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Sustainable Framework for Smart Transportation System: A Case Study of Karachi

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Abstract
In this paper, a framework of smart transportation system is proposed, aiming to address the transportation problem in Karachi city. In modern day world, the mega cities and urban areas are on the edge of transformation into smart cities. With the advancement of engineering and technology, smart cities are designed to integrate and utilize these scientific innovations to provide smart solutions and social innovations for sustainable infrastructure, thus they are able to provide its resident highest quality of life by utilizing its resources effectively. One of the major application of smart cities is the Smart Transportation System, which provides safer, quick, environment friendly service to the residents. Thus, this study highlights the current traffic situation of Karachi and propose a framework to transform it into a smart transportation system. In order to have a smart transportation system, it is necessary to have in-depth knowledge and information about the city dynamics and its traffic related issues. Therefore, this study also highlights current traffic situation of Karachi, its road conditions and capacity, vehicles condition, alternate mean of transport (other than road-based system) and its present condition, and finally proposes a framework to develop a smart transportation system while keeping in mind the aforesaid traffic problems.

Keywords Smart cities · Smart transportation · Smart solution · Smart technologies · Sustainable transport infrastructure

1 Introduction

United Nation published a report about the world population, which clearly shows that the urban population of the world in 2010 was 2.6 Billion, and it is estimated that it would rise to 5.2 Billion by 2050, making it almost twice as compared to 2010 [1]. If the urban population increases with such a pace, then it would be very difficult for leaders, who govern the cities, to provide a quality life for its residents. Thus, it becomes a necessity for the administrators to develop such policies which lead to enhance the city performance and quality of life. This theory provides the basis to make the Cites Sustainable and Smart, hence, termed as Smart Cities. The concept

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of the smart city is broad, but the aim is to have a socio-economic atmosphere for the residents, and other institutions in order to utilize the city resources effectively and efficiently and to provide highest urban living quality [2].

The concept of Smart City receive the utmost attention of the researchers from various domains and explore different kind of approaches which can be integrated within smart cities, but Information and Communication Technologies (ICTs) remain fundamental for smart city development, putting emphasis on improving the city's existing performance, logistics, and socio-economic conditions.

Subsequently, the development of smart cities heavily relies on robotics, advanced ICT, and smart solutions, which ultimately pave the way towards smart and automated services, thus enhance the city performance, infrastructure and living standards of its residents. Another main feature of a smart city is to provide cheaper infrastructure and related services with good performance [3]. Thus, it can be said that the ICT solutions and its combination with smart city services, collectively determine the design, quality, and operation of the smart city.

Moreover, the most common problem which is faced by urban settlement around the world is traffic congestion. The traffic congestion can be caused by various reasons at any given interval of time, such as increase in number of vehicles is certain area at certain interval of time (mostly during office hours or school/college disassembling times), or due to some roadside accidents, or due to some construction related work, thus, the traffic authorities require special arrangements for such events [4]. This leads to their search for a solution that not only manages but also decrease the traffic congestion in an efficient manner. The smart city can provide a cost effective and reliable solution to traffic congestion problem, and thus, termed as Smart Transportation System [5].

Now, in order to develop a Smart Transportation System, it is necessary to mark those areas in the city where traffic flow is higher, its road status and capacity, the cause of traffic congestion, number of vehicles and etc. It's necessary to have availability of real time data of these factors, otherwise static cameras are still in operation in urban areas but they lack real time communication, and therefore they don't fulfill the smart transportation job, whereas, in case of smart transportation system, real time data and surveillance is available, thus providing live coverage of traffic congestion sectors and its surrounding areas.

Traffic congestion is also caused by uneven parking at roadside or when multiple vehicles maneuvers around the area to find a parking location. Additionally, in case of some event, the drivers usually maneuver around the event location several time, mostly at a slower speed, in order to find a parking location.

On the other hand, the traffic congestion problem is one of the main sources of pollution and environmental damage in urban areas. It is estimated that the pollution from the transport division will be twice in 2025 [6]. Thus, the study proposes a smart transportation framework, primarily focused according to the traffic congestion problems in Karachi City. The proposed idea not only provide a concept to transform the city transport infrastructure into Smart Transportation System but also reduce the environmental pollution in the city.

