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Research article

EFFECT OF TRAFFIC LIGHT SCENARIO ON VANETS CONNECTIVITY WITH LOW PENETRATION RATE

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Abstract

Traffic light with Vehicular Ad-Hoc Networks (VANETs) has been developed recently. Many issues and challenges come up with this development that required an investigation. One of the most prominent challenges is connectivity under low penetration of vehicles with VANET technology. Traffic light scenario has been proposed in this field to overcome low penetration problem, but no studies have been done on their connectivity.

In this paper, VANET connectivity with traffic light scenarios had been investigated. The most significant metric in this investigation is penetration rate, more specifically low values of it. Connectivity measurements, i.e. reachability, connection duration and re-healing time had been studied with real-time simulation. Three traffic light scenarios had been considered; no traffic light, normal traffic light and intelligent traffic light. The effect of these scenarios on VANET connectivity had been analyzed with low penetration rate and important conclusions had been stated for future works.

Keywords: Traffic light, VANET, connectivity, penetration rate, real-time, static and dynamic analysis.

摘要 最近开发了具有车载 Ad-Hoc 网络（VANET）的交通信号灯。这一需要调查的发展带来了许多问题和挑战。最突出的挑战之一是使用 VANET 技术的车辆低渗透率下的连接。在该领域中已经提出了交通灯情景以克服低穿透问题，但是尚未对它们的连通性进行研究。在本文中，已经研究了 VANET 与交通灯情景的连接。该调查中最重要的指标是渗透率，更具体地说是低值。已经使用实时仿真研究了连通性测量，即可达性，连接持续时间和再愈合时间。已经考虑了三种交通灯情景;没有红绿灯，正常的红绿灯和智能交通灯。已经分析了这些场景对 VANET 连接的影响，其渗透率较低，并且已经为未来的工作提出了重要结论。

关键词: 交通灯，VANET，连通性，渗透率，实时，静态和动态分析。

I. INTRODUCTION

Vehicular ad hoc networks (VANETs) are an emerging class of mobile ad-hoc (MANETs) networks. The IEEE 1609 wireless access in vehicular environments (WAVE) standard, which use IEEE 802.11p, are used to improve the VANETs applications.

VANETs are configured by combining a moving vehicles and a fixed road side unit (RSU), which are equipped by wireless transceiver to enable communication among them. VANETs can be categorized broadly into vehicle to vehicle (V2V) communication, vehicle to infrastructure (V2I) communication, and hybrid of them (V2X) communication [1, 2].

Intelligent transportation system (ITS) is considered as a major driver to develop and deploy research activities on inter-vehicle communication [3]. The major aim of ITS is decreasing accident and enhancing traffic condition through providing information's to vehicles, drivers, and passengers.

Generally, applications of VANETs are classified in to two types' safety and non-safety. Safety applications carry sensitive data from vehicles surrounding environment or RSU to inform other vehicles to avoid the emergences situation[2]. Such applications rely on time sensitive delivery of information (i.e. real-time analysis), e.g. information about road condition and accident announcement.

Non-safety applications include online connectivity and entertainment. However, this category of applications has found a way for big cities development but gained little attention from the research academic field. Hence network connectivity is a key factor of VANETs applications. Vehicles should be able to communicate with each other either by single hop or by multi-hop connections.

In big cities, intersections are crowded by vehicles in most time of day. Some of these intersections have no traffic light while many others have. Normal traffic light has static setting (i.e. fix time of red and green phase) with time and fuel consumption problems. On the other hand, intelligent traffic light has the ability to dynamically change their setting depending upon number of vehicles that joining and leaving the traffic light region.

With fixed infrastructure and VANETs technology, many intelligent traffic light algorithms had been developed in this field [4,5]. Performance of the developed algorithms depend on number of vehicles penetrated with VANET technology. In other words, traffic light operation is affected by VANET connectivity. For example, when traffic light is red and penetration rate is very low then the connectivity of equipped vehicles become reachable for small period of time (i.e. red light duration) while unequipped vehicle becomes an issue for traffic flow and decrease connectivity measurements.

