traffic conditions:** The numerous high-resolution roadside sensors and on-board sensors need to be deployed to sense all real-time traffic conditions including vehicle speed, direction, location, road throughput, weather condition, temperature-humidity and etc.
- **Low-latency communication and massive-data storage**: Sensors intermittently produce huge amounts of raw data that grow over time, and easily touch the petabyte (PB) order of magnitude in size. In view of the difference of data type, size and dimensionality and huge volume, the bandwidth of communication network, storage capability and data process speed need to expand than ever.
- **Traffic prediction and real-time responsiveness:** The massive traffic data helps the city planner to monitor traffic density, throughput and events in real time, and the traffic control systems should have

real-time responsive ability to reply traffic events, and make immediately decisions based on traffic prediction algorithm to guide traffic flow. Designing a context-aware traffic light control system to decrease the waiting time at intersections, a rapid accident rescue system to improve the emergency responsiveness, a novel data analysis and traffic prediction system based on massive traffic data to optimize the efficiency of the existing roads are considered as key elements.

Unfortunately, the existing data collection system, VANETs, and the traditional traffic flow prediction model [3] are far from sufficient to solve abovementioned issues. For example, VANETs support a variety of services and achieve success in a certain aspect such as vehicular collision avoidance system using vehicle-to-vehicle or vehicle-to-infrastructure communication [4]. However, its inherent defects such as unbalanced traffic flow and low bandwidth impact the deployment of urban-traffic management. Therefore, exploring a high-efficiency urban-traffic management system is becoming extremely urgent.

Thanks to the rapid development of 5G communication network, SDN [5] and MEC [6], these emerging technologies are expected to boost the advancement of urban-traffic management. Introducing the 5G and SDN technologies into vehicular network, the new SDN-based heterogeneous vehicular network shall offer high-bandwidth communication service with flexibility and programmability[7]. The environmental sensing becomes more agile when assisted by the high-resolution sensors and SDN-based heterogeneous network. Meanwhile, the MEC places the computing resource at the edge of mobile vehicular network, and performs critical mission with real-time or near real-time responsive speed. The main contributions of this article are that a) propose a novel architecture combined with 5G wireless network, SDN, and MEC technologies, b) using a paradigm of road accident rescue to validate the high efficiency of the proposed architecture, and c) discuss the key technologies and potential solutions. In short, the novel architecture of urban-traffic management architecture would be more high-efficiency than ever before with the features of intelligent sense, low-latency communication, and real-time response.

The article is organized as follows. The Section 2 proposes novel four-tier architecture to resolve the urban-traffic management issues. Afterward, the rapid accident rescue, a practical case, is used to validate the high efficiency of the proposed architecture; several key technologies towards architecture are discussed in Section 3 and Section 4 respectively. Finally, the conclusion is made.

2. Architecture of Urban-traffic Management

Nowadays, the tremendous traffic congestion makes the daily commuter extremely distressful. However various emerging technologies provide a potential opportunity to cut down traffic congestion and exhaust emission by monitoring the traffic conditions over time. Based on these technologies, it is necessary to construct a new architecture to improve emergency responsiveness, balance the traffic flow, and save the fuel and time on transportation of the citizens.

When the artificial intelligence combines with the big data, a new data-driven computing model, such as deep learning, is explored. Apart from data collection and communication, the new architecture needs to carefully take into consideration the storage, access, and analysis technologies. The four-tier architecture for urban traffic management is shown in Fig. 1, including the environment sensing layer, communication layer, MEC server layer, and remote core cloud server (RCCS) layer.

2.1 Environment sensing Layer

Similar to most IoT applications, the data collection layer is the foundation and plays a vital role [8]. The traffic data mainly derives from the roadside infrastructure (sensors) and the on-board sensors. As usual, the roadside infrastructure such as the inductive loop is responsible for counting the vehicular number, identifying the license plate number and so on. Such data from the road detector is classified as passive data. The vehicles that act as a big intelligent sensor employ the on-board sensors to sense vehicular status including engine speed, velocity, direction, and surrounding environment information, including location, lane, temperature, humidity. This type of data is classified as active data. In the environment sensing layer, the precision and integrity is better than traditional way since the high-resolution sensors are deployed massively, and the vehicles report their status and environmental data actively. In particular, the vehicle location, an important traffic data, can also be estimated by new wireless localization technology in urban environments where the GPS coverage is not available.

