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NETWORK PERFORMANCE ANALYSIS AND MANUEVER MODEL FOR OVERTAKING ASSISTANT SERVICE USING WAVE

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ABSTRACT−We present network requirements for an overtaking assistant service using wireless access in vehicular environment (WAVE). Currently, DNPW has been proposed as a representative overtaking assistant service with vehicle-to-vehicle (V2V) communication. In order to analyze its network performance, we construct a maneuver model for an overtaking system. According to this model, we configured a scenario for network simulation based on the 802.11p WAVE standard. The results confirm that a radio range for overtaking needs only a single hop without routing methods. Moreover, we propose an additional safe distance for the communication delay generated by an increase in the numbers of neighboring vehicles. And for high priority activity of safety services, we present a proper access category (AC) of enhanced distributed channel access (EDCA). These analysis results should be tested considered in real safety service systems that use V2V communication.

KEY WORDS : Intelligent transport system (ITS), Vehicle-to-vehicle (V2V) communication, Vehicular safety service, Overtaking maneuver

1. INTRODUCTION

According to the development of various communication protocol, the concept of connected vehicles and services was proposed (Choi *et al*., 2012; Lee and Kim, 2012; Seo *et al*., 2013). Especially, vehicle-to-vehicle (V2V) communication is being used by international vehicular safety service projects and consortiums. In Europe, the SAFESPOT project and CAR 2 CAR Communication Consortium (C2C-CC) have suggested the concept for various safety services and have standardized the V2X communication protocol (Papadimitratos *et al*., 2009). In North America, the U.S. Department of Transportation (USDOT) has led the Intellidrive and Vehicle Safety Communications-Applications (VSC-A) projects. Many automotive OEMs are participating in the VSC-A project, which is developing detailed safety services using V2V communication and a related safety message set (NHTSA in USDOT, 2011) . VSC-A proposed various services such as forward collision warnings (FCW), lane change warnings (LCW) and do not pass warnings (DNPW).

The DNPW service provides drivers with assistance and warning for dangerous situations when a slowing vehicle tries to overtake a vehicle on a rural, 2-lane road. In the DNPW service, the host vehicle, preceding vehicle and oncoming vehicle exchange information through V2V communication. Then, the service calculates a safe distance based on the other vehicles' location and speed information etc, and provides a message, either warning about or approving overtaking. So, in case of bad weather or insufficient line of sight, if drivers use a safety service with V2V communication, they benefit from accident prevention and overtaking assistance.

Various research on overtaking has been conducted. In The Netherlands, vehicles were equipped with cameras and the moving patterns for overtaking were recorded (Hegeman *et al*., 2004). And in order to build a dynamic modeling for overtaking, there is a mathematical model using speed data (Rilett *et al*., 1990) and research based on field observation results for overtaking situations (Hegeman *et al*., 2005). However, a model using real time information has not yet been proposed and the requirements of an overtaking assistant service for use with V2V communication has not yet been developed. Therefore, based on patterns for overtaking, in this paper, we construct a model and scenario to extract network requirements for the V2V environment. Moreover, we report on network simulations for this overtaking scenario using the latest WAVE standards for MAC IEEE STD 802.11p and PHY IEEE STD 1609.4 (IEEE STD 802.11p, 2010; IEEE STD 1609.4, 2011). We confirmed that, when the total overtaking distance is compared with the radio range of WAVE, the basic safety message (BSM) of J2735 standard can be transmitted in a single hop. Additionally, we increased the traffic overload by increasing the number of neighboring

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vehicles, and compensated for the error of communication delay and low reception ratio by increasing the safe distance. And as an AC of the EDCA changed, we analyzed the priority requirements of BSM needed in overtaking.

This paper is outlined as follows. In Section 2, we introduce the concept of overtaking and construct an overtaking maneuver model. Based on the modeling results in Section 2, we show network simulation results in Section 3. Finally in Section 4 we present the conclusions determined by this research.

2. OVERTAKING MANEUVER MODELING

In this section, we construct a model for overtaking using network performance analysis. We define the vehicle names used in the modeling work as follows. A host vehicle is the vehicle wishing to overtake and the preceding vehicle is the one to be overtaken by the host vehicle. And an oncoming vehicle is a vehicle coming on the opposing lane. Additionally, we assume that the preceding vehicle moves with low speed on a two-lane rural road. This overtaking situation is represented with five steps as shown in Figure 1 (Hegeman *et al*., 2005). We defined the host vehicle, the preceding vehicle and the oncoming vehicle on opposite lanes as HV, PV and OV, respectively in Figure 1. First, a host vehicle follows the preceding vehicle as a starting point to prepare for overtaking. At this point, the driver judges whether or not to try to overtake. Second, the host vehicle starts overtaking and moves into the opposing lane. Third, the host vehicle occupies the opposing lane and starts accelerating. Fourth, the host vehicle returns to its own lane and finally completes overtaking.

