Performance Analysis of LTE Smartphones-based Vehicle-to-Infrastrcuture Communication

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Abstract—**With an increase in number of vehicles on road, applications and services offered by Intelligent Transportation System are growing in demand. However, there are still coverage and capacity limitation of wireless links that support such services. In this work, we address a new and novel concept that leverages 4G network for vehicle-to-infrastructure communications. Instead of considering on-board units communication interface, we make a case for using smart-phones as economical alternative given that an interface exists between vehicle navigation system and smartphone. The applications considered in this paper are broadband internet access and entertainment applications (video streaming etc.) We provide performance analysis results using LTE-simulator. Our high-level conclusion is that smartphones enriched with LTE capabilities are feasible for vehicular communications given that fourth generation network penetrates market rapidly.**

Keywords-component; LTE, Vehicle-to-infrastructure communication, Smartphones

I. Introduction

Vehicular communications are becoming increasingly popular as matured wireless link technology (IEEE 802.11p, Wi-Fi, 3G, WiMAX, and LTE) is paving the way to unlimited opportunities for vehicle-to-infrastructure applications [1]. Until recently, a lot of research work was done focusing on road safety applications such as accident warning, vehicle-to-vehicle distance warning, traffic jam information, etc. In modern-day societies, the amount of time people spend in vehicles is increasing day by day. Therefore, the next step in Intelligent Transportation System (ITS) is online vehicles, which are connected to internet. Consequently, the broadband internet access, video streaming and gaming are emerging vehicular applications.

Recently, the converged wireless access for vehicular communication is investigated in [2][3][4]. However, the high cost of vehicle's on-board unit (OBU) can hinder the widely usage of such converged wireless platform. In general, there are three modes of vehicular communications. These are vehicle-to-vehicle (V2V), vehicle-to-roadside unit (V2R) and vehicle-to-infrastructure (V2I) communication. The applications and services considered in this paper relate to V2I.

Specifically, in this paper we address vehicular applications such as broadband internet, information and entertainment applications accessed through fourth generation networking technologies such as LTE [6]. In doing so, we answer this question: *Is it feasible to use LTE smartphones inside a car and still able to achieve all functionalities such as high-speed internet access and video streaming?* The authors in [5] conducted research and found out that smartphones are feasible to utilize for vehicular ad-hoc networking, however only in high-way scenarios. Furthermore, the study performed on 802.11g interface of smartphone rather than testing its 3G functionalities. Taking a step further, in this work we investigate about feasibility of LTE smartphones for V2I communications.

The cell phone has great benefits; however it is also cause of distraction on road-way. For example a National Highway Traffic Safety Administration reported 995 fatalities and 24,000 injuries occurred in 2009 as result of cell phone usage [7]. One possible solution is to ban use of handheld cellphones while driving, however this may stop endless possibilities that can be achieved with smartphones beyond call and messaging services. Following the launch of iPhone 4S in October 2011, financial times cite that 657 million smart phones will be sold in 2012. Moreover, IMS research predicts the numbers to go up-to 1 billion by 2016 [8].

Having said previously, the ubiquity of smartphones brings new applications to smart vehicular domain. In 2010, the number of vehicles on roads worldwide surpassed 1 billion that will eventually come much closer to number of smart phones during next decade [9]. Our contributions in this paper are as follows:

a) Our work is among the very first who intoduced the concept of LTE smarthphone based vehicle-to-infrastructure or internet communication. This has commerical appeal for motorway authorities, mobile companies and telecom operators.

b) We use the fact that smartphones are becoming ubuiqtious and their usage may be limited inside vehicle unless they are meant to interact with vehicular on-board system via USB port (Android) or Bluetooth (iOS).

c) We show that LTE network for vehicular communication obtain better throughput, low delay and packet loss as compared to 3G network and Wifi.

