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Throughput and Delay Limits of 802.11p and Its Influence on Highway Capacity

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Abstract

Based on VANETs (Vehicle Ad-hoc Networks), a stable, reliable and low delay wireless network access environment is an inevitable element of vehicle safety applications. The IEEE 802.11p is a specially designed protocol for ITS (Intelligent Transportation Systems) for V2V and V2I communication. It provides 10 MHz channel bandwidth and up to 27-Mbps data transmission rate. This paper analyzes the theoretical throughput and delay limit of the 802.11p protocol. Considering PLR (Packet Loss Rate) and delay of VANETs, we analyzed the theoretical highway capacity upper limit of 802.11p for V2V communication. The results show that 802.11p communication technology can increase highway capacity. If all of the vehicles are equipped with 802.11p communication technology, the increase in highway capacity is about 491 percent.

Key words: VANETs、802.11p、Throughput、Delay、Capacity

1. Introduction

Wireless communication technology is a foundation of vehicle network and can achieve information interaction between V2V and V2I. Different communication technologies are applied to suitable application scenarios, such as a low delay vehicle safety application, a wide range of vehicle group management and a convenient entertainment services, et al. But the vehicle safety application, particularly when broadcasting the emergency message required a low latency and high transmission rate communication network, which was under a high-speed vehicle environment and must adapt to frequent changes in the network topology.

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IEEE 802.11p has been proposed for WAVE (Wireless Access in Vehicle Environment) to meet the requirements of ITS applications. The IEEE 802.11p is a supplement of IEEE 802.11 family, which aims to provide both V2V and V2I communications in ranges up to 1000 m and support transmission rates from 3 to 27 Mb/s (Data Rate) over a bandwidth of 10MHz. It is physically similar to the IEEE 802.11a standard and MAC layer and uses an EDCA sub-layer protocol. MAC layers of varieties IEEE 802.11 standards are the same. The overhead in the MAC determined a TUL (throughput upper limit) and a DLL (delay lower limit) when the data rate increased (Xiao & Rosdahl, 2002).

V2V communication can improve the safety of VII (Vehicle Infrastructure Integration) by allowing vehicles to exchange information. In emergence, they exchanged speed and braking messages, in order to coordinate their acceleration (deceleration) rates. A research result shows that if all vehicles used both V2V communication and sensors could increase highway capacity about 273% compared with all of manual vehicles (Teintrakool, Ho & Maxemchuk, 2011). In nearly 8 years research, Europe and the US have launched a series of projects. From constructed fundamental facilities and developed vehicle network standards to decreased energy consumption, reduced gas emission, advanced vehicle safety and improved road capacity. But now the systems have encountered many problems in practice, the most popular methods to estimate its benefits are through simulation (Ma, Chowdary & Sadek, 2009).

2. Throughput and delay limits of 802.11p

The 802.11p parameters are defined in Table 1 (Vandenberghe, Moerman & Demeester, 2011). For 802.11p, all the nodes have one data rate and control rate homogenous pair among (3,3),(4.5,3),(6,6),(9,6),(12,12),(18,12),(24,12), and (27,12).

Table 1. PARAMETERS OF IEEE 802.11P

Parameters	IEEE 802.11p	Notations
Tslot	13μs	A slot time
τ	2μs	Propagation delay
TP	32μs	Transmission time of the physical preamble
TDIFS	58μs	DIFS time
TSIFS	32μs	SIFS time
CWmin	15	Minimum backoff window size
TPHY	64μs	Transmission time of the PHY header
TSYM	8μs	Transmission time for a symbol
LH_DATA	28bytes	MAC overhead in bytes
LACK	14bytes	ACK size in bytes
TH_DATA		Transmission time of MAC overhead
TACK		ACK transmission time
LDATA		Payload size in bytes
TDATA		Transmission time for the payload
Mbps	3, 4.5, 6, 9, 12, 18, 24, 27	Million bits per second
NDBPS	24,36,48,72,96,144,192,216	Data bits per OFDM symbol

IEEE 802.11 MAC layer employs CSMA/CA protocol called DCF and PCF. DCF defines a basic access mechanism and an optional RTS/CTS (Request-To-Send/Clear-To-Send) mechanism. This paper only focused on the basic access mechanism, and the RTS/CTS mechanism is similar. To derive the TUL and DLL, we first need to derive two performance metrics: the achievable MT (maximum throughput) and the achievable MD (minimum

delay). Because the channel exist noisy interference, throughput is lower than MT and delay is higher than MD in the practical environment. This paper analysed the TUL, DLL, MD, and MT of 802.11p in an ideal condition. The assumed conditions are as follows:

1) The channel is an ideal channel without errors

2) At any transmission cycle, there are no hidden node and exposure node problems.