RSU positioned in the traffic light region, mutual communication between vehicles and RSU can be made to measure VANET connectivity. This communication required a significant period of time of traffic light operation to investigate its effect on connectivity measurements. Hence connectivity becomes vital factor that supports the various traffic light scenarios.

Our research is focusing on study of the effect of low penetration rate on connectivity in an intersection with different traffic light scenarios. Three scenarios were selected here; no traffic light, regular traffic light, and intelligent traffic light. Figure 1 depicts these scenarios with static and dynamic behaviour of traffic light operation (i.e. red and green time).

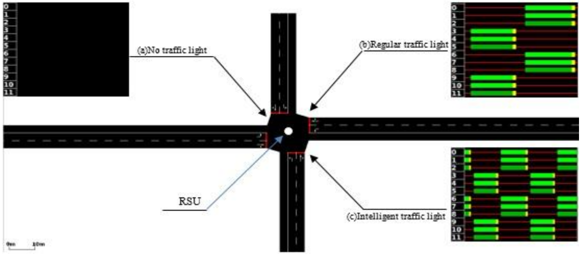

Figure 1. An intersection with RSU and (a) no traffic light (b) regular traffic light or (c) intelligent traffic light.

The rest of this paper is organized as follows. Section 2 presents the related works on connectivity analysis in ad-hoc networks with traffic light model. Section 3 describes connectivity analysis approach in details. Section 4 defines traffic light scenarios under consideration in this paper. Section 5 analyses the primary simulated results collected so far. Discussions of the approach is presented and conclusive remarks are provided at the end of the paper.

II. RELATED WORKS

Connectivity in ad-hoc networks has gained a keen interest in academia research; many of them discussed it by analytical evaluation and applicable simulation [6]. It explains the influence of different parameters on connectivity which helps us to understand the change of topology in the networks.

In VANETs most of the studies have analysed the connectivity problems using simulation. For instance, in [7,8], Artimy et al.discussed the connectivity through simulation and found the relationship between the transmission range and the connectivity. Their studies focused on traffic jam occurrence at intersections and the fact that minimum transmission range is partly influenced by the vehicle intensity.

In [9], Fiore et al. used different mobility models to analyse the network connectivity. They provide physical reasons to explain special dynamic connectivity. In another study [10], Marfia et al. focused on the RSU role in VANETs reliable connectivity through using realistic and simulation traces. The whole network performance is improved by avoiding the multi-hop paths. However, it has only been proved using the simulation, but it requires proper theoretical analysis to get meaningful and interesting results.

In [11], Ho et al. studied the connectivity of special VANETs relying on buses as a directories in the proposed scenario. They examined the impact of various transport parameters; traffic signal, topology, and vehicle traffic on the network connectivity. In [12], Kafsi et al. used percolation model and simulation results to analyse the network connectivity. However, Bollobas model proves its suitability for very large transmission range than percolation model [13].

In [14], Viriyasitavat et al. revealed disconnection network problem in various aspects especially when the vehicle density is less than percolation threshold. The network suffers from high path redundancy problem which produce a heavy broadcast storm problem also proved in the studying. Finally, the authors suggested a novel approach to broadcast storm suppression and store-carry-forward mechanism.

Different form these works, Liu et al. [15] suggested to increase the connectivity through using parked vehicle. Static parked vehicle used to support VANETs. Evaluation in theory and simulation results are made to prove that small number of parked vehicle can support connectivity greatly. Successful routing protocol designing rely basically on achieving reliable connectivity.

In [16], D.P et al. proposed a routing protocol in an intersection region. An intersection based connectivity-aware geo-cast routing protocol (IB-CAGR) tested in simulation to demonstrate the leverage of traffic light on the connectivity.

None of the above studies investigate the effect of penetration rate on VANETs connectivity with intersection. Also, in real life different scenarios for traffic light are exist and significantly important where real-time behaviour is dominant. Hence, their VANET connectivity dynamically effected and an analysis is required. Through this research, these issues have been addressed.