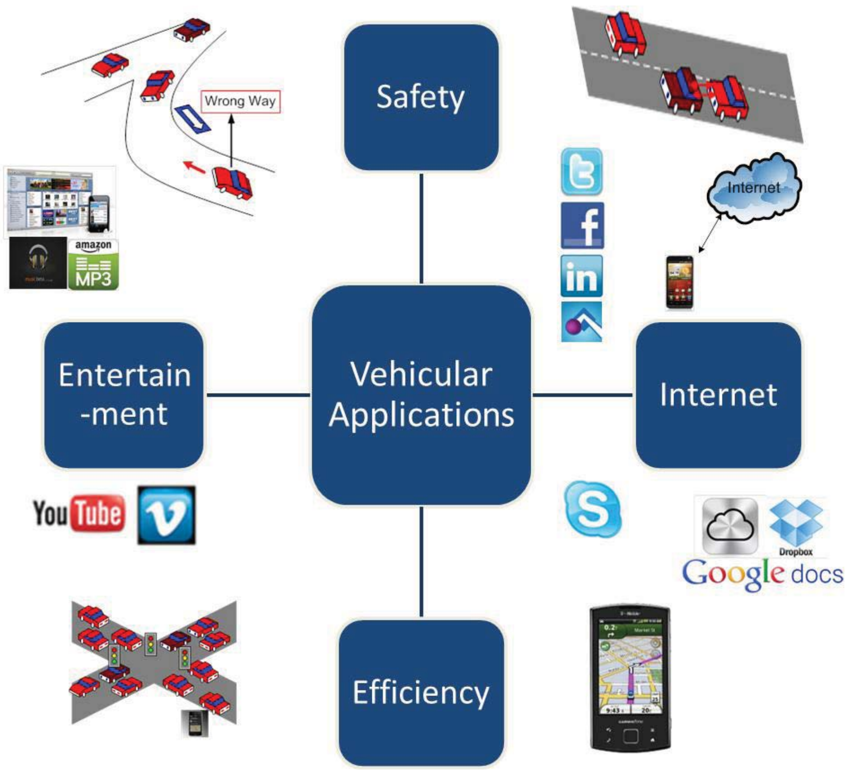

Figure 1. Vehicular Applications

d) Lastly, our work provides an envision of online vehicle; a vehicle that has permanent internet conenction and opens up new application domains for third party vendors and developers.

The rest of the paper is organized as follows: In Section 2, we discuss applications and services that are making vehicular communications increasingly popular. We provide related work in section 3, followed by proposed architecture in section 4. The performance evaluation of proposed system is given in section 5. Finally, we discuss results and provide conclusion in section 6 and 7 respectively.

II. MOTIVATING APPLICATIONS

The wireless technologies mentioned above are either short-range (DSRC, Wi-Fi) or long-range (cellular, LTE, WiMAX). The motivating factor behind advance Intelligent Transportation System (ITS) is wide range of applications and services as shown in figure. 1. These can be divided into following three categories.

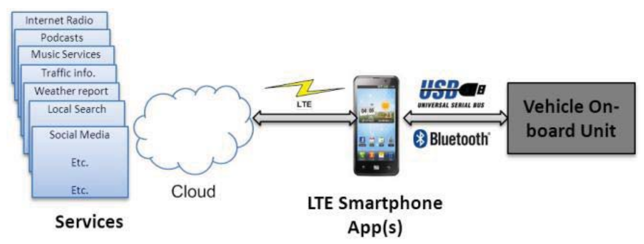

Figure 2: Accessing Infotainment services from Cloud

A. Safety:

Traditionally, the envisioned ITS applications were safety-related. These include but are not limited to, collision avoidance, wrong-way indication, accident warning, lane-change warning etc. These applications are critical and require certain allowable latency and communication range. For example lane change warning, collision detection, and accident warning permits maximum latency of 100msec, however they are provisioned for 150m, 300m and up-to 1000 meters communication range [10].

B. Traffic Efficiency:

The efficiency applications are real-time traffic congestion information, routing and navigation information etc. For example, based on driver's history, the navigation service gives an estimated time for reaching the destination. These also help traffic controlling authority to smoothen the flow of traffic.