According to this overtaking pattern, we can divide the distances needed for modeling overtaking as follows: The distance that the host vehicle moves from the overtaking starting point, the distance that the oncoming vehicle moves during the overtaking preparation of the host vechicle, the distance that the host vehicle moves during overtaking (OD1), the distance that the oncoming vehicle moves during OD1 (OD2) and the safe distance between the host vehicle and the oncoming vehicle at overtaking completion (OD_S). In this paper, we exclude the overtaking preparation step: the necessary time is difficult to calculate and the overtaking preparation step depends on a driver's characteristics. Therefore, in order to calculate the actual overtaking distance, we model OD1, OD2 and ODs.

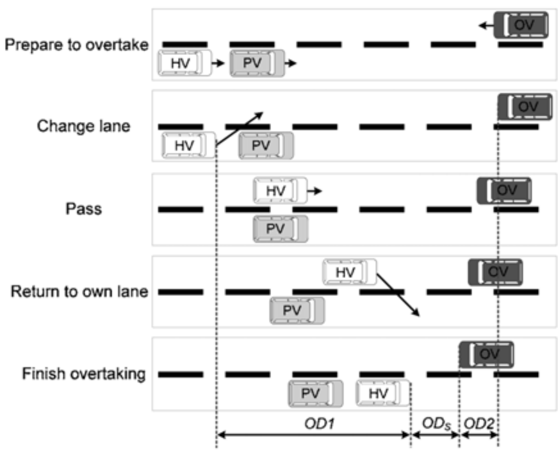

Figure 1. Definition of the overtaking steps and distances.

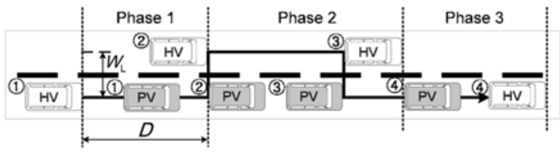

Figure 2. Overtaking phase.

2.1. Overall Overtaking Maneuver Concept and Definition

We divided the overtaking steps into three phases in OD1 of Figure 2. Where, D is a horizontal distance and W_L is a lane width. Numbers such as ①, ②, ③ and ④ mean the overtaking step of the host vehicle and the preceding vehicle. In Phase 1, the host vehicle changes lanes and in Phase 2, the host vehicle accelerates in the opposing lane. And finally in Phase 3, the host vehicle returns to its own lane. Phases 1 and 3 are important steps due to the lane change. The trajectory of Phase 1 is similar to the shape shown in Figure 3. We can represent this moving distance S by Equation (1).

In order to ensure the greatest possible safety, we set the longest trajectory distance as $D + W_L$. Before starting overtaking, the host vehicle follows the preceding vehicle (Hegeman *et al*., 2005). In this case, the intitial speed of the host vehicle becomes the same as the speed of the preceding vehicle. And when starting overtaking, the host vehicle accelerates to overtake the preceding vehicle. Figure 3 shows the speed of the host

$$\sqrt{D^2 + W_L^2} < S < D + W_L \quad (1)$$

vehicle during overtaking. From the graph, v_{h_init} is the initial speed of the host vehicle, while v_{h_max} is the constant speed after the host vehicle reaches its maximum speed.

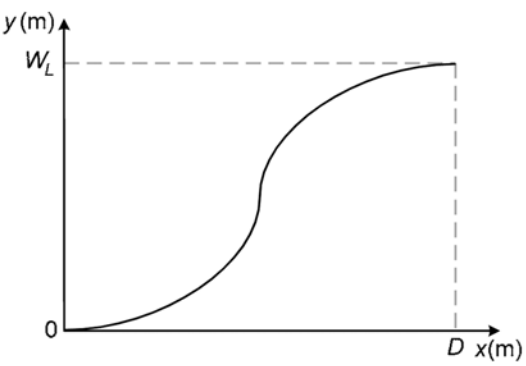

Figure 3. Trajectory during the lane change.