III. CONNECTIVITY ANALYSIS

In traffic light scenarios there are various aspects of connectivity that facing VANETs members. Especially, when the region of the intersection traffic lights is involved a fixed RSU. The connectivity among RSU and all neighbour vehicles has an important factor that affects various VANETs applications. The nature of traffic flow vehicle in this area encompasses real-time operations as well as joining and leaving vehicles. In this scenario members of VANETs have both static and dynamic connectivity in the intersection imposes special measuring of connectivity. However, different applications in VANETs urge different connectivity characteristics should be interest. As in [14] authors analyse the connectivity in two types (static and dynamic) which are affected by penetration rate. Hence, in next paragraphs this issue will be discussed.

A. Two dimensional connectivity

Since forwarding the packet in the urban vicinity is guided by network road map which almost have two dimension, then two-dimensional connectivity should be imposes. Intersections represent this type of connectivity where the connection occurs among RSU and group leader (GL) vehicle in two-dimensional direction. To study this type of connectivity, network reachability metric which reflects the presence of communication between GL and RSU in a specific time and direction had been adopted here. This metric can be determined by the following equation:

$$\mathrm{NC}\left(G\text{屨}_d, RSU, t\right) = \sum_{t=0}^{T} C(GL_d,\mathrm{RSU},\mathrm{t}) = \begin{cases} 1\ if\ GL_d\ and\ RSU\ is\ connected \\ 0 \qquad\qquad\qquad\qquad otherwise \end{cases} \tag{1}$$

Where NC network connectivity between group leader GL_d with d direction and RSU within a specific time $0 \leq t \leq T$.

The above metric covers the behaviour of the routing protocols with short-period of time application. For dynamic analysis, such metric is not enough because it does not reflect the real-time communication with long period of time. Safety-related VANETs application such as Post Crash Notification required short-period of time to ensure that all intended recipient is received warning message [12]. Since this warning message should broadcast ones per communication session to all vehicles, then message delay which is related to the quality of service is crucial. Traffic management related VANET application such as Traffic Signal control required medium to long period of time to ensure that all approach vehicles are preserved efficiently [4]. Since this service should evaluate ones per control session (for enough period of time, e.g. fifteen minutes) to only VANET penetrated vehicles, then penetration rate which is affect the quality of service is crucial.

B. Vehicle penetration rate

The potential connectivity of vehicles in an intersection directly related to VANETs equipped vehicle. Indirect influence of non-equipped vehicles should also be included in connectivity measurement. In this section, the impact of penetration rate is studying with equipped and non-equipped vehicle. In our research the penetration rate simulated modelled into various ratio, more specifically low penetration. The reason behind that is most of authors focusing on the low penetration rate to design an intelligent traffic light under VANETs environment. There is a relation between the density and penetration rate as done in [17] but it's not clear with VANETs connectivity analysis. This is because penetration rate is a function of time and cannot be estimated without real-time analysis. For instance, authors in [17] state that 40% penetration rate in a 200 veh/km^2 vehicle density equal to 80 veh/km^2 with full penetration rate. In other words, reducing in penetration rate directly translates to reducing in network density. This translation is not true without considering the real time analysis for long period of time. The above issue required more analysis with real-time change of penetration rate to overcome this ambiguity.

C. Real-time connectivity

Real-time connectivity is the nature of the relation among the RSU and group leader where many applications characterize. It captures the varying of the network connectivity during long period of time. Our study adopts two metrics that cover real-time connectivity; *re-healing interval time* and *link duration time*. Re-healing interval time refers to the time taken for group leader vehicle after disconnection, and waiting to discover a new group leader for establishing. Furthermore, link duration time covers the group leader connection with RSU where it required to stay until link is broken [17].

Briefly, re-healing period time indicates disconnection time, while link duration time indicates the link presence. Both of these metrics indicate network communication for period of time which related to real-time connectivity analysis. The above sections required a model for our scenario which described in next section.

IV. TRAFFIC LIGHT SCENARIOS

To investigate the effect of traffic light in vehicular network connectivity under different penetration rate, three scenarios have been considered. First, with no traffic light in an intersection as a base platform for comparison in our simulation study. Traditional fixed time traffic light scenario as the second model and finally intelligent traffic light scenario.

These scenarios have three major components in an intersection: i) RSU; ii) vehicles communication; and iii) traffic light model. RSU is responsible for collecting vehicles information under specific coverage area in which vehicles communicate and traffic lights operate. Vehicles communication participates through grouping communication protocol [18] and updates the states of all vehicles. The traffic light model component has rules for the coordination of vehicles at all road intersections.