In the basic access mechanism, a transmission cycle includes a DIFS deferral, backoff, data transmission, SIFS deferral and ACK transmission.

The symbol notation is defined in Table I, the average backoff time $\overline{CW}$ is formulated by

$$\overline{CW} = \frac{CW_{\min} T_{slot}}{2}$$

(1)

For IEEE 802.11p, the data transmission delay T_{D_DATA} and the ACK transmission delay T_{D_ACK} are expressed as follows:

The function Ceiling accords to the upper integer of absolute value. For example, Ceiling (0.5) =1, Ceiling (-0.5) =-1.

$$T_{D\_DATA} = T_P + T_{PHY} + T_{SYM} * Ceiling\left(\frac{16+6+8L_{H\_DATA}+8L_{DATA}}{N_{DBPS\_DATA}}\right)$$

(2)

$$T_{D\_ACK} = T_P + T_{PHY} + T_{SYM} * Ceiling\left(\frac{16+6+8L_{ACK}}{N_{DBPS\_CONTROL}}\right)$$

(3)

Packet delay is defined as the time elapsed between the transmission of a packet and its successful reception. The MT and the MD are expressed as follows:

$$MT = \frac{8L_{DATA}}{T_{D\_DATA} + T_{D\_ACK} + 2\tau + T_{DIFS} + T_{SIFS} + \overline{CW}}$$

(4)

$$MD = T_{D\_DATA} + \tau + T_{DIFS} + \overline{CW}$$

(5)

It is easy to see that the throughput (delay) is an increasing (decreasing) function of the data rate. From (1) to (5), letting the data rate go into infinite, we have get the TUL and DLL based on Limit Theorem (Xiao & Rosdahl, 2002).

$$TUL = \frac{8L_{DATA}}{2T_P + 2T_{PHY} + 2\tau + T_{DIFS} + T_{SIFS} + \overline{CW}}$$

(6)

$$DLL = T_P + T_{PHY} + \tau + T_{DIFS} + \overline{CW}$$

(7)

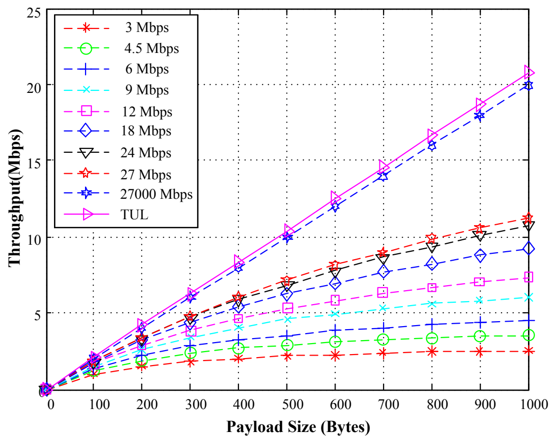

Fig 1 Maximum throughputs and TUL of 802.11p

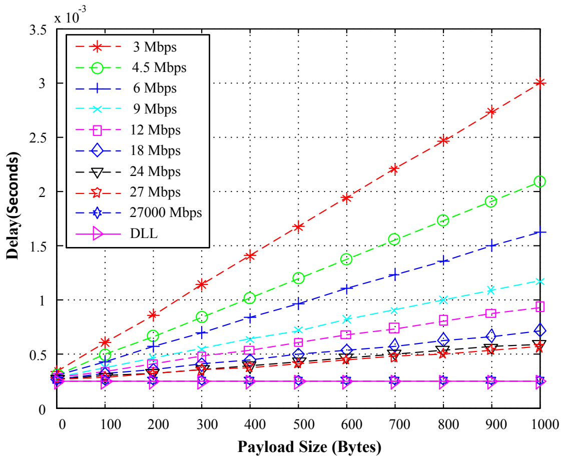

Fig 2 Minimum delays and DLL of 802.11p

Fig 1 shows that the TUL upper bounds all the MTs for IEEE 802.11p. When the payload size is 1000 bytes, the MT for 27 Mbps is 11.2Mbps and the TUL is 20.9Mbps. The MT for 27 000Mbps with the same set of overhead parameters almost reaches the TUL. Fig 2 shows that the DLL lower bounds all the MDs for IEEE 802.11p. The DLL is the same for all payload sizes, i.e., 253.5μs. When the payload size is 1000 bytes, the MD for 27 Mbps is 565.5μs. The MD for 27 000 Mbps with the same set of overhead parameters almost reaches the DLL.