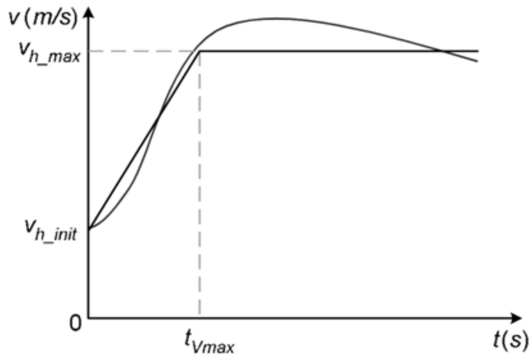

Figure 4. Host vehicle velocity.

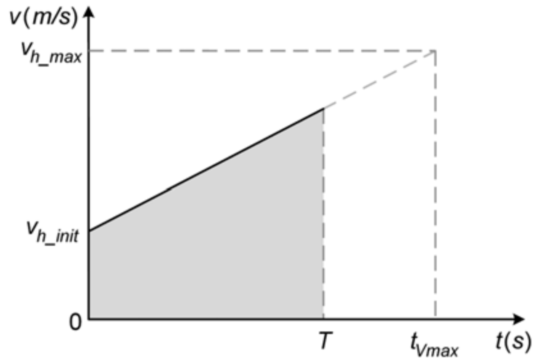

Figure 5. Case for overtaking with a consistent acceleration.

And t_{V_max} is the time to reach v_{h_max}. The curve part of the graph represents when the vehicle actually overtakes. And for the simple model, we change the curved part to a straight line.

We consider the host vehicle's speed for overtaking with the following two cases: First, the host vehicle overtakes with consistant acceleration as in Figure 5. So, in this case, the total overtaking time is T, and $t_{Vmax} > T$. The second type is that after the host vehicle reaches its maximum speed during overtaking, and then it completes overtaking by maintaing the maximum speed as shown in Figure 6, with $t_{Vmax} < T$. And the moving distances of the host vehicle for these two cases are given by Equations (2) and (3) respectively, where, a is the acceleration value of the host vehicle.

$$S = v_{h\_init}T + \frac{1}{2}aT^2 \tag{2}$$

$$S = v_{h\_init}t_{V\max} + \frac{1}{2}at^2_{V\max} + v_{h\_\max}(T - t_{V\max}) \tag{3}$$

2.2. Detailed Overtaking Maneuver Modeling

In this subsection, we propose a detailed model for each phase based on the results analyzed in the previous subsection. In Phase 1, the variables and the moving distance of the host vehicle are represented with Figure 7 and Equation (4) respectively. S_n is the moving distance of the host vehicle during phase n. d_{s_out} is the distance between the host vehicle and the preceding vehicle at the point when overtaking is started. v_a is the preceding vehicle's speed and t_n is the overtaking time in phase n.

$$S_1 = d_{s\_out} + v_a t_1 + W_L \tag{4}$$

Phase 1 is divided into two cases depending on whether or not the host vehicle speed reaches its maximum speed in Phase 1. According to these two cases, Equations (5) and (6) show the moving distance of the host vehicle for the host vehicle speed, respectively. And the graph for host vehicle speed is shown in Figure 8, where, ① is the case that the host vehicle's speed reachs a maximum in overtaking and ② is the case that the host vehicle's speed

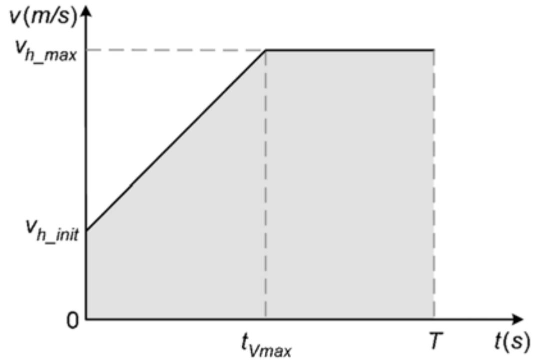

Figure 6. Case for overtaking with a consistent speed after the host vehicle reaches maximum speed.