The rest of the paper is organized into eight sections. After the Introduction in Sect. 1, the smart city concept is presented in Sect. 2, followed by smart technologies in Sect. 3. Section 4 discusses the smart transportation system, while Sect. 5 presents transport related issue in the Karachi city. Section 6 presents the proposed smart transportation system framework, whereas Sect. 7 presents its analysis, and finally conclusion is given in Sect. 8.

2 Concept of Smart City

The basic concept of the smart city is to uplift the living standards of its residents, the city resources are utilized in an effective manner, rising the sustainability, and thus improving the city environment, by using different optimization approaches, innovations, and comparison of past and present real time data. Moreover, smart variables such as transport and mobility, environment, economy, residents, living, and tourism, determines the degree of smartness for any city.

There are numerous causes that influence different cities around the world to become smart city [7], such as raise in city population, deficiency in the availability of empty areas, deficiency in the resources, and focus on efficient use of energy, economic development, and sustainability of the environment.

In a smart city, distributed sensors infrastructure having firm network architecture with appropriate communication technology is deployed in order to collect data from various locations around the city, such as traffic data, weather information, energy grid, and etc. [8]. The communication technology is either wired or wireless or both of them. In a majority of the cases, the communication technology may consist of

- *Fiber Optic Network* It acts as a backbone of communication network due to its characteristics of high bandwidth, security, and reliability, low attenuation and interference.
- *Wi-Fi Communication* Smart cities are now going through Wi-Fi connectivity to interconnect their resources. Mostly, Wi-Fi networking is deployed for the smart transportation system, to interconnect vehicles, or traffic signals, or lampposts, due to its limited bandwidth.
- *Cell Based Communication* Presently, with the advancement in smartphones and cellular communications (3G, 4G, 5G, and LTE), cell based communication are now become vital for smart cities due to its wide bandwidth, and large distributed cellular infrastructure. Cell based communication is playing a pivotal role in the smart transportation system, including transport sharing apps such as Uber, Careem, and etc. Furthermore, present-day smart transportation system use V2V for inter-vehicle communication, but in future, 5G can replace it as faster and reliable platform.
- *Dedicated Short-Range Communication (DSRC)* DSRC is specifically designed, as a radio based communication having short to medium range, for smart transportation system offering V2V connectivity.

The selection of communication technology depends on the particular application and requirement. Moreover, aside from smart city advantages, there exist some obstacles which inhibit deployment of smart solutions, nevertheless three major issues consist of

- *Insufficient Exchange of Data* Many smart cities are deployed in such a way that they are unable to exchange data with other cities, thus making them expensive.
- *Dissimilar Criteria* Every city have different dynamics with respect to other, therefore smart cities are deployed by considering these dynamics, this results in different approaches, which may sometime oppose each other.
- *Inadequate Scalability* The scalability of smart technologies such as IoT and CPS, which act as a foundation for any smart city application, is also a big barrier.

Furthermore, shortage of resources, priorities, technical expertise with adequate experience are some example of barriers in smart city deployment.

3 Smart Technologies

The smart cities require integration of other smart technologies with smart city services such as big data analytics, cloud computing, wireless sensor network, fog computing and Internet of Things [9].

In order to improve the process of decision making by extracting the useful information from a large pool of exponentially increasing data obtained from the process of examination, conversion and cleaning of information raises the requirement of Big Data analytics. Thus, it can be used to analyze data from different services of smart cities and hence enable smart decision making process.

Cloud computing enables the users to access the shared computing resources via a standard protocol. One major advantage of cloud computing is the ability of on demand scaling of computing. Cloud computing can provide various services related to the smart city such as autonomous decision making, machine learning, simulation, storage and etc.

Wireless sensor network (WSN) is a distributed sensor architecture design to monitor various physical phenomena in real time, such as heat, pressure, sound, and etc. As far as smart cities are concerned, WSN is used to monitor various resources of the situation and real time situation such as traffic density, pollution, electricity consumption, water supply, and etc.

The architecture of Fog computing provides localize service for IoT applications by using devices such as a computer, router and etc. The services may include monitoring, storage, security, communication, real time answers and etc. In smart cities, for computing nodes are distributed throughout the city.