3. The highway capacity limits of the condition using V2V communication

We defined D_f as the safe following distance in meters that the vehicle maintains to the preceding vehicle.

$$D_f = \left(T_d * V/3.6\right) + \left[V^2/\left(25.92\left|a_0\right|\right)\right] - \left[V^2/\left(25.92\left|a_{\max}\right|\right)\right] \tag{8}$$

Where T_d is the delays from vehicles detect an emergence to the brake operation is carried out automatically. This delay contains detection time, V2V communication time and mechanical response time of an automobile braking system. The constant 3.6 is to convert vehicle speed V from km/h to m/s. The terms 25.92|a| are from 2|a| times 12.96, which is the constant to convert V^2 from $(km/h)^2$ to $(m/s)^2$. The symbol "*a*" represents deceleration rates, which is in the range of $[a_{min}, a_{max}]$. The symbol a_0 is the deceleration rates of target vehicle. In this paper, we use a_{min}=-5 m/s^2 a_{max}=-8.5 m/s^2 (Mehmood & Easa, 2009).

This paper calculated the theoretical highway capacity under the ideal conditions. We assumed the conditions as follows:

1) All of vehicles in highway are equipped the 802.11p communication unit.
2) Vehicle will brake automatically when it receives the emergency messages.
3) All of vehicles are aware of emergency, and then brake with the negotiated deceleration rates –x.

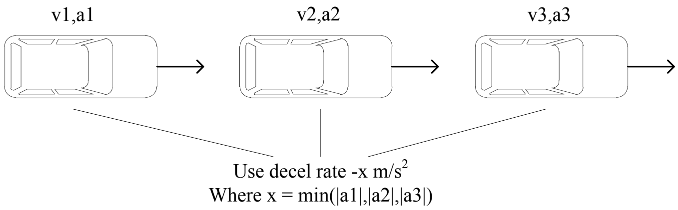

Fig 3 Negotiated deceleration rates used by communication vehicles

In Fig 3, after vehicles received the emergency messages, they brake at the negotiated deceleration rates –x which is the minimum value in absolute. Define the minimum value as a_c, the V2V communication time as T_c, the detection and reaction time T_r is 0.1s as in Maciuca & Hedrick (1995). When there exist some interference sources in V2V communication environments, the occurrence of losing package in the wireless channel increases the delays of V2V network. We defined the total number of losing packages in percentage of transmission packages as PLR and the T_d is given by:

$$T_d = T_c/(1-PLR)+T_r$$

(9)

PLR varied from four values [0%, 5%, 10%, and 15%].The vehicle safety following distance for V2V communication is given by:

$$D_c = T_d * V/3.6$$

(10)

Highway capacity definition is the capacity of a facility as the maximum hourly rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions. From this definition, highway capacity (C) in vehicles/hour/lane can be estimated as:

$$C = 3600 * V/[3.6*(L+\overline{D})] = 1000 * V/(L+\overline{D})$$

(11)

Where vehicle length (L) average is 4.3m as in (Hill, Rhodes and Voller et al, 2005) and $\overline{D}$ is the average vehicle safe following distance. In this paper, we discussed the situation all of vehicles use V2V communication, and $\overline{D}$ was calculated by formulation (10) as D_c.

Fig 4 shows the highway capacity change at speed 120km/h in different PLR for V2V communication vehicles. In Fig 4, the delay is set to DLL of 802.11p and the payload size is set to 1000 bytes. The capacity improves significantly when the vehicle speeds up. However, PLR have little impact. When all of vehicles speed is 120km/h, PLR is 0%, the capacity is increased to 15703 vehicles/hour/lane. Fig 5 shows the partial enlarged details of Fig 4 near speed 118km/h. When all of vehicles speed is 118km/h, PLR is 0%, the capacity is 15555 vehicles/hour/lane and PLR is 15%, the capacity is 15552 vehicles/hour/lane.

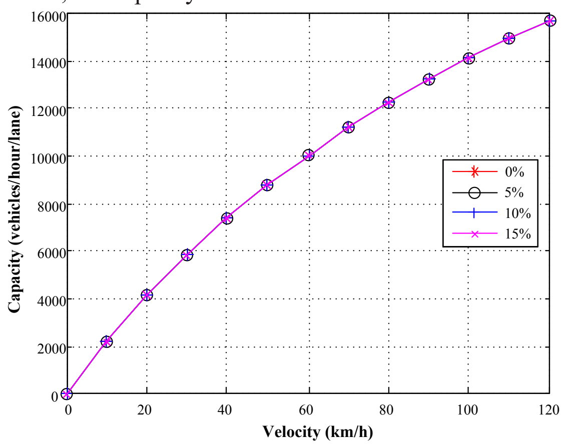

Fig 4 Highway capacity with varied PLRs at different speeds (Delay=DLL, Payload size=1000 bytes)