A. No traffic light scenario

In this scenario, no traffic light model is exist. Thus, vehicles will coordinate based on the priority of entering or approaching ones. For example, way must be given to any vehicle entering or approaching the intersection from right side. In turning right case, way must be given to incoming vehicles going straight through the intersection or turning left.

B. Traditional traffic light scenario

In this scenario, traditional traffic light model is exist. In other words, fixed time setting is used for traffic light (green-red-yellow). Hence, vehicles had no effect on coordination or the priority of entering or approaching ones.

C. Intelligent traffic light scenario

With the development of intelligent techniques, new traffic light model have emerged into VANET application. The main idea of which is to get benefit from VANET information in the coordination of traffic light setting. Here, VANET information could be used directly with simple rules as used in [4] with Fuzzy logic algorithm or in a sophisticated optimization way as used in [5] with Genetic algorithm and linear programing.

V. SIMULATION RESULTS

Connectivity metrics examined previously had been measured with incoming and outgoing direction and different traffic light scenarios. For incoming direction, figure 2 show that poor path reachability accomplished in the beginning of the simulation time (till 500 sec, which is the time required to warm up the scenario). After that, path reachability increase with the incoming vehicles. Traffic light algorithm try to solve delay of vehicles before become congestion. The major observation for this figure is that intelligent traffic light scenario has less value of path reachability versus no-traffic light scenario with 100% penetration rate. This indicate the fact that high path reachability mean high traffic congestion (i.e. high number of waiting vehicles in the intersection). Also, path reachability and traffic congestion is not proportional directly with traffic light scenario under low penetration rate as shown in figure 2 (i.e. (b) and (c)). In fact, for 20% penetration rate shown in figure 2 (b), intelligent traffic light has more path reachability than others. While for 10% shown in figure 2 (b), intelligent traffic light has less path reachability than others. This mean connectivity analysis required more than path reachability to be measured.

On the other hand for outgoing direction, path reachability shown in figure 3 degraded obviously in comparison with incoming direction. As penetration rate is decreasing (e.g. 20 and 10 %), path reachability is degrading obviously. Path reachability measured by RSU centred an intersection is more accurate with closer coming vehicles than farther going vehicles. Furthermore, path reachability of traditional traffic light scenario has more value than others almost for 20% and 10% penetration rate.

In figure 4, link duration for all penetration rate show long period for no traffic light scenario in comparison with others. This indicate that vehicles take more time to pass the intersection with no traffic light. In spite of link duration measured with traditional and intelligent traffic light have almost the same for all penetration rate cases, but latter has less delay time. Hence, it is important to investigate re-healing time with traffic light scenarios (i.e. traditional and intelligent).

In figure 5, re-healing period time for no traffic light scenario with all penetration rate indicate low value after warming up period. Although other scenarios (i.e. traditional and intelligent) have almost the same behaviour for 20% penetration rate shown in figure 5(b) but intelligent scenario has less re-healing time than traditional for 10% penetration rate shown in figure 5(c).

VI. CONCLUSIONS

In this paper, dynamic and static aspects of VANET connectivity with different traffic light scenarios under low penetration rate are investigated. Connectivity metrics such as reachability, link duration and re-healing time are studied in detail. Direction and penetration rate of vehicles participating in determined these metrics are stated. This approach reveals the disconnected network problem existence when the penetration rate is low, more specifically less than 20%. In traffic light scenario with intelligent algorithm this problem should be overcome. Results also indicate that no traffic light has long link duration for high penetration rate severe congestion problem. However, disconnected network problem still observed in traditional traffic light scenario. The vehicles' direction via two-dimensional vehicular motion make group leader selection and RSU connection is an adequate mechanism for network connectivity analysis. Hence, new designs are needed for traffic light algorithm as well as group leader selections. While the observed link duration redundancy is a major cause of the low penetration problem, several ways to overcome the link duration redundancy as new intelligent traffic light control can be implemented to improve the performance of an intersection with VANETs technology. Results and observations presented in this paper provide key insights and pave the way for designing an intelligent traffic light for an intersection with VANETs technology. This conclusion based on connectivity analysis taking into consideration the low penetration problem on VANET technology.