Internet of Things (IoT), enables physical device network i-e sensor, vehicles and etc., to exchange message and communicate with each other, thus, in smart cities, IoT can be used to integrate various devices in the smart city network, and called IoT smart city applications.

4 Smart Transportation System

The smart transportation system is composed of various sensors designed to conduct different sensory operations [10]. Generally, smart transportation system uses following sensor technologies.

- The detection of Traffic volume and accidents, automobiles type, and their presence, and the speed are performed by Loop detectors.
- The detection of automobiles flow and their presence, and the speed are performed by Microwave radar. Radar mounted on a vehicle can also be used for detection of hindrance and automatic cruise control.
- Automobiles type and its characteristics can be determined by using IR sensors via echo measurement.

- Intra-vehicle safety information sharing is proved to be very effective for the smart transportation system and can be performed by using bi-directional Vehicle to Vehicle (V2V) communication offered by DSRC radio.
- In order to monitor traffic, their presence, and red light compliance, a vision based system is necessary, such as cameras.
- For autonomous vehicles, Obstacle detection and navigation is performed by Light Detection and Ranging (LiDAR).

In order to provide safer, efficient and quick transport service for goods transportation, and to the city residents, the transportation system is now transforming into smart transportation system via V2V, V2H, and V2I communications, in addition to the automobiles automation and their respective communication structure. The concept of Smart Transportation System is shown in Fig. 1 [11].

The older and conventional type of automobiles lacks the ability of communication with other vehicles or transportation infrastructure in the surrounding, while advance automobiles have various kinds of sensors installed in them serving various operations such as cruise control, emergency braking, different warning functions including blind spot, lane departure, and rear cross-traffic, thus offer safety and mobility. Additionally, more advanced automobiles enable drivers to connect with cloud services via Drivers assistance systems.

Moreover, it is predicted that the next decade will be of automated automobiles integrated with multiple sensory technologies, navigation, control and motion planning

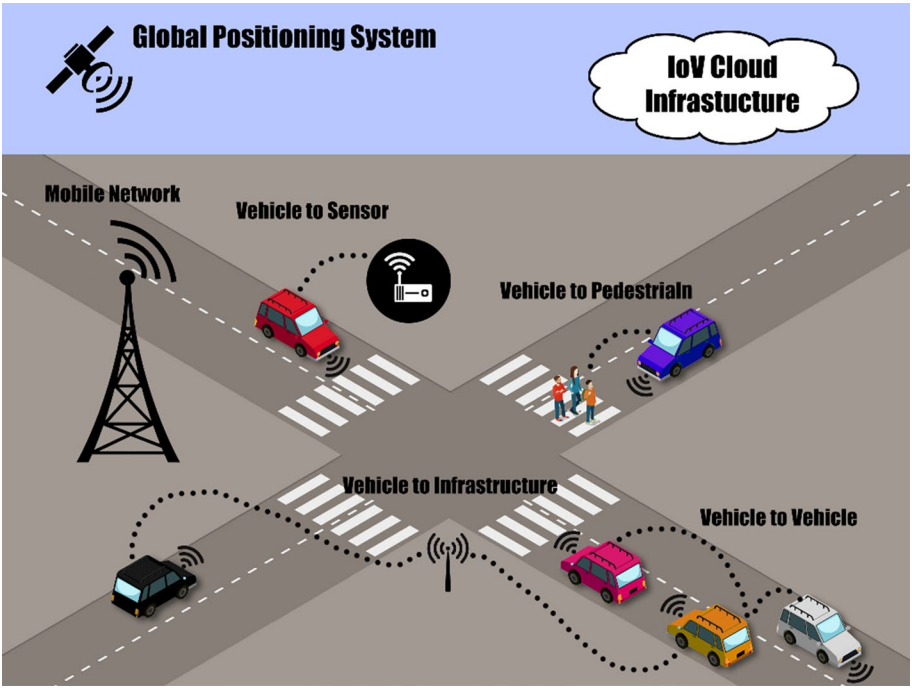

Fig. 1 Concept of smart transportation system

algorithms to support unmanned transportation, such that sensory technologies provide obstacle avoidance along the route, navigation gives route planning from origin to destination, and motion use sensory and navigation output to develop automobile route for the next time [12]. Navigation gives route planning from origin to destination such that it can give guidance about stays or change the lane, accelerate or brake the vehicle, turning the vehicle around and obstacle avoidance en route to the destination.