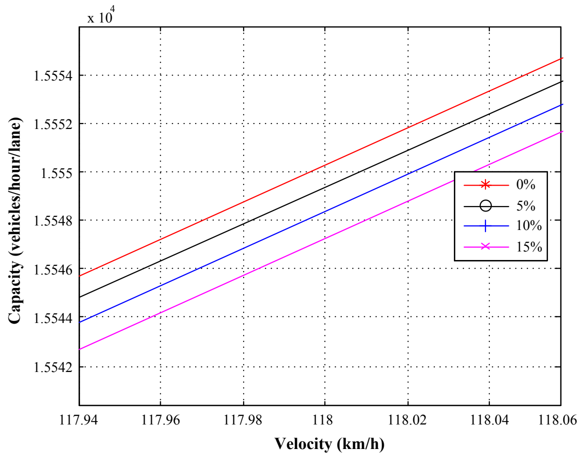

Fig 5 Details of highway capacity with varied PLRs at different speeds (Delay=DLL, Payload size=1000 bytes)

Fig 6 shows the highway capacity change at speed 120km/h in different bitrates for V2V communication vehicles. In Fig 6, the payload size is set to 1000 bytes and PLR is set to 0%. The capacity improves significantly when the vehicle speeds up. However, bitrates have little impact. When all of vehicles speed is 120km/h, delay is MD of 27Mbps, the capacity is increased to 15682 vehicles/hour/lane. Fig 7 shows the partial enlarged details of Fig 6 near speed 118km/h. When all of vehicles speed is 118km/h, delay is MD of 27Mbps, the capacity is 15534 vehicles/hour/lane and delay is MD of 3Mbps, the capacity is 15372 vehicles/hour/lane.

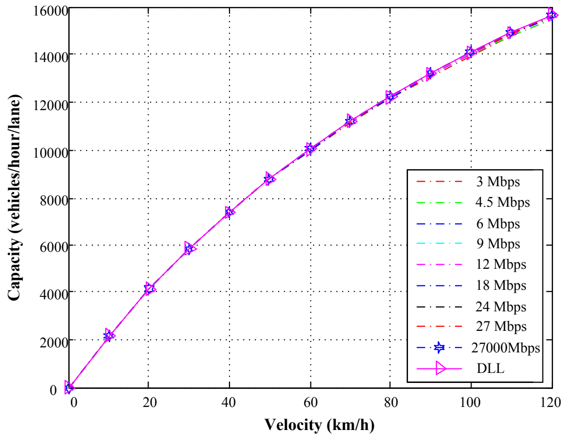

Fig 6 Highway capacity with varied bitrates loss rates at different speeds (Payload size=1000 bytes, PLR=0)

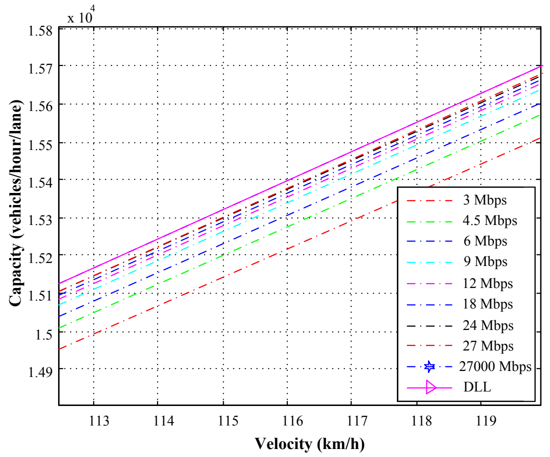

Fig 7 Details of highway capacity with varied bitrates at different speeds (Payload size = 1000 bytes, PLR = 0)

Fig 8 shows the highway capacity change at speed 120km/h in different PLR for V2V communication vehicles. In Fig 4, the delay is set to 50ms according to DSRC technology and the payload size is set to 1000 bytes (Morgan, 2009). The capacity improves significantly when the vehicle speeds up. However, in a certain scope, PLR have a more obvious influence. When all of vehicles speed is 120km/h, PLR is 0%, the capacity is 12903 vehicles/hour/lane. Fig 9 shows the partial enlarged details of Fig 8 near speed 118km/h. When all of vehicles speed is 118km/h, PLR is 0%, the capacity is 12803 vehicles/hour/lane and PLR is 15%, the capacity is 12413 vehicles/hour/lane. The capacity decreased because the delay of DSRC is higher than the theoretical delay of 802.11p.