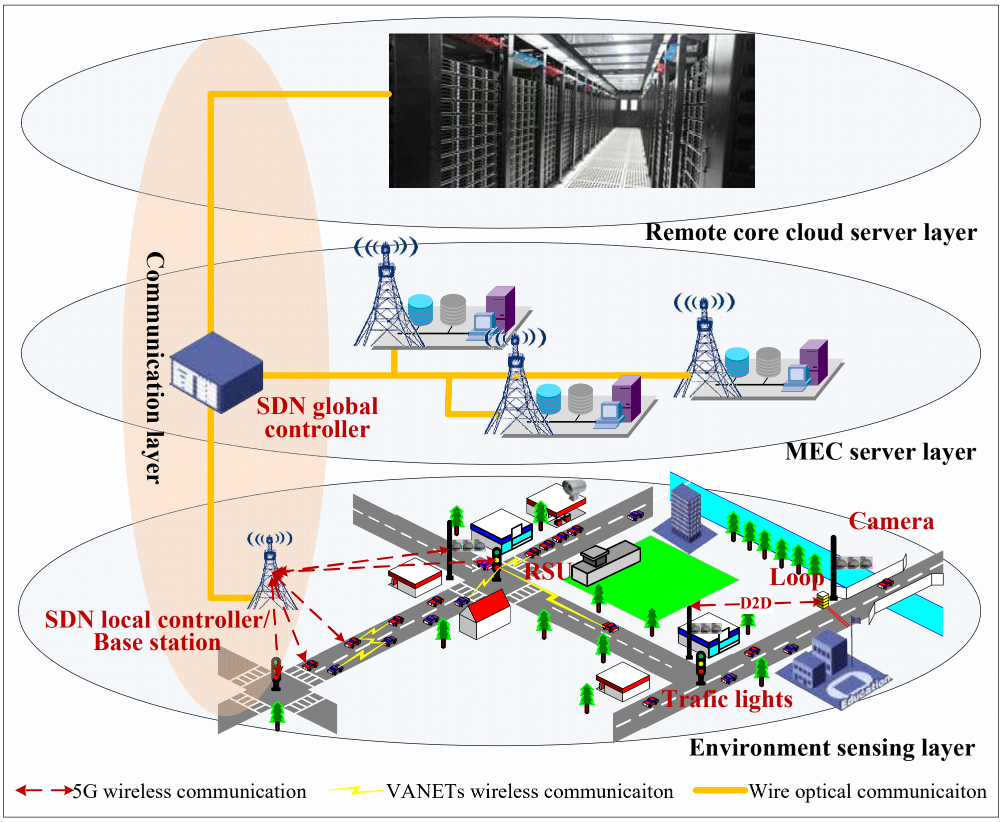


Figure 1. The four-tier architecture for urban-traffic management

2.2 Communication Layer

The VANETs have been viewed as one of the most enabling technologies for "connected car", but huge amount of traffic data bring some challenges to VANETs, such as unbalanced traffic flow [9]. In order to break the bottleneck of communication, we consider two emerging network paradigms: 5G and SDN. The 5G network employs multiple input multiple output (MIMO) and radio cognitive technologies to achieve 1.2Gbps communication speed in a mobile environment from a vehicle traveling at over 100km per hour, whilst the device to device (D2D) technology can offer more flexible and direct information exchange and new position service. SDN architecture, a new revolutionary novel thinking in networking, decouples the network control (control plane) and the forwarding functions (data plane), enabling network control to become programmable. The underlying infrastructure can be abstracted from applications and network services. SDN-based networks provide flexibility, scalability, programmability and global knowledge of network. The SDN model operate with OpenFlow protocol [10], as shown in Fig. 2, the components of which are as follows:

- **SDN global controller:** The global central controller controls all the network behaviors of all the SDN-based heterogeneous wireless and wire networks. It belongs to the control plane, and communicates with the data plane using data-controller plane interface (D-CPI) and with the application plane using application-controller plane interface (A-CPI).