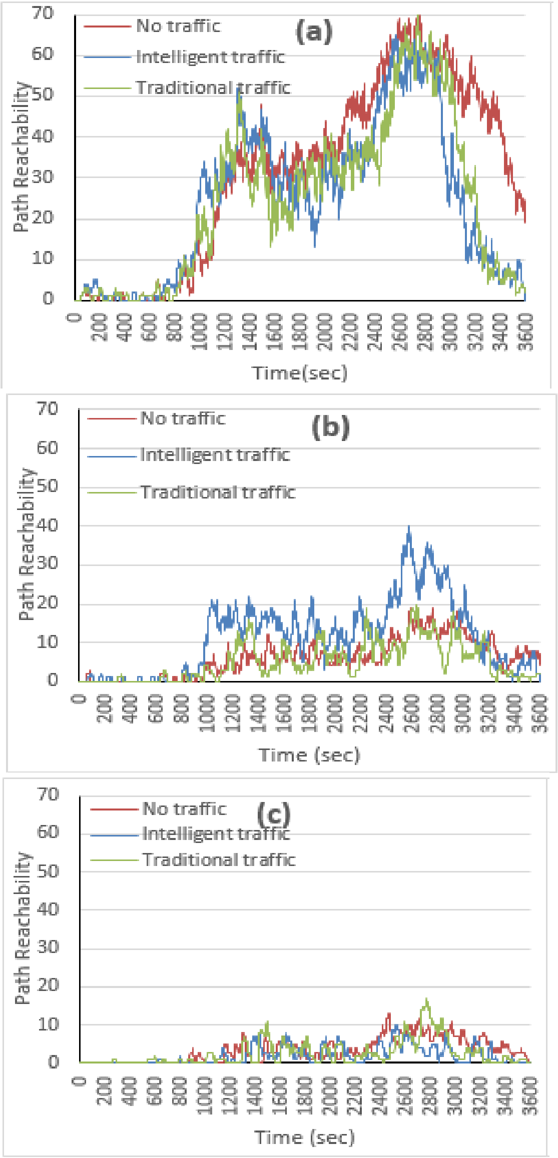

Figure 2. Path reachability for incoming direction and different traffic light scenario with (a) 100, (b) 20 and (c) 10 % penetration rates.