C. Internet and Infotainment:

Infotainment applications are entertainment and information services. *What is next in this domain?* An online car that enables driver and passengers to access broadband internet, information and entertainment services inside car. The applications include internet acess (email, web), social networking, personalized location-based and context-aware services, video streaming, Voice over IP (VoIP), online gaming, content sharing and downloading, GPS map updates etc. Each of the aforementioned applications has different QoS requirements which we give in section 4. We assume that web services and data is hosted inside cloud platform, therefore they are consistently updated. A general architecture for accessing infotainment services from cloud is shown in figure.2.

III. Related work

There are numerous works in literature that are related to V2V and V2R communications. A good survey of these works is given in [11]. European Union has been very active in sponsoring projects of Vehicular Ad-hoc NETworks (VANET) and its applications. A brief comparison of European projects such as COOPERS, CVIS and SAFESPOT is provided in [12]. An interesting point to note here is that all of previous mentioned projects focused on safety-related applications either using short-range (IEEE 802.11p, Wi-fi) or long-range (Cellular) communication platforms.

Content sharing and downloading is another promising application investigated in literature [13][14]. Smartphones embedded sensors can be used to collect raw data and later transmits this information to cloud where it is utilized for modeling, prediction and analysis purposes. The most notable of work in this regard is CarTel project by MIT [15], specifically, targeting applications such as road-surface monitoring and traffic delay estimations.

As mentioned earlier, vehicular communication, especially vehicle-to-infrastructure, use several wireless technologies. However, they are either capacity limited or coverage limited. Scalability is another issue considered in such platforms. For example wireless access in vehicular environment (WAVE) system is coverage limited, but it scales well and provides ample capacity. On the other hand, the Universal Mobile Telecommunications System (UMTS) is capacity limited but scales well in terms of geographical coverage [16]. In contrast, we consider fourth generation high-speed telecommunication network (LTE) in this paper that is envisioned to replace current cellular networks (GSM and UMTS).

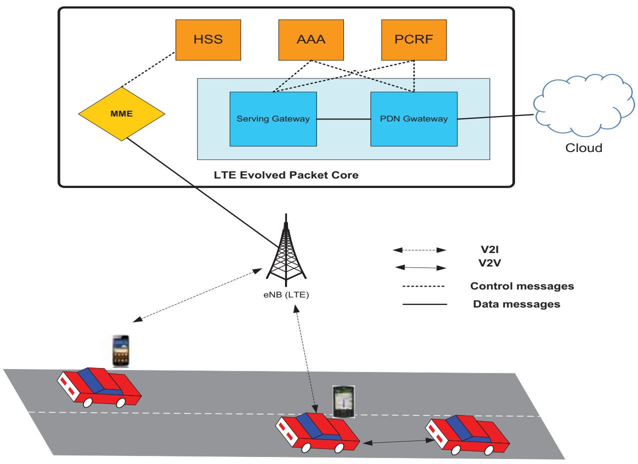

Figure 3. LTE Smartphone-based Vehicular Network

In past, significant work has been done on safety critical applications that fall under circa of V2V communications. But this may not be enough due to intermittent connectivity issues. Therefore, in order to improve vehicular communications especially routing process, the usage of 3G capabilities for VANETs are investigated in [17]. Consequently, this results in improving routing process and ultimately enhancing packet delivery ratio. Furthermore, a measurement study was performed in [18] for using Wi-Fi networks for vehicular internet access. They found out that it is suitable to use Wi-Fi network for variety of applications, however intermittent connectivity and low data-rates are main drawbacks.

This draws attentions of research community towards comparison between Wi-Fi and 3G networks. The authors in [2] provide a head-to-head comparison between WiFi and 3G network in realistic scenarios. They concluded that 3G network for vehicular network access are characterized by vast coverage and low throughput. On the other hand, Wi-Fi network outperforms 3G networks in terms of throughput when connected. However, it is not efficient in fast speed mobile scenarios such as high-ways.

Recently, there is work that advocates about integration of 3GPP LTE and 802.11p networks for seamless connectivity in VANETs [4]. The 3GPP network establishes connection with vehicles and 802.11p is used for ad-hoc routing incase vehicle out of base station range. Taking necessary steps ahead, an LTE connected car is on verge [19]. This all discussion suggests that advance ITS will be based on connected vehicle infrastructure concept [20] where potential wireless technologies such as 802.11p, Wi-Fi, GSM, 3G and LTE have crucial role to play.