Other than vehicle based communication technologies, smart transportation system also requires that the transport infrastructure must be upgraded by incorporating different technologies which enable it to make a level based conditions using the data obtained from different sensors, thereby improving safety and system performance [13].

5 Transportation Issues in Karachi

Karachi, being the city of more than 14.5 million people (2017 Census), and Pakistan's financial and business capital, holding biggest and busiest port of the region fulfilling the trade needs of Pakistan and central Asian countries, is the biggest city of Pakistan. As with other big cities of the world, Karachi is also facing the problem of traffic congestion and its related environmental pollution [14]. The traffic congestion problem in the city is multi folds such as uneven urban expansion, old transport design, road's capacity and etc. Thus, the city needs urgent deployment of a smart transportation system to provide a reliable and sustainable transportation system to the peoples of this megacity, which can overcome the aforesaid problems. In this study, we propose a simpler and well-organized framework that can address the traffic congestion problem of the city and thus overcome environment issue too.

Implementation of Smart transportation system has now become very important for Karachi due to personal motorization culture caused by a high income of its people [15]. On the other hand, the existence of old transport planning and policies leads to traffic jams which ultimately cost fuel and travel time, and pollution, thereby significantly disturb the city's environment.

Moreover, the rise in city population (as much as 35% since 1947), and uneven latitudinal expansion of the city are major factors in the traffic congestion. This increase in city population and expansion of the city reflects the urgency of smart transportation.

The Government approved a development plan for Karachi city, as much as 5 times, since 1949, but nothing formulated [16]. Consequently, the city now faces the problem of poor public transport, lack of fresh water supply, frequent electricity breakdown, and housing facilities. The lack of housing leads to squatter settlers having poor socio-economic conditions. These squatter residents are mostly poor and rely on cheaper, ill-maintained public transport.

Furthermore, the present traffic condition of the city is highlighted by the fact that the city's transportation totally relies on road based system, as Karachi Circular Railway (KCR) ended its function in 1999 [17]. Thus, the increased population put too much pressure on the present motorized transport facilities, therefore causes a tremendous increase in the roadway organization. The city has approximately 7400 km network of road, this yields road area of 207 km per 100 km^2 region. Now, with this limited capacity of the road, the problems of road maintenance, delays in repair, construction quality, also leads to the traffic congestion problem. Also, there are certain areas in the city where the influx of residents are high at the same time (usually office hours), with limited link road choices,

and this situation became worse in those areas where there is roadside parking or encroachments, thus, once again cause traffic congestion.

In Karachi, the private sector holds a major share of road transport as compared to Government sectors, thus can't catch up with the standard of travel demands [18]. Generally, the road transport share of the city reflects only 2% of the total vehicles running on the road at given time, serving the demand of only 50% population of the city, which still faces the problem of traffic management. Furthermore, this lack of public vehicle problem is further increasing due to the capacity of vehicles operated in the city, which mostly comprise of minibuses and coaches having a capacity of 27 and 32 passengers respectively.

One common solution to the traffic congestion problem in megacities is the alternate mean of transportation such as the Metro Train service. In 1964, KCR projected was started in Karachi, which provides cheaper and quick transport service to the resident of Karachi, and it is estimated that about 0.3 Million people use KCR daily till 1978, but from 1979 KCR started to decline due to lack of Government interest in maintain the railway crossings, stations and associated infrastructure which eventually lead to regular delays in train arrival and departure, thereby decreasing its travelers [19]. According to Pakistan Railways, in the 1970s, KCR operated 104 daily journeys which drop to single trip in 1999, this openly reflects the decline in KCR operation, and finally concluded its operation with more than RS.6 million ($0.1 million) loss annually.

Urbanization and Motorization can be seen as parallel to each other, thus whenever a city starts to expand, the level of motorization also increases, thereby increasing the requirement of sustainable and adequate Government policies and technological advancements to manage the traffic, but in case of Karachi, it lacks all the aforesaid policies. Aged and poorly maintained vehicles also contribute to the road safety and environment which also lead to traffic jams, and escalation in noise and air pollution.