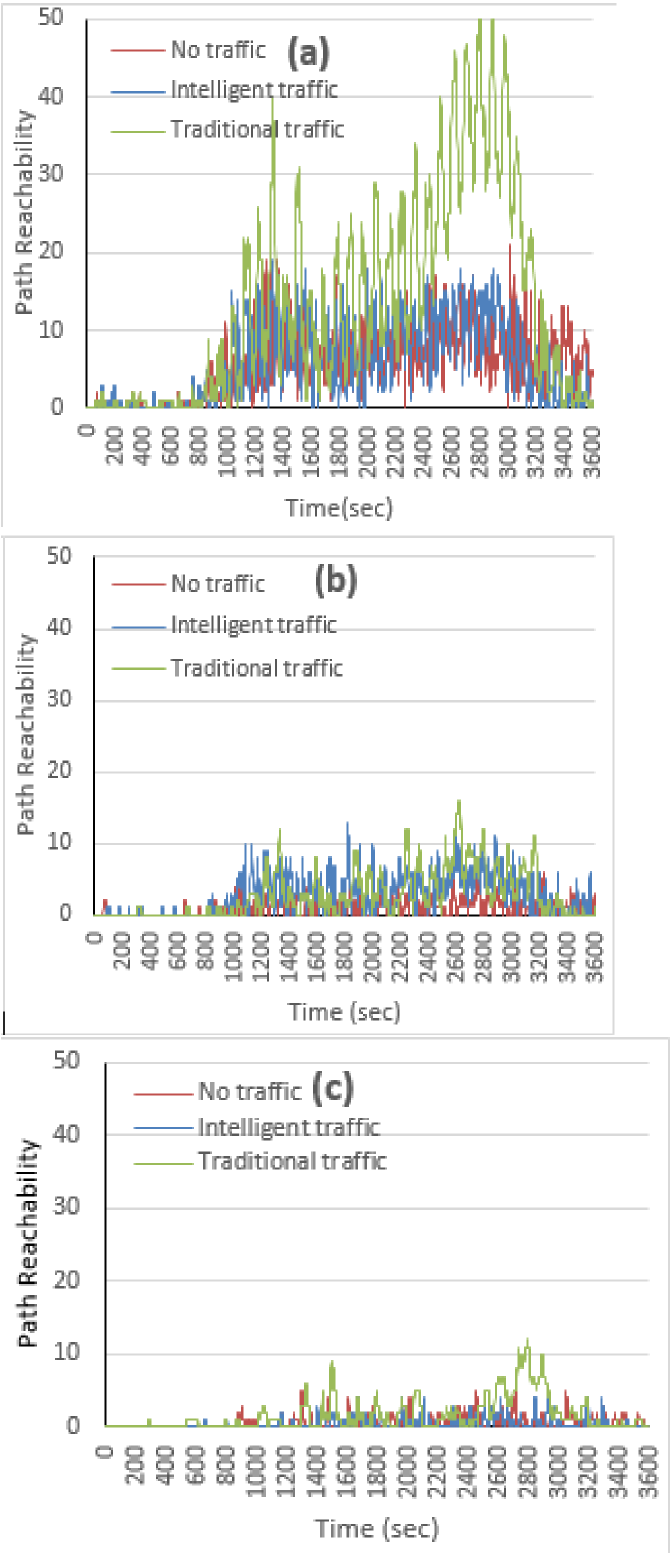

Figure 3. Path reachability for outgoing direction and different traffic light scenario with (a) 100, (b) 20 and (c) 10 % penetration rates.