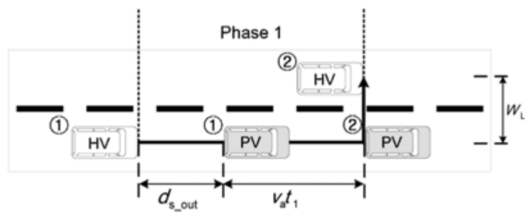

Figure 7. Horizontal moving distance in Phase 1.

does not reach a maximum in overtaking. Therefore, after judging whether the speed for overtaking reaches its maximum speed or not, the moving distance can be calculated by the equation (4) and, (5) or (6).

$$t_1 < t_{V\max} : S_1 = v_{h\_init}t_1 + \frac{1}{2}at_1^2 \tag{5}$$

$$t_1 > t_{V\max} : S_1 = v_{h\_init}t_{V\max} + \frac{1}{2}at^2_{V\max} + v_{h\_\max}(t_1 - t_{V\max}) \tag{6}$$

The overtaking distance and time in all phase can be calculated by using this method. For extracting the overtaking distance and time, overtaking cases are divided into four cases by determining when the maximum speed is reached. In Cases 1, 2 and 3, the maximum speed is reached in Phase 1, 2 or 3 respectively. In Case 4, the speed

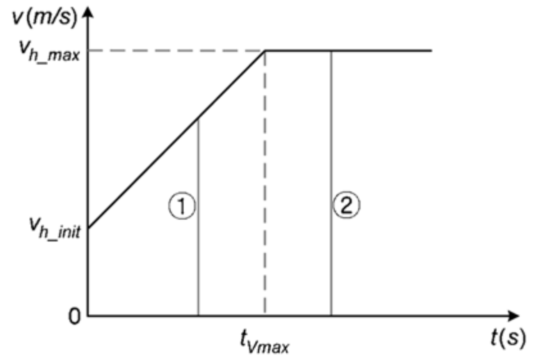

Figure 8. Overaking speed of the host vehicle in Phase 1.

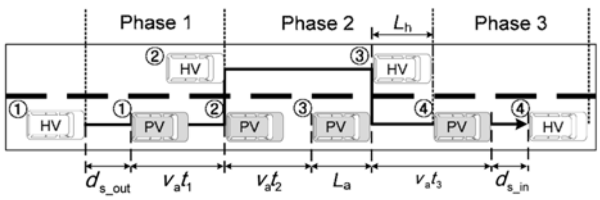

Figure 9. Horizonal and moving distances of the host vehicle.

increases continuously and does not reach a maximum in overtaking.

First, we analyzed the overtaking distance and the time when the maximum speed is reached in Phase 1. Figure 9 shows the horizontal distance of each phase and trajectory of the host vehicle. D_n is the horizontal distance in Phase n while t is a overtaking time. d_{s_out}

$$\begin{aligned} D_1 &= v_a t_1 + d_{s\_out} \\ D_2 &= v_a t_2 + L_a + L_h \\ D_3 &= v_a t_3 + d_{s\_in} \end{aligned} \tag{7}$$

$$\begin{aligned} S_1 &= D_1 + W_L \\ S_2 &= D_2 \\ S_3 &= D_3^2 + W_L \end{aligned} \tag{8}$$

and d_{s_in} are the safe distances between the host vehicle and the preceding vehicle. L_h and L_a are the length of the host vehicle and the preceding vehicle, respectively. Therefore, the horizontal distance of the host vehicle is shown in Equation (7). And when we choose the longest distance for the lane change trajectory, the moving distance is as given in Equation (8). The moving distance of each phase is shown in Equation (9) when the maximum speed is reached in Phase 1.

$$\begin{aligned} S_1 &= S_{V\max} + v_{h\_\max}(t_1 - t_{V\max}) \\ S_2 &= v_{h\_\max} t_2 \\ S_3 &= v_{h\_\max} t_3 \end{aligned} \tag{9}$$

Based on the moving distance of Equations (8) and (9), the overtaking time t_1, t_2 and t_3 can be calculated, respectively. So, the overtaking time and the total horizontal distance can be represented with Equation (10).

$$\begin{aligned} T &= t_1 + t_2 + t_3 \\ D &= D_1 + D_2 + D_3 \end{aligned} \tag{10}$$

Also, the case 1 is $t_{Vmax} < t_1$ and is represented as shown in Figure 10. We can analyze the other cases 2, 3 and 4 with the same methods as Case 1.

Case 2, that the host vehicle's speed reaches a maximum in Phase 2, is $t_1 < t_{\mathrm{Vmax}} < t_1 + t_2$ and is represented as Equation (11) and Figure 11 respectively.

$$\begin{aligned} S_1 &= v_{h\_init} t_1 + \frac{1}{2} a t_1^2 \\ S_1 + S_2 &= S_{V\max} + v_{h\max}(t_1 + t_2 - t_{V\max}) \\ S_3 &= v_{h\_\max} t_3 \end{aligned} \tag{11}$$

Case 3, that the host vehicle's speed reaches a maximum in phase 3, is $t_1 + t_2 < t_{Vmax} < t_1 + t_2 + t_3$. This is represented by Equation (12) and Figure 12, respectively.