6 Framework for Smart Transportation in Karachi

Traffic congestion occurs when the number of vehicles at any given time exceeds the road capacity, thus causes a traffic jam. Smart cites not only provide a solution for urban smart transportation management to avoid traffic congestion, but also suggest alternate routes that help to keep continue the traffic flow and avoid any jams [20].

Karachi has seen a drastic rise in its population in the last decade, which leads to uneven development in the city infrastructure that narrow's its road capacity, and at the same time, facing rise in motorized flow on its road network, and now it's becoming difficult for traffic authorities to manage the traffic flow, day by day. Thus, it becomes the necessity of the city to deploy a smart transportation system that can effectively meet its traffic demands, or else the city residents will face adverse effect related to its transport sector. Once the infrastructure of smart transportation is deployed in the city, the need for smart vehicles will also increase automatically. Generally, for Karachi city, smart transportation can be deployed in several ways, such as smart light, smart toll collection, and etc.

Apart from advancement in vehicle technologies, the overall transportation infrastructure is getting more and more advance due to the influx of smart technologies, thus making the system able to detect, accumulate and exchange data, hence provide real time traffic estimation and assist in traffic flow, and safety. The proposed framework of smart transportation for Karachi is shown in Fig. 2.

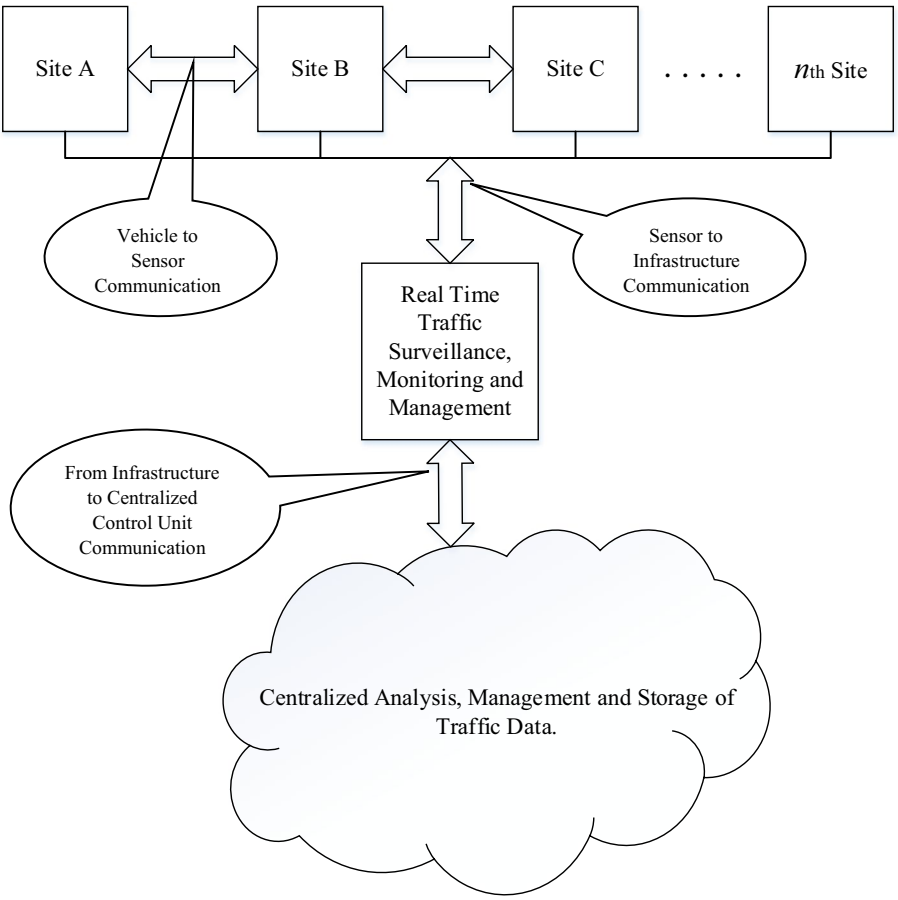

Fig. 2 Proposed framework for smart traffic monitoring

Figure 2 shows the proposed concept of the transportation system. It can be seen that the framework is modeled according to the dynamics of Karachi i-e the city is divided into different administrative zones so as the framework. The system manages the city traffic in coordination with the autonomous sub-systems involved, which is further connected with the centralized traffic data management system, acting as a junction for information and data collection, and then convey information to the residents and suggest solutions to traffic congestion at a particular site and guide to an alternate route.