- **5G BS:** In proposed architecture, BS plays three types of roles: (a) router for mobile communication device, act as resource (router); (b) MEC could server, the portable virtual machine (VM) is deployed on the BS; (c) SDN local controller that controls the network elements roadside units (RSUs) and vehicles in a certain local area.
- **SDN RSUs:** RSUs that acts as resource (switch) are responsible for forwarding the data and are controlled by the SDN local controller, i.e., BS. They belong to the data plane, and provide service using D-CPI.
- **SDN wireless node**: The vehicles, equipped with on-board radio frequency module, act as the resource (transceiver). Their role is to provide client-to-request communication services.

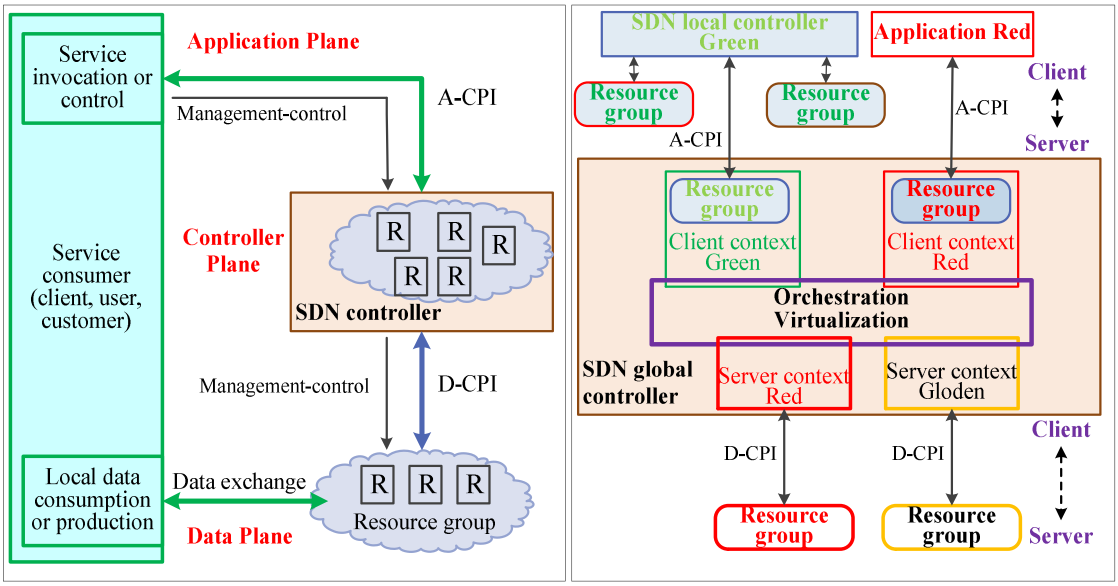


Figure 2. SDN-based network model

The SDN-based heterogeneous network offers various advantages. Firstly, due to the separation between the control and the data planes, we can set out forward policy to make more informed routing decisions that can resolve the unbalanced traffic flow issue, and offer more flexible path selection strategy with the network's programmability. Secondly, the channel or frequency selection becomes more flexible. The vehicles are often equipped with several wireless modules to support different modes of communication; the SDN-based communication layer offers a selection policy according to the cognitive radio and channel allocation policy, which enables low latency and high-bandwidth communication. For example, we can assign different bandwidth and channel for camera and radar. The information exchange becomes easier and more agile in the communication layer.

2.3 Mobile-edge Computing Server Layer

The MEC, initially introduced by IBM and Nokia Siemens Network, aims at optimizing the existing mobile infrastructure service, and minimizing the mean delay of general traffic flow in the LTE downlink [11]. Due to its characters of low latency, on-premises, and location awareness, MEC is introduced into the proposed architecture to improve the responsiveness for traffic light control and accident rescue. The MEC server, deployed on the 5G base station, is close to the end-user at the edge of the mobile vehicular network, and each application runs on it. Besides, in order to facilitate the VM migration, data pre-fetching and synchronization, a uniform framework and management infrastructure is necessary, which is illustrated in Fig. 3.

The framework includes MEC hosting infrastructure, MEC application platform, and applications layer. The

MEC hosting infrastructure consists of hardware virtualization layer and a set of hardware resources, especially vehicular communication devices. The MEC application platform includes infrastructure-as-a-service and a set of middleware (service management, communication components, cognitive radio network information, and traffic offload function). Applications are deployed on an independent VM. In order to facilitate the urban traffic management, the proposed architecture offers four basic service components.