$$\begin{aligned} S_1 &= v_{h\_init} t_1 + 0.5 a t_1^2 \\ S_1 + S_2 &= v_{h\_init}(t_1 + t_2) + 0.5 a (t_1 + t_2)^2 \\ S_1 + S_2 + S_3 &= S_{V\max} + v_{h\_\max}(t_1 + t_2 + t_3 - t_{V\max}) \end{aligned} \tag{12}$$

Case 4, that the host vehicle's speed does not reach a maximum during overtaking, is $t_1 + t_2 + t_3 < t_{Vmax}$. This is represented by Equation (13) and Figure 13 respectively.

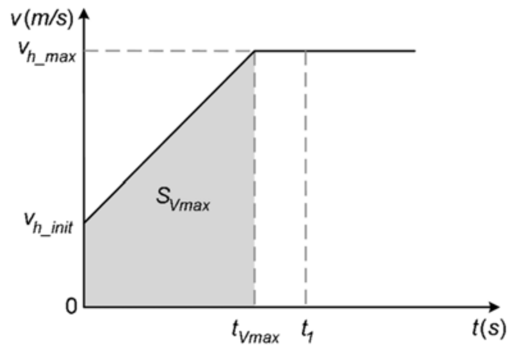

Figure 10. Host vehicle's speed in Case 1.

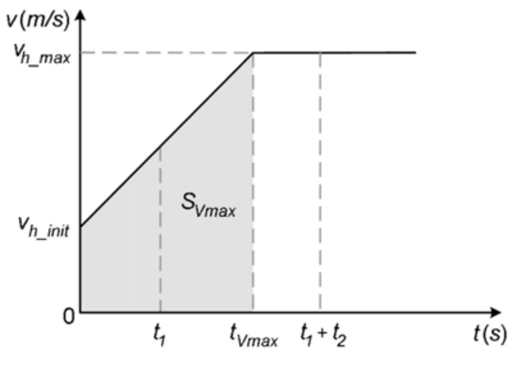

Figure 11. Host vehicle's speed in Case 2.

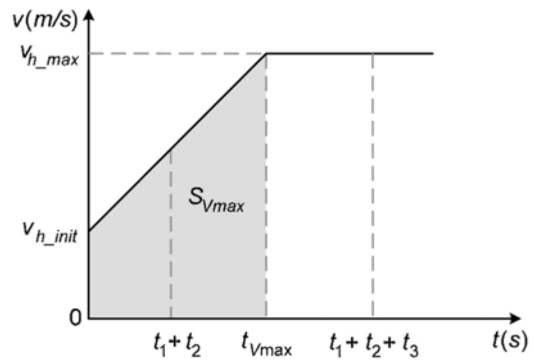

Figure 12. Host vehicle's speed in Case 3.

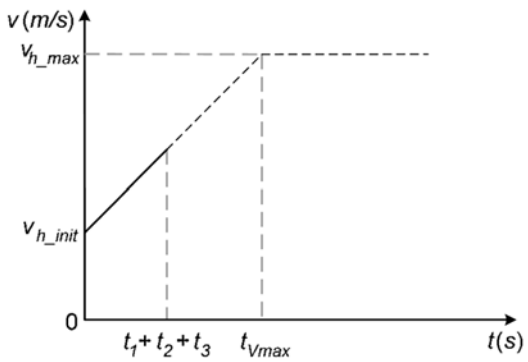

Figure 13. Host vehicle's speed in Case 4.

$$
\begin{aligned}
&S_1 = v_{h\_init}t_1 + 0.5a_1^2 \\
&S_1 + S_2 = v_{h\_init}(t_1 + t_2) + 0.5a(t_1 + t_2)^2 \\
&S_1 + S_2 + S_3 = v_{h\_init}(t_1 + t_2 + t_3) + 0.5a(t_1 + t_2 + t_3)^2
\end{aligned}
\tag{13}
$$

With the calculation method of these four cases, the overtaking time and horizontal distance can be calculated.

2.3. Safe Distance During Lane Change

In order to reduce the risk of accidents, it is important to ensure a safe distance between the host vehicle and the preceding vehicle during the lane change maneuver. In this paper, the safe distance is defined as d_{s_out} , d_{s_in}, where d_{s_out} is the distance between the host vehicle and the preceding vehicle when the host vehicle starts moving to opposing lane and d_{s_in} is the distance between the preceding vehicle and host vehicle when the host vehicle returns to its own lane. In order to calculate a safe distance between the host and the preceding vehicle, the forward vehicle collision warning system (FVCWS) was applied (ISO 15623, 2002).