Our approach is novel in the sense because we consider LTE capable smartphones for establishing vehicle-to-infrastructure communications that will earn revenue to both motor-way authorities as well as telecom operators.

IV. Proposed Architecture

In this work, we focused on LTE network due to its recent popularity and deployment as an alternative to wired broad band network. The simplified architecture of LTE smartphones-based vehicular network is shown in figure 2. Note that we assume high-way scenario throughput the paper, however, urban scenario is our future work. An LTE network is characterized by e-node B (eNB) and an evolved packet core (EPC). The driver and passengers inside vehicles moving on high-way are possessive of LTE smartphone. In case of driver, the smartphone is attached to vehicle on-board system through a proper interface.

Let number of users denoted as N. Note that users N can either be passengers or driver himself. Let throughput, packet loss ratio, and delay of QoS class or service under consideration represented as T, PLR, and d respectively. The whole process works like this: A user connects to an eNB while driving on high-way and requests subscribed or free service using smartphones. The eNB forwards request to PDN gateway, and after authenticating user, it establishes a flow or connection for data transmission. The QoS parameters are

QCI	Resource Type	Priority	Packet Delay	Packer error loss ratio (PLR)		Mapped Services
1	GBR	2	100 ms	10^{-2}	M A P P E R	Conversational Voice (Voice over IP Class)
2		4	150 ms	10^{-3}		Conversational Video (Video Class) Services : Skype
3		3	50 ms	10^{-3}		CBR Class Services : Safety Critical , real-time gaming
4		5	300 ms	10^{-6}		Non-Conversational Video (Video Class) Services : Youtube, Vimeo
5	Non-GBR	1	100 ms	10^{-6}		Signaling
6		6	300 ms	10^{-6}		Best Effort Class Services: Facebook. Twitter, WWW, email, file sharing)
7		7	100 ms	10^{-3}		CBR Class
8		8	300 ms	10^{-6}		Non-Conversational Video (Video Class)
9		9				

TABLE I. QOS MAPPING

assigned to flow based on QoS mapper that will be discussed shortly.

A. Qos mapper

As we have considered broadband internet, and entertainment applications in this paper, therefore it is necessary to map these applications to the existing QoS classes of LTE identified in [21]. Since LTE network was launched by 3GPP group in order to enhance data-rate, hence it is important to map resources marked by their priority number to emerging applications such as internet browsing, emails, video streaming, social networking, and personalized location-based and context-aware services.

The bearer in LTE network, which is responsible for establishing a packet flow between packet data-network (PDN) gateway and end-user terminal, offers two types of resources. These are guaranteed bit rate (GBR) and non-guaranteed bit rate (Non-GBR) depending on QoS attributes such as QoS class identifier (QCI), priority, packet delay budget, and packet error loss rate. However, the simulator we use to evaluate the performance offers four distinguished classes such as constant bit rate (CBR), best effort (BE), voice over ip (VoIP) and video streaming. Hence, to better understand simulation results, it is necessary to map QoS classes. The mapping is shown in table 1.

The packet delay of GBR (which may be considered as premium service) varies from 50 ms to 300 ms. the services supported by GBR are conversational voice and video (live), real-time gaming, and buffered video streaming. On the other hand, Non-GBR may incur packet loss in case of congestion. The services offered by Non-GBR are signaling, TCP-based applications, interactive gaming etc.

B. Coverage analysis

The adequate coverage is another critical aspect that must be studied in vehicle-to-infrastructure communications. To enable a vehicle to stay connected with internet over entire road-way, it is pertinent to properly parameterized and design the network. We estimate the maximum cell range of LTE network similar to UTMS network as presented in [16]. In doing so, we provide link budget analysis of LTE network adapted from [22] as shown in table 2. The outcome of the link budget analysis is essentially the maximum allowable path loss.

The transmitter of the network is eNB, and receiver is smartphone that is connected to on-board unit (OBU) inside vehicle through either USB port or Bluetooth. The suitable cell range for LTE networks is 1 Km that nearly equals to existing compatriots such as HSPA+ and GSM. Hence, the LTE network can be deployed on existing infrastructure (Cellular network towers).