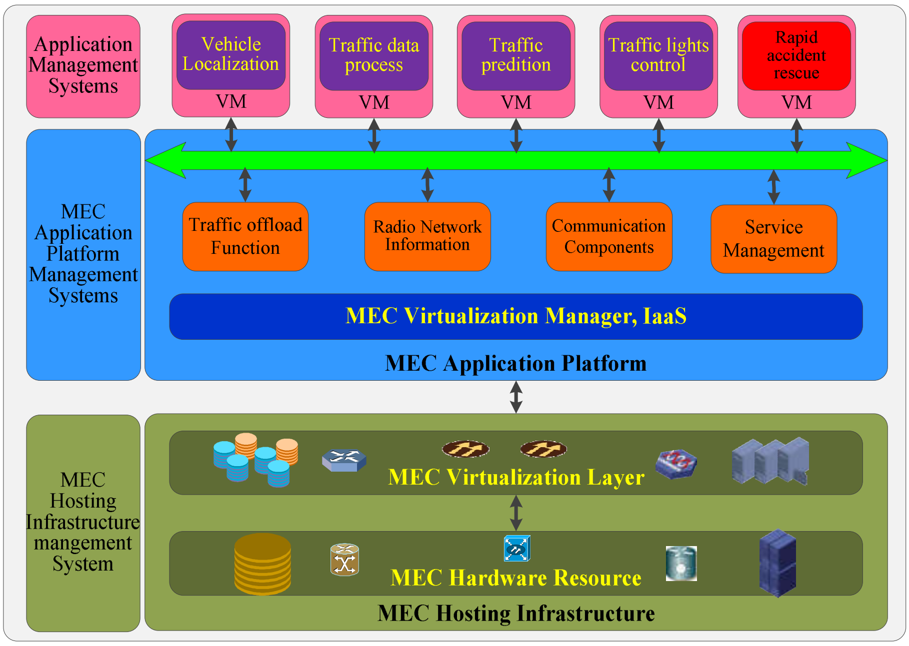


Figure 3. The portable MEC server framework

- **Vehicle localization service:** This service is deployed only on MEC server, and aims at supporting reliable location service in a complex urban environment. As the satellite signal is blocked by skyscrapers, this service employs DOA/TOA or vision to realize GPS-free localization based on 5G antenna or D2D communication.
- **Traffic data process service**: This service is deployed on the MEC server and the RCCS simultaneously. The raw traffic data in certain areas are converged into the MEC server, but these data contain some invalid and coarse data that needs to be cleansed. This service in the MEC server aims at filtering the unnecessary data and storing it temporarily. In the RCCS, this service aims at data pre-fetching, data synchronizing and data storage.
- **Traffic prediction service:** The traffic prediction service is deployed on the MEC server and the RCCS simultaneously, and aims at alleviating the traffic congestion and offering personalized services such as dynamic route planning. In RCCS, based on the massive traffic data, the service employs a deep learning algorithm to learn the generic features for predicting the traffic flow in future short-term time. In the MEC server, the service is responsible for dissemination of message to the drivers according to the prediction result.
- **Traffic lights control service:** The traffic lights control service is deployed only on the MEC server, and aims at controlling the traffic lights in real time. Due to its proximity to the source of traffic data, the service is particularly useful to capture key information for local traffic flow analysis, and can realize dynamic management according to the traffic flow, which can increase the throughput at the intersection.

2.4 Remote Core Cloud Server Layer

The RCCS, same as the commercial cloud server Google Hadoop, provides on-demand network access to a shared pool of resources including the processing power, storage, applications and services[12]. The framework of the RCCS is the same as MEC server, and the VM (i.e. service) can migrate freely among the RCCS and the MEC servers. In comparison with the MEC server, the difference here is that the RCCS has more storage resource and more high-performance computing power, which may make up for the MEC server's drawback of limited resources. The MEC server focuses on critical mission with real-time responsiveness; in contrast, the RCCS focuses on the big data storage, and big data analysis. Therefore, the entire traffic data is eventually converged into the RCCS and permanently stored, while the traffic prediction service employs a deep learning algorithm to predict traffic flow in future short-term time based on the massive traffic data.