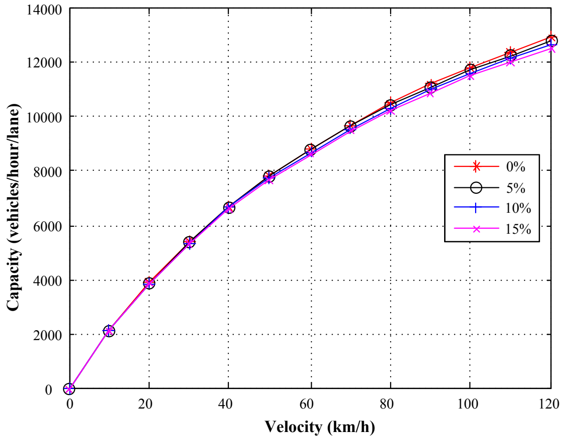

Fig 8 Highway capacity with varied PLRs at different speeds (Delay=50ms, Payload size=1000 bytes)

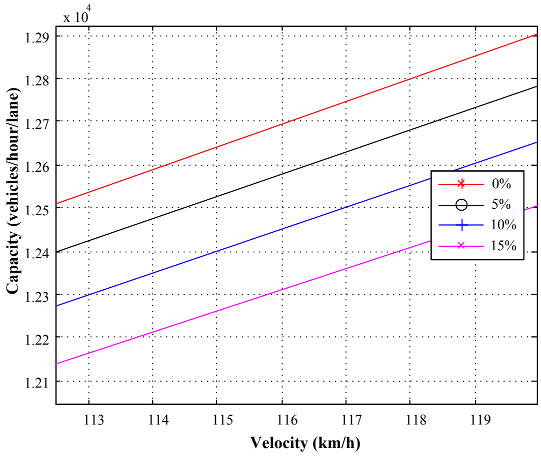

Fig 9 Details of Highway capacity with varied PLRs at different speeds(Delay=50ms, Payload size=1000 bytes)

When all of vehicles are at speed of 100km/h, the highway capacity for all manual vehicles is 2868.98 vehicles/hour/lane (Teintrakool, Ho & Maxemchuk, 2011). With the same speed and 0% PLR, the achievable highway capacity upper limit of 802.11p for V2V communication is 14097 vehicles/hour/lane, which is 4.9 times the capacity in the case of all manual vehicles.

4. Conclusion

This paper analysed the 802.11p limit and achievable value of throughput and delay. According to delay, we calculated the limit and achievable value of highway capacity. The results show that V2V communication can significantly improve highway capacity. In a certain scope, PLR have little impact on high capacity. Vehicle speed is primary factor to increase highway capacity.

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References

Xiao Y, Rosdahl J. (2002) , Throughput and Delay Limits of IEEE 802.11. *IEEE Communications Letters,* Vol. 6(8), pp: 355-357

Tientrakool P, Ho .Y.C, and Maxemchuk N.F. (2011) Highway Capacity Benefits from Using Vehicle-to-Vehicle Communication and Sensors for Collision Avoidance*, Vehicle Technology Conference,* pp: 1-5

Ma Y. C, Chowdhury .M, Sadek .A. (2009) Real-Time Highway Traffic Condition Assessment Framework Using Vehicle–Infrastructure Integration (VII) With Artificial Intelligence (AI), *IEEE Transactions on Intelligent Transportation Systems,* Vol. 10(4) pp: 615-627

Vandenberghe W, Moerman .I, Demeester .P. (2011) Approximation of the IEEE 802.11p Standard Using Commercial Off-The-Shelf IEEE 802.11a Hardware , *International Conference on ITS Telecommunications,* pp:21-26

Mehmood A, Easa S. M. (2009) Modeling Reaction Time in Car-Following Behaviour Based on Human Factors, International *Journal of Applied Science, Engineering and Technology ,* Vol.5(2), pp. 93–101

Transportation Research Board (2000), *Highway Capacity Manual.* National Research Council, Washington, DC, ch. 2, pp. 2–2.

Maciuca D. B., Hedrick K. J., (1995) Brake Dynamics Effect on AHS Lane Capacity, *Future Transportation Technology Conference & Exposition.*

Hill J. D., Rhodes G., Voller S., et al. (2005). *Car Park Designers' Handbook. Telford, Thomas Limited,* pp: 28

Morgan Y. L. (2009). Notes on DSRC & WAVE Standards Suite: Its Architecture, Design, and Characteristics, *IEEE Commnications, Surveys&Tutorials,* pp:1-15