V. PERFORMANCE EVALUATION

In this section, we present the simulation results we have conducted to evaluate the performance of LTE smartphone-based vehicular network. We performed our experiments on LTE simulator (LTE-sim) [23]. In our experiments, we considered an LTE infrastructure-based mobile network. We used mobility traces with LTE-Sim. The simulation parameters are given in table 3.

We compare performance metrics (QoS attributes) such as throughput, packet loss rate (PLR), packet delay budget of leading four QoS classes. The vehicular speed varies from 3 Km/h to 120 Km/h. We set average number of vehicles moving on high-way in range of 5 to 20. Firstly, we evaluate single flows such as there is only QoS class occupying the LTE network. Lastly, we use mixed flows where data of each QoS class is present.

In course of our experiments, we varied number of users as well as vehicular speed and observed performance metrics. We considered 3 Km/h as our base case as show in figure 4. We can see that CBR, BE and VoIP throughput increases linearly with number of users. However, video traffic drops after number of users exceed 15. In case of PLR and delay we observed that CBR traffic shows a nearly constant behavior behavior. Furthermore, the video traffic shows anomaly again in PLR and delay when users exceed beyond 15 in numbers.

The results with vehicular speed 30 Km/h are shown in figure 5. Note that the throughput, PLR and delay performance is nearly same as compared to 3 Km/h case. We assume that 30 Km/h speed on high-way is possible during congestion or road-accident. The maximum allowable speed on high-way is around 120 Km/h; therefore we provide results of this case in figure 6. Surprisingly, the throughput, PLR and delay behavior doesn't vary much with previous results. But we zoom into the throughput of CBR and VoIP indicating maximum value of 65 Kbs (Kilo bits per second) and 41 Kbs respectively.

TABLE II. LINKG BUDGET ANALYSIS

Link Budget Calculations	
Transmitter (TX) eNB	**1024 Kbps**
Maximum transmitter power	23 dbm
Transmitter Antenna gain	18 dbi
Cable and connector losses	2 db
EIRP (	62 dbm
Receiver(Rx) User Terminal (UT)	
UT noise figure	7 db
Thermal Noise	-104.5 dbm
Rx noise floor	-97.5 dbm
SINR (Signal to Interference Ratio)	-9 db
Rx sensitivity	-106.4 dbm
Interference margin	4 db
Control channel overhead	20 %
Rx Antenna gain	0 db
Body loss	0 db
Maximum Allowable Path loss	163.5 db

We provide results of mixed flows traffic at both 30 Km.h and120 Km/h in figure 7. In case of BE throughput, we see it decreased as number of user's increased. But, this compensates for video traffic and we see a slight increase in throughput for very first time as compared to single flow results. The PLR metric shoes same behavior for CBR, VoIP and BE as previously, however video traffic shows a sharp increase in PLR and comply with previous results. Another result to note here is nearly exponential rise of delay value for CBR, VoIP and video traffic for mixed flows case.

VI. DISCUSSION

In this section we analyze the results of experiments, and give some insights. The measurements performed in literature shows that Wi-Fi network can deliver best possible throughput of 2.5 Mbs (Mega bits per second) in approximately one-third of time spend on road. Moreover, the 3G network far less throughput than Wi-Fi [2]. However, we have shown by simulations that LTE network can offer higher average throughput (up-to 4 Mbs) for most of the time. Another point to mention here is that cell range of LTE network is nearly same as 3G or GSM cellular network; however an added advantage is enhanced capacity.

In our results, we show that behavior of CBR traffic is nearly constant throughout the experiments with an exception of increased delay in case of mixed traffic flows. Therefore, the safety critical vehicular applications can utilize CBR premium services. Furthermore, important safety-related messages for traffic controlling authority are viable to broadcast using CBR.

The voice over IP traffic requires low PLR and delay values. In our experiments, we observe that VoIP performs consistently with having PLR and delay values as high as 10^{-3} and 1.9 milliseconds respectively. The BE class standouts in terms of high-throughput value, which states that broad-band internet usage with LTE network is highly feasible. Moreover, users can freely access social networking websites and other location-based services with ease and comfort.