The host and the preceding vehicle's speed are v_{2_init}, v_{1_init} respectively in Figure 14. If the host vehicle's driver recognizes the deceleration of the preceding vehicle, and then decelerates until stopping with the deceleration of a, then the host vehicle needs a safe distance of d_s (Yang *et al*., 2012; Lee *et al*., 2012). Threrefore, the forward

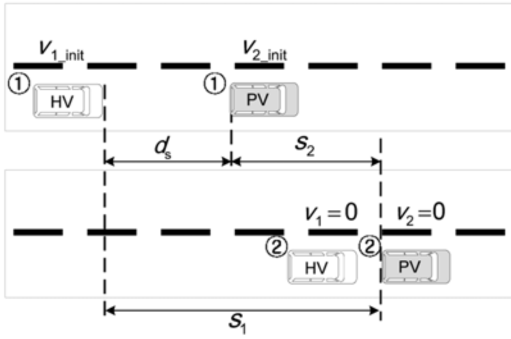

Figure 14. Distance to prevent a forward collision.

collision warning distance is given by Equation (14) where, t_{react} is the driver's brake reaction time.

$$
\begin{aligned}
&d_s + s_2 = s_1 \\
&s_1 = v_{1\_init}t_{react} + \frac{v_{1\_init}^2}{2a}, \quad s_2 = \frac{v_{2\_init}^2}{2a} \\
&d_s = v_{1\_init}t_{react} + \frac{v_{1\_init}^2 - v_{2\_init}^2}{2a}
\end{aligned}
\tag{14}
$$

3. NETWORK SIMULATION AND RESULTS IN WAVE

WAVE is a representative V2V communication protocol used in vehicle safety services. Its MAC and PHY layer are specified in 802.11p based on the 802.11 WLAN and upper layers specified in 1609.X. And the WAVE architecture is shown in Figure 15. According to the overtaking model in Section 2, we analyzed WAVE network performance and requirements for an overtaking assistant service using WAVE. First, we set up a simulation environment based on WAVE in QualNet and confirmed whether or not the WAVE radio range is able to cover the overtaking distance. In addition, we analyzed the requirements for the transmission delay time and the reception ratio. Finally, we propose a method that compensates for the distance errors that result from communication degradation.

3.1. Network Simulation Environment

For network simulation, we used string topology, which is generally used in a traffic model of two lanes (Xu and Saadawi, 2001).

Nodes for the networks load were uniformly placed on scope that does not affect a overtaking maneuver. The number of nodes was set from 1 to 10. MAC and PHY parameters of QualNet were configured by using WAVE as proposed in the U.S.. The configured parameters for network simulation were shown in Table 1 (Cash, 2004).

3.2. Analysis for Network Simulation Results

We analyzed the network performance and requirements for overtaking assistant service in simulation environments.

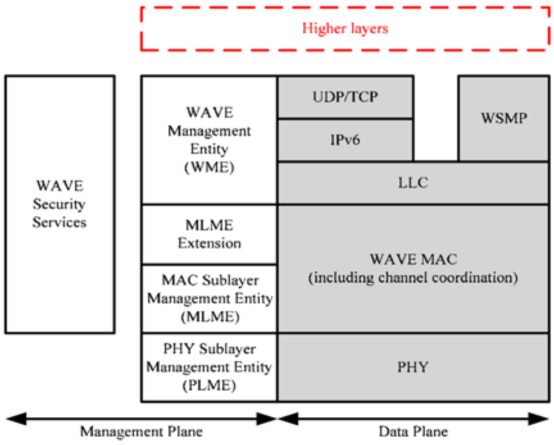

Figure 15. WAVE architecture.

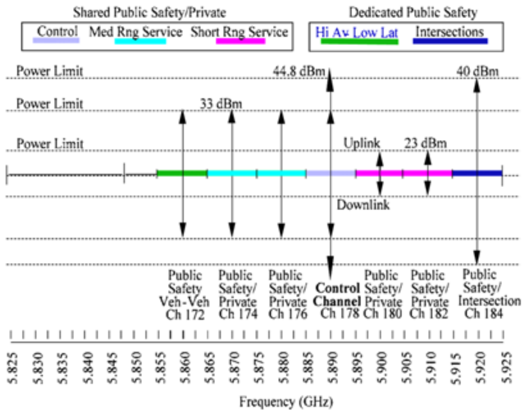

Figure 16. U.S. 5.9GHz DSRC band plan.