3. Case study: Rapid Road Accident Rescue

The ***golden hour*** philosophy indicates that the casualties have a much poorer chance of survival if they are not delivered to the hospital and got definitive care within one hour, including the time taken for call-out, traveling to accident spot, extrication and transport to the hospital. The tight collaboration of on-site personnel, medical workers (hospital), firefighters, and traffic management agencies, would reduce the entrapment time and consequentially mortality rates through better organization and a methodical approach to extrication. In an urban environment, the crucial obstacle to rescue is that of the severe traffic congestion. In practice, once the road accident blocks the traffic in urban area, the ambulance would not be able to rapidly enter into the emergency scene due to lack of special rescue lanes. The accident causes the congestion in the traffic, and the congestion decrease the rescue speed and results in furthering of the congestion. This phenomenon looks like a deadlock, and the existing rescue mechanism offers no solution.

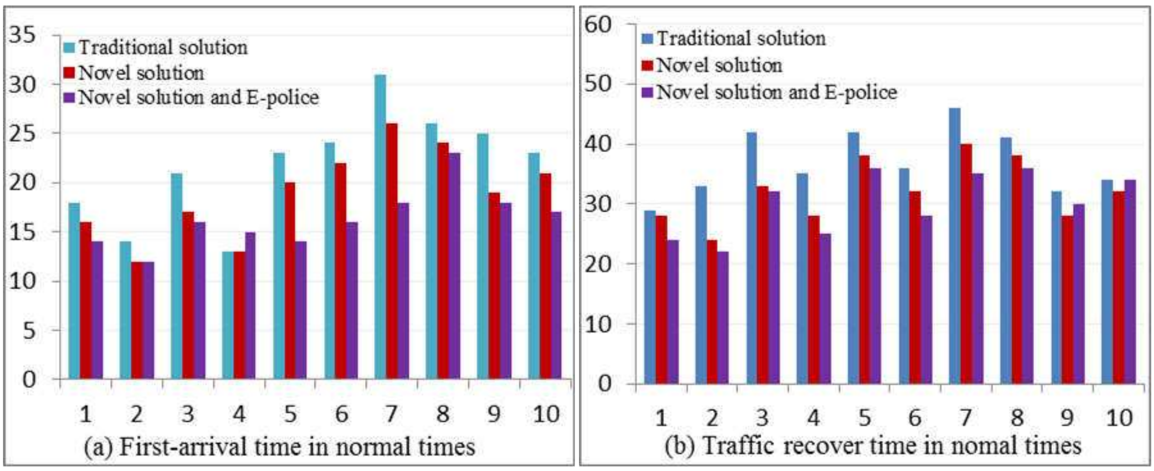
Figure 4. Rapid road accident rescue system in urban

The proposed architecture has a potential opportunity to change this impasse, as shown in Fig. 4. With assistance of the high-bandwidth and low-latency SDN-based heterogeneous network and rapid-responsive MEC server, the novel rescue system would be improved by three significant measures as follows:

- **Remote video diagnosis and initial assessment:** In the process of traditional rescue, when the emergency medical responders receive the aid request, they immediately depart for the incident scene in order to shorten the rescue time. Due to the limited network bandwidth, there is no initial assessment for the casualties and no advice to on-site personnel for avoiding the risk of another collision and removal of the injured from the vehicle with the right way. In the proposed architecture, the damaged-related information collected by sensors along with the vehicle location would be forwarded to the rescue center through the heterogeneous vehicular network. The real-time video diagnosis can be conveniently guaranteed with high bandwidth, and the emergency medical responders can acquire the first-hand information required to evaluate extent of the injuries [13], and thus prepare the suitable doctors and devices to further treatment.

- **Early-warning and no-go area:** The main reason of the accident-related traffic congestion is that the drivers are not aware of the accident time and location. The vehicular stream unknowingly enters into accident area incessantly and results in traffic congestion. With the assistance of vehicle localization service, the rescue system can obtain the location of every vehicle. The system can thus set a virtual early-warning and no-go area on the electronic map, and then disseminate warning messages to the drivers. Once a vehicle enters into the early-warning area, the driver would be alerted by a message to keep away from the accident spot. Meanwhile, based on the traffic lights control service, the system can adjust the "green time" of traffic lights at the edge of no-go area, and force the vehicles to bypass the accident spot.
- **Green rescue lane for emergency vehicles:** Rapid removal of the injured to the hospital will improve their chances of survival. In order to minimize the entrapment time from the hospital to the accident spot, the proposed rescue system calls for the traffic lights control service to coordinate all traffic lights in a certain area, and clear a green rescue lane for the ambulance and other emergency vehicles.