One drawback of using LTE network might be high cost and overloading. Till now, market is too-small to interest mobile and telecom companies in order to develop more vehicular services and applications. Moreover, web contents and services are not optimized for drivers. As of today, there is no cellular wireless technology which scales well, provides ample capacity, and enhanced coverage other than LTE. The counterpart of LTE network is mobile WiMax which is left out as our future work. Moreover, web contents and services are not optimized for drivers.

VII. CONCLUSION

In this paper, we presented a new and novel concept that uses LTE network for vehicle-to-infrastructure communication. The popularity and ubiquity of smartphones is utilized inside vehicle in-order to reduce cost of on-board communication unit as well as time for availability of up-to-date contents. Moreover, the LTE capable smartphones can support high-data rate as well as enhanced coverage on road-ways. In our simulations, we show that safety critical services as well as high-end video and VoIP services are flexibly supported by LTE networks. Lastly, by using next generation networks for vehicular network access, both motorway authority and telecom operators can earn decent revenue. In our future work, we will conduct more experiments and give comparison between leading wireless technologies that are used for vehicular communications.

TABLE III. SIMULATION PARAMETERS

Parameter Name	Value
Wireless Medium	LTE Air interface
Bandwidth	10 MHz
Avg. Vehicular Speed	0, 30, 120 (Km/h)
Video data rate	440 Kbps
CBR data rate	12 Kbps
VoIP data rate	8 Kbps
Number of Vehicles	5 ~ 20
Cell range	1 Km
Simulation time (seconds)	Depends on number of veh.

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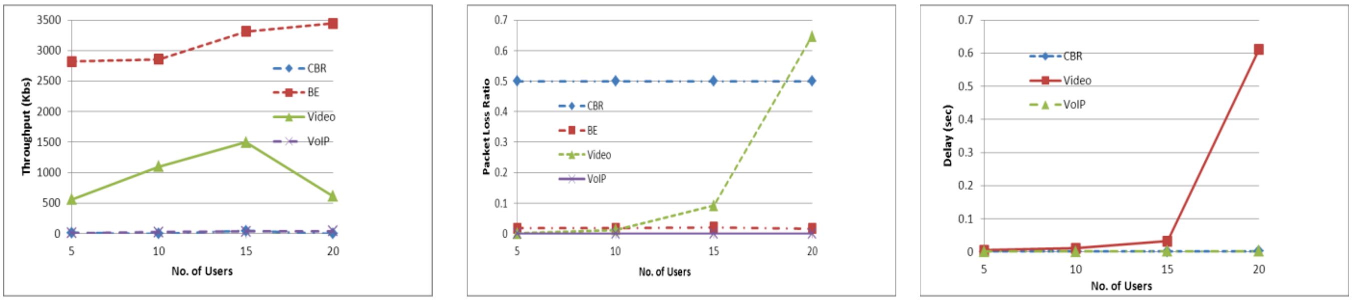
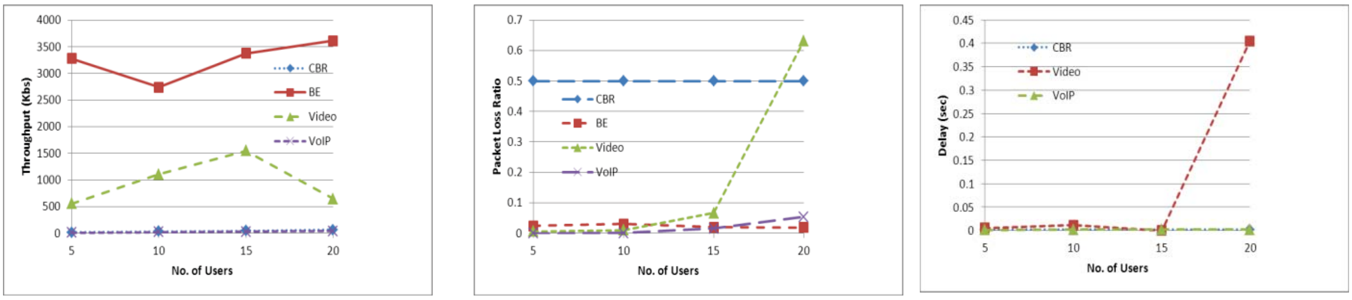