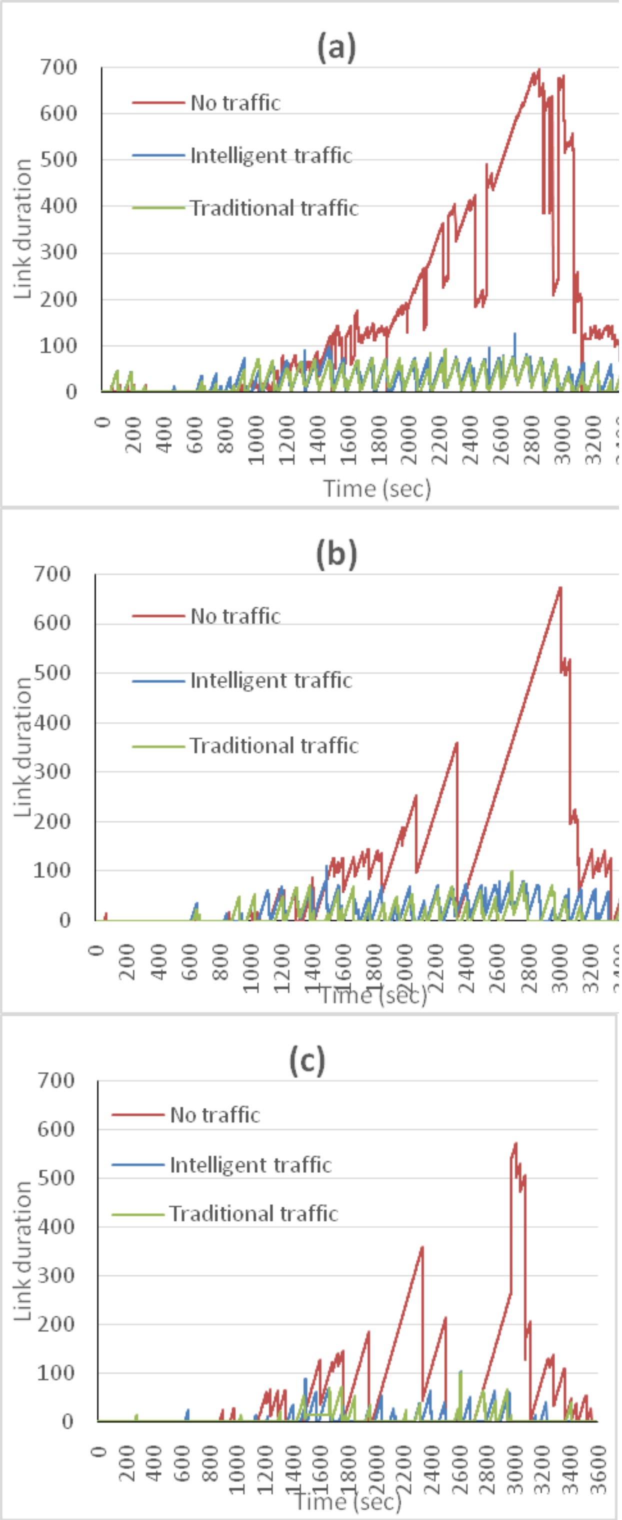

Figure 4. Link duration for different traffic light scenario with (a) 100 (b) 20 and (c) 10 % penetration rates.

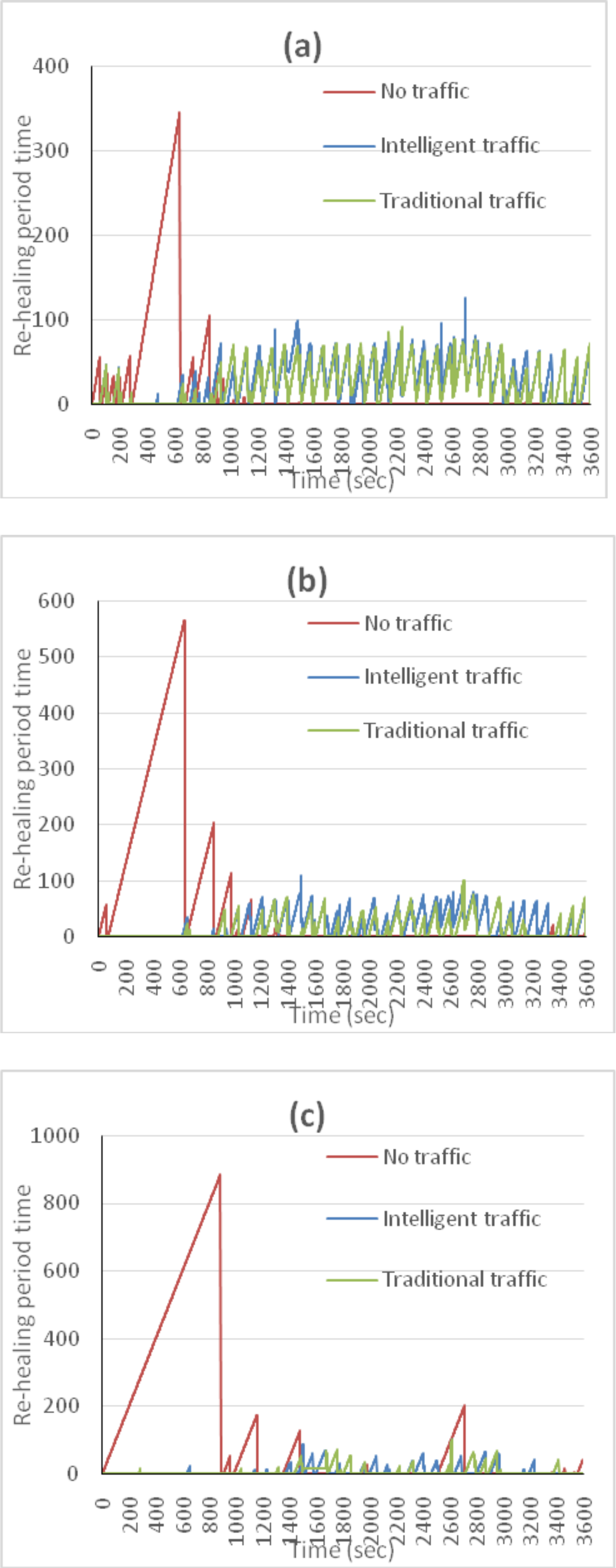

Figure 5. Re-healing period time for different traffic light scenario with (a)100 (b)20 and (c)10% penetration rates.

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