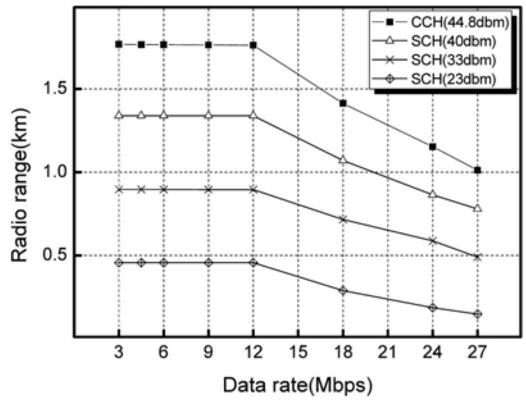

Figure 17. Simulation results for radio range of channels.

For an overtaking assistant service, the most important factor is the radio range, since the longer the distance to recognize opposing vehicle is, the safer the overtaking. The WAVE channel assignment proposed in the U.S, is from CH 172 to CH 184 as shown in Figure 16 (J2735, 2010), with one control channel and six service channels. Each channel has a default bandwidth of 10 MHz. In accordance with the purpose of services, the maximum transmit power of each channel was defined.

Simulation results for the radio range of WAVE for each channel are shown in Figure 17 by the central frequency, maximum transmit power and maximum data rate. And the radio range for WAVE is determined by the transmission power. The maximum radio range was 1,800 m for CCH with 44.8 dBm while the maximum was 450 m for SCH with 23 dBm. In the simulation, as the data rate increased, the radio range decreased. To investigate whether the radio range of WAVE supports an overtaking assistant service, the total overtaking distance was calculated using the model from Section 2. The speed limit was set to 80 km/h based on a national highway with 2 lanes. And the speed of the oncoming vehicle was set as 80 km/h and the initial speed of the host vehicle was set as the same as one of the preceding vehicles. The maximum overtaking speed was set as the initial speed plus 20 km/h. Figure 18 represents the horizontal overtaking distance given the host vehicle's speed and overtaking acceleration. When the initial speed of the host vehicle and overtaking acceleration are 60 km/h and 1 m/s^2 respectively, the horizontal distance needed for overtaking is 620 m. CH 172, used in public safety, has a maximum radio range of 850 m. This range can sufficiently cover the overtaking distance so that the service can be supported within a one hop communication range.

Table 1. Network simulation parameters.

Parameter	Value
PHY/MAC model	802.11p
Frequency	5.850~5.925 GHz
Information date rate	3, 4.5, 6, 9, 12, 18, 24 and 27 Mbits/s
Transmit power limit	23, 33, 40 and 44.8 dBm
Type of casting	Broadcasting(using MCBR)
Payload	39 bytes (BSM set)
Update rate	10 Hz

Next, we analyzed the end-to-end delay and message reception ratio by the network traffic load. For analysis of the end-to-end delay, the transmit message size of all the nodes was set up as 39 bytes based on J2735 BSM (DSRC Implementation Guide, 2010). Nodes that did not overtake transmitted messages with AC0. And nodes that were involved in overtaking transmitted a message by increasing the AC value. The average end-to-end delay by the number of nodes and AC value is shown in Figure 19. In the case of AC0, the end-to-end delay was linearly increased by increasing the number of nodes. In case of values over AC1, the delay time was stably about 4.5 ms. A simulation result for the message reception ratio is shown in Figure 20. In the case of a message with AC0, the reception ratio

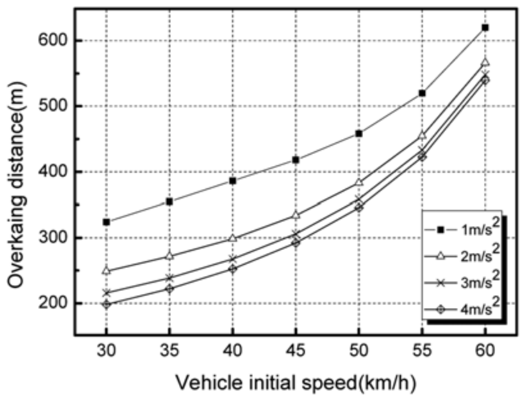

Figure 18. Simulation results for the overtaking distance based on the initial speed of vehicle.