In order to simplify the verification of the proposed system, we select ten accidents randomly from all traffic accidents in a month, and use the traffic data to simulate the practical traffic flow. In view of the "ambulance priority" law is not observed well in some developing country, we make two assumptions: a) there are 60 percent drivers or pedestrians keep clear of ambulance without electronic police (E-police) monitor; b) there are 95% percent drivers or pedestrians keep clear of ambulance with E-police monitor. Fig. 5 shows the preliminary validation of the proposed system in normal times and in the rush hour. We first compare three solutions in normal times without congestion. The novel solution can save averagely 2.8min without E-police monitor, and 5.5min with E-police monitor in the first-arrival time, and saves averagely 4.9min and 6.8min respectively in the traffic recover time aspect. It seems that the improved effect is not obvious. Secondly, we compare them in the rush hour. The novel solution saves averagely 9.9min without E-police monitor, and 12.5min with E-police monitor in the first-arrival time of ambulance prospect, and saves averagely 15.5 and 19.5min respectively in the traffic recover time aspect. The rapid road accident rescue system can decrease the consuming time and increases the chance of survival.



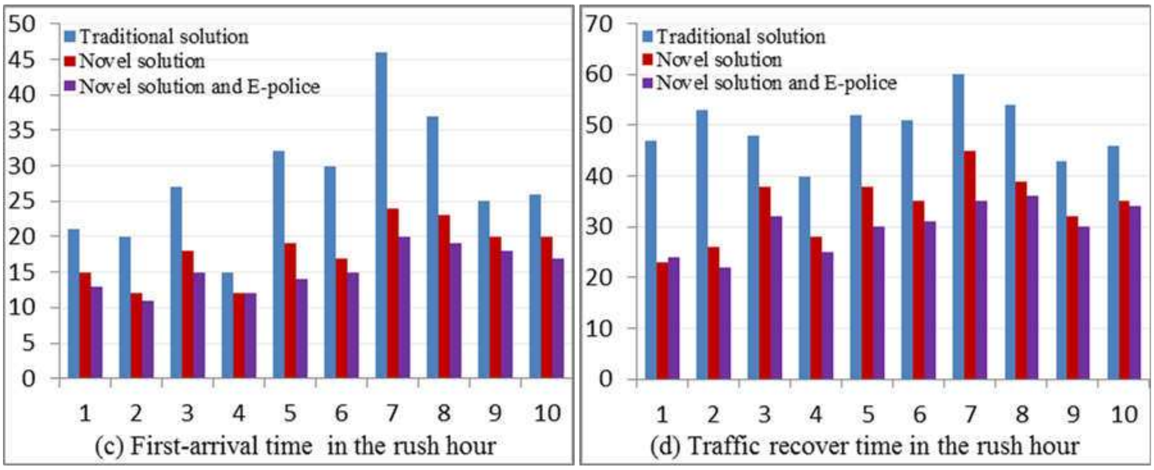


Figure 5. The comparison of consuming time in rescue action (units: minute)

4. Discussion and Future work

The rapid road accident rescue has achieved a great success with the help of the proposed architecture, but there still exist some key technologies that need to be addressed respectively. We focus on four aspects (vehicle localization, data pre-fetching strategy, traffic prediction, and traffic lights control) to state the challenges and possible solutions.

4.1 Vehicle Localization in Urban Environment

With the growth of urbanization, the dense skyscrapers have impacted on GPS-based localization, and therefore the high-reliability GPS-free localization need to be addressed. The ultra-dense networks, one of the key technologies of the 5G network, are expected to operate under the coverage area of multiple BSs simultaneously. This technology brings a new opportunity to provide localization services for vehicles. Firstly, the direction-of-arrival (DOA) estimation method based on the 5G antenna array is feasible. Secondly, the received signal strength can be utilized to estimate the distance between vehicle and BSs. Thirdly, the millimeter waves of 5G have a higher bandwidth and more severe propagation losses, which enable time-of-arrival (TOA) estimation with high accuracy. Finally, as the MEC server is placed at the edge of the vehicular network with the near real-time response speed, the vision-based localization method could be used. The vehicle-centric localization is gradually replaced by network-centric localization due to the higher accuracy and better robustness.