Moreover, since Karachi city is divided into the zone, therefore the autonomous sub-systems is responsible to collect data from different zones across the city. The subsystem receives data from the cloud data deployed at a particular site. Whereas subsystem represents WSN, network layer, data layer while zone represents real time data monitoring and collection, its storage, and processing. The zones are able to communicate with each other so that they have information of traffic flow of its neighboring zone.

7 Numerical Analysis

For an effective approach of proposed infrastructure, the mathematical analysis is important. However, the femtocell technique is better than other techniques for this kind of work. This research proposed technique only for 5 femtocells which can be enhanced further in future. The one in five femtocells is a leader and remaining configured as followers. Furthermore, the parametric configurations including channels gain are presented in the coming section.

- Capacity of proposed model

The communication delivery time required for the leader and follower nodes with maximum toleration with respect to vehicle speed is presented in Fig. 3. This graph shows the variation in the pair response when the number of vehicles reaches to 10, according to a given formula [21],

$$\sum_{i=1}^{N} p_i g_{i,0} \leq Q$$

While vehicles dynamics are given as

$$\frac{dv}{dt} = a\left(1 - \left(\frac{v}{v_0}\right)^{\partial} - \left(\frac{s^*(v, \Delta v)}{s}\right)^2\right)$$

Where

$$s^*(v, \Delta v) = s_0 + vT + \frac{v, \Delta v}{2\sqrt{a}, b}$$

Here v is the speed of ith vehicle in meter per second, Δv is a change in speed with respect to the neighboring vehicle, s is the net distance (in meters), between an ith vehicle and its corresponding vehicle in the front, and ∂ is an acceleration in m/s^2.