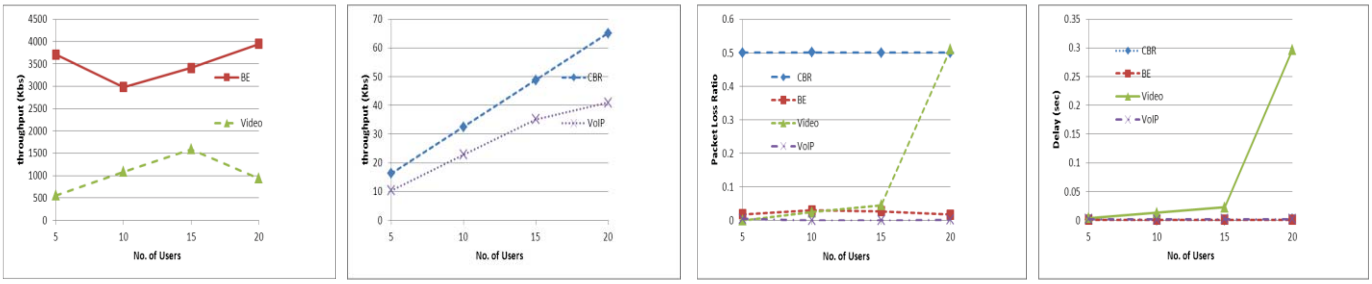
(a) Throughput (b) Packet Loss Ratio (c) Delay

Figure 4. QoS Metrics for Vehicular Speed 3 Kmh (Single Flow: QoS Classes CBR, Video, VoIP and Best Effort)



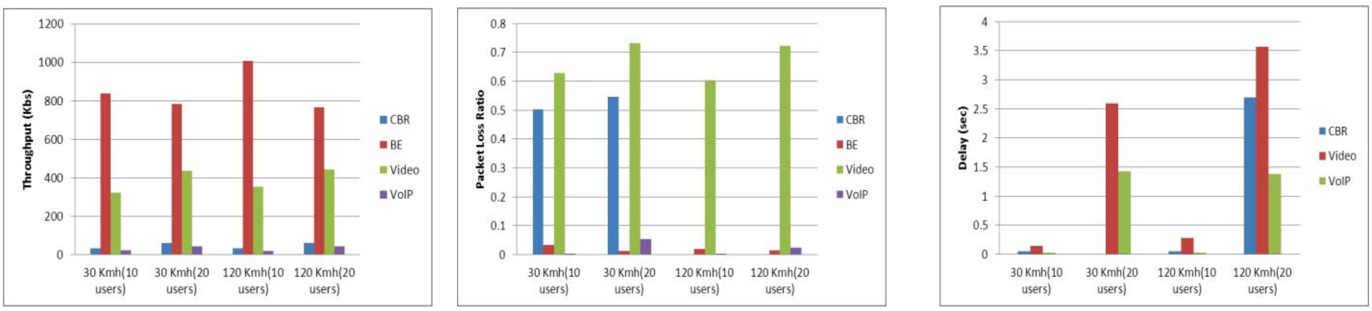
(a) Throughput (b) Packet Loss Ratio (c) Delay

Figure 5. QoS Metrics for Vehicular Speed 30 Kmh (Single Flow: QoS Classes CBR, Video, VoIP and Best Effort)



(a) Throughput(BE and Video) (b) Throughput(VoIP and CBR) (c) Packet Loss Ratio (d) Delay

Figure 6. QoS Metrics for Vehicular Speed 120 Kmh (Single Flow: QoS Classes CBR, Video, VoIP and Best Effort)



a) Throughput (b) Packet Loss Ratio (c) Delay

Figure 7. Compairson of QoS metrics for Vehicular Speed 30 kmh and 120 Kmh (Mixed Flows: CBR, Video, VoIP and Best Effort)