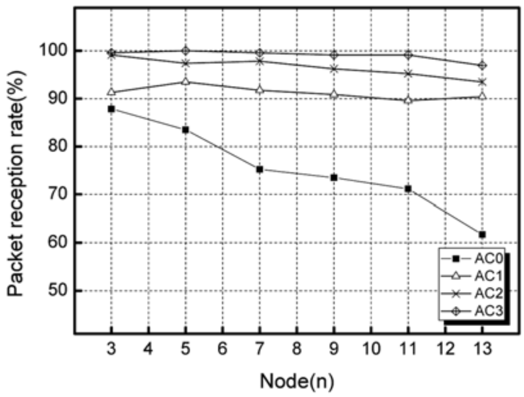

Figure 20. Simulation results for the message reception ratio based on the number of node.

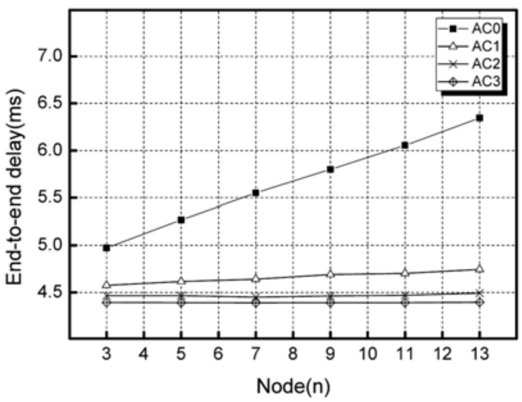

Figure 19. Simulation results based on the number of nodes.

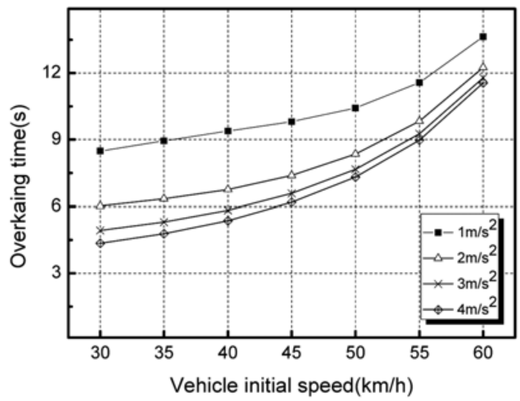

Figure 21. Simulation results for the overtaking time based on the initial speed.

was significantly decreased by increasing the number of nodes. If the number of nodes is 13, the reception ratio is 60%. For values over AC1, the reception ratio showed success rates higher than 90%. Therefore, for lower delay time and reliable reception ratio, the messages transmitted by overtaking vehicles should be assigned with higher priority than AC1. The safe distance should be considered for delay time and message reception ratio because the overtaking assistant service takes place in a wireless communication environment. In case of AC0, the end-to-end delay was increased by increasing the number of nodes, but in the case of AC1, the delay time was stably about 4.5 ms. However, because the delay time may have a greater value in a real wireless communication environment, this factor should be reflected. And in case of the priority with AC1, the message reception ratio was 90% but the reception loss of 10% should be considered.

In Figure 21, to investigate the error distance for reception loss, we calculated the total overtaking time by the initial vehicle speed. The total overtaking time was 13 sec at initial speed 60 km/h and acceleration 1 m/s^2 as shown in Figure 21. Therefore, if the reception loss is 10%, the time loss is 1.3 sec and this time loss increases the error distance based on the vehicle's speed. Figure 22 shows the error distance based on the error time and vehicle speed. If the vehicle speed is 80km/h, the error distance becomes 29 m. So this error distance should be compensated by safe distance when the total overtaking distance is calculated.

4. CONCLUSION

In this paper, we proposed network performance analysis and maneuver modeling for an overtaking assistant service using WAVE. Using the overtaking model, we calculated the overtaking distance and time. Additionally, we set up a network simulation environmenet, and then analyzed the network performance and requirements of WAVE. First, we analyzed the radio range for the transmit power of the channel and data rate based on WAVE. We extracted the maximum overtaking distance as 620 m based on the results of the model. V2V communication was possible in one hop based on a message data rate of 12 Mbps and transmit power of 33 dBm. In order to analyze the performance of the network traffic load, as the node number changed, we analyzed the delay time and reception ratio. And to analyze the requirement of message priority, we changed the AC value in our simulations. In case AC0 in used for message transmission, as the number of nodes increased, the delay time increased by 2% and the reception ratio decreased by 3%. However, if AC was over AC1, the delay time was constant at 4.5 ms and the reception ration showed performance over 90%. Finally, we reflected a safe distance for errors generated by the delay time and reception ratio. For future work, safe distance based on our research results should be verified through real vehicle tests of V2V communication.

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