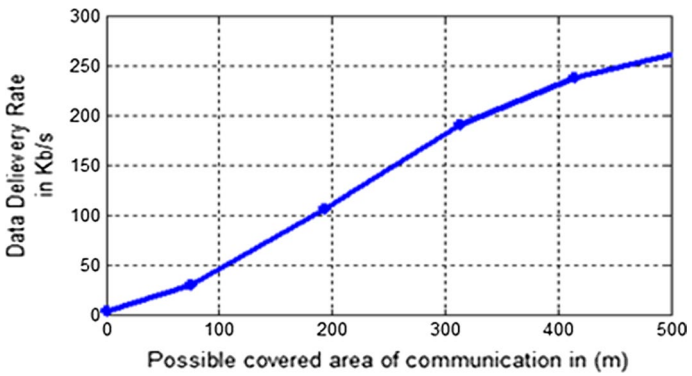

Fig. 3 Delivery time

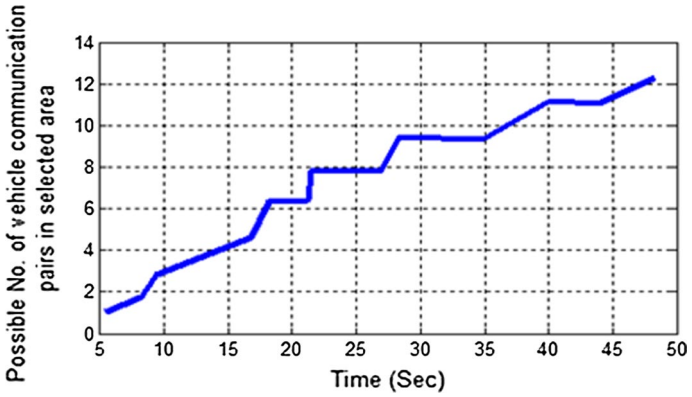

Fig. 4 Average neighbor in given time

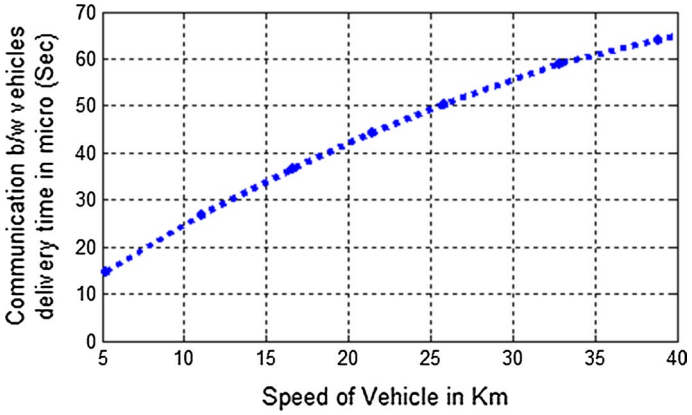

Fig. 5 Delivery of data in a given area

In Fig. 4 average neighbors per vehicle with respect to time is shown. Each pair consumes microsecond for the communication to inform about the traffic condition around their neighbors. As the traffic increases the average neighbors per vehicle also increases.

In another graph, the data delivery rate vs. covered area is presented. As soon as the distance between the communicating cars increases, the data rate drops exponentially. Around 500 meters range all the communicating car is shown in Fig. 5.

When there is fog between the communication cars, the data lost and error occurred in communication. Least no of vehicles are responsible for least data error rate in foggy condition. The variation in the graph shows between cars with and without fog is presented in Fig. 6.

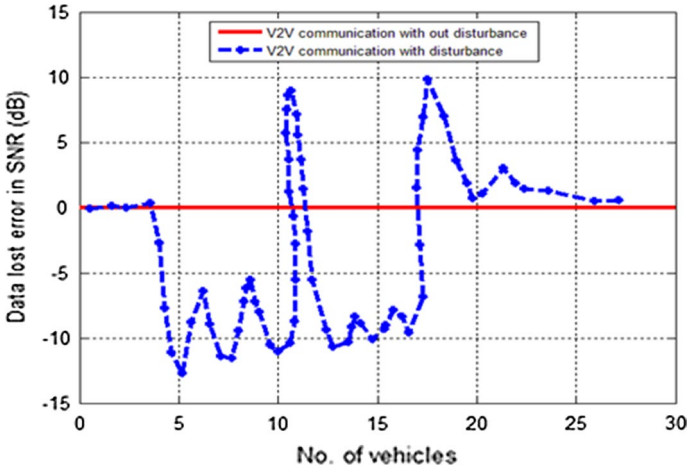

Fig. 6 V2V communication in foggy environment

8 Conclusions

In this paper, a case study was presented which uses the largest urban settlement of Pakistan i-e Karachi, facing unorganized and traditional mean of transportation. The study highlights the transportation problems in Karachi, and make it clear that the city is facing a crisis in its transportation sector, and there is almost zero percent of Government intent, or policies, or Private sector investment, to develop this sector. Therefore, it is the responsibility of city residents to explore the problems and presented some solution which can help Government or Transportation policymakers, thus, the presented work then propose a solution by developing a framework, about the transformation of existing transport structure into smart transportation. The framework is designed by carefully examining the dynamics of Karachi, especially those areas where the heavy flow of traffic exists, round the clock. Moreover, the study also considers different smart communication techniques which enable bidirectional flow of data, thus providing the driver a current traffic condition and related data, en route to its destination. Therefore, it can be concluded that the proposed study can provide a smart transport solution to its present problems, and may become the first drop of water for its future smart transportation system.

There are three possible types of communication available in the transportation system, i-e Vehicle to Vehicle (V–V), Vehicle to Man (V–M) and Vehicle to Sensor system (V–IS). In this research, Vehicle to Vehicle communication is proposed for smart transportation system using pair formation of cars via wireless communication. In Pakistan, only Japanese cars have certain frequency bands for communication but it does not match with frequency bands operated in Pakistan. If this frequency bands matched then smart communication will be much easier. In future, the other types of a communication system can be used for this purpose in which vehicle can communicate to the cell phone for V–M and Sensors for V–IS communication.

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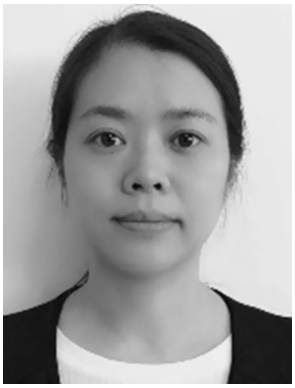

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