4.2 Predictable Data Pre-fetching

The mobile vehicles are typically subjected to network fluctuations and intermittent downtimes, which lead to an unpleasant experience. Hence, in order to compensate for the link disconnection, it is important to pre-fetch and buffer the data in local. In order to further enhance the responsive speed, a two-tier predictable pre-fetching strategy is proposed as the vehicular traverse route can be predictable. First, the MEC server pre-fetches the entire traffic data from the previous MEC server and RCCS simultaneously through high-speed optical networks. Second, the vehicles pre-fetch the data from the MEC sever. The location-based predictable pre-fetching strategy can efficiently decrease the latency in data transmission, enhance the responsiveness of urban-traffic management system, and improve quality of user experience.

4.3. Traffic Prediction

With the widespread installation of on-board and on-roadside sensors, the huge amount of traffic data is collected. The objective of traffic prediction is to utilize the massive historical and real-time data to mine the trend of traffic flow in near future time and guide route plan for drivers. In past, some prediction models have been developed with a small amount of traffic data collected in a specific small area, and the accuracy of traffic prediction is dependent on the traffic-flow features embedded in the collected spatiotemporal traffic data. Practically, these models have not get success. Recently, the big data is increasingly being used to analyze global problems and find solutions using the massive data, Yisheng Lv et al. have proposed a novel prediction model based on deep learning algorithm to alleviate the traffic congestion [14]. This model has the ability to improve traffic conditions and reduce travel delays. The proposed architecture is more suitable for the deep-learning-based prediction model. Firstly, the active and passive traffic data is more comprehensive than ever. These massive data can help the models to discover the latent traffic-flow feature such as the nonlinear spatial and temporal correlations from the traffic data. Secondly, the low latency make the model be easier to utilize the real-time traffic data. Thirdly, the cloud sever is divided into MEC cloud server and RCCS in proposed architecture. As real-time responsive tasks are turned to the MEC server, RCCS can be dedicated to deep learning calculation, the prediction performance is better.

4.4 Intelligent Traffic Lights Control

The traffic lights controller is designed to ensure that the traffic flow moves as smoothly and safely as possible, whilst the pedestrians are protected when they cross the intersection. Some researchers have long used historical data to create signal plans that optimize the "green time" to improve traffic flow with sophisticated systems using different plans for different times or day. As accommodating to the practical dynamic traffic condition is difficult, the existing traffic lights control strategy is unable to adapt real-time response with the change in traffic flow.

Fortunately, the SDN-based heterogeneous network and the MEC technologies shall reform the way of data collection. Firstly, the vehicle actively reports its status and environmental information including trajectory and route. Secondly, the high-definition camera and high-performance sensors are deployed to take high-quality video or raw traffic data, whilst the delay in data transmission and processing can be constrained within near real-time. In addition, the non-motorized, such as pedestrians, can be identified and timely counted by camera. Based on the new traffic data collection system, the advantage of traffic light control service can make the traffic flow more smooth and efficient. At heavy intersections, this can extend the “green time” and offer preference to the longest line of vehicles.

5. Conclusions

The urban-traffic congestion is becoming a difficult problem, and has intrigued many researchers to find effective solutions. Fortunately, many emerging technologies have the potential to alleviate traffic congestion. Firstly, the SDN-based heterogeneous network with the convergence of VANETs, 5G wireless network, and SDN technologies can provide high-bandwidth and low-latency communication services along with programmability. Secondly, the MEC cloud server offers a real-time or nearly real-time response speed for critical missions. Finally, the RCCS can run deep learning-based prediction algorithm with high-performance computing power and ultra-large storage space. The proposed architecture may decrease the traffic congestion, and boost the capability of urban-traffic management. The paradigm of the rapid road-accident rescue application has validated the feasibility and high efficiency of the proposed framework.

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