SCIENCE CHINA
Information Sciences

• **Supplementary File** •

Link QoS Analysis of 5G-Enabled V2V Network Based on Vehicular Cloud

Guilu WU* & Pingping XU

National Mobile Communications Research Lab.,Southeast University, Nanjing 210096*, China*

Appendix A Scenario description

In this article, the unidirectional three-lane highway is shown in Figure A1. The vehicle v_a cannot communicate with the vehicle v_b directly due to limited transmission range. Hence, a multi-hop V2V link is required to transmit messages. Apparently, there are many links c_i which constitute potential communication link and these links constitute a set C,$C \supseteq c_i, i \in \{1, 2, \cdots, k, \cdots, x\}$, where x ia an indefinite value and depends on practical V2V network. When we analyze specifically one link c_k in set C to judge its reliable, c_k is mapped to one-directional V2V communication link, as shown in Figure A2. The source vehicle v_a attempts to transmit messages to the destination vehicle v_b.

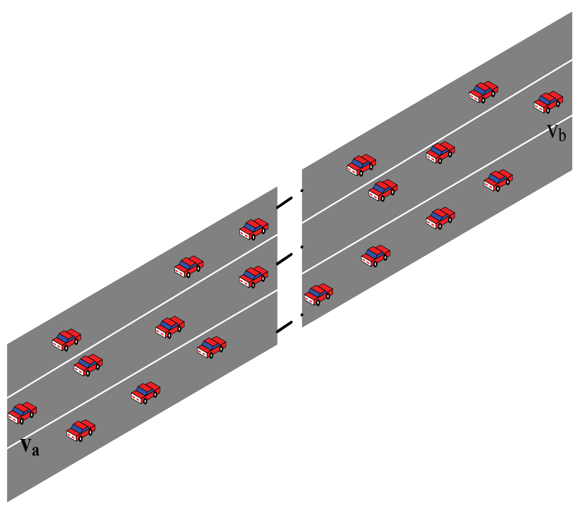

Figure A1 Unidirectional three-lane highway V2V network.

Appendix B Link selection algorithm

In the process of selecting an optimal link in set C, the LQSI model is adopted. The corresponding analysis and calculation with each link c_i in set C are carried out by vehicular cloud(VC). In order to select an optimal link, we design a link selection algorithm.

* Corresponding author (email: wgl@seu.edu.com)

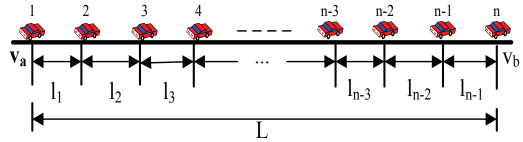

Figure A2 One-dimensional equivalent analysis V2V network.

Algorithm B1 An optimal link selection algorithm pseudocode

Require: $n \geqslant 2, \alpha, \beta, T_{toler}$;

Ensure: $I^*_{c_k} = \alpha P_{c_k} + \beta(1 - \frac{T_{c_k}}{T_{toler}})$;

for i = 1:1:n **do**

$P_{c_k} \Leftarrow \sum_{j=0}^{\lfloor a^{-1} \rfloor} \binom{n-1}{j} (-1)^j (1-ja)^{n-2}$;

$T_{c_k} \Leftarrow n \cdot \frac{2t_{slot}}{1+erf(\frac{b(r)}{\sqrt{2}\sigma})} + (n-1) \cdot T_t$;

$D \Leftarrow 1 - \frac{T_{c_k}}{T_{toler}}$;

$I^*_{c_k} \Leftarrow \alpha P_{c_k} + \beta D$;

end for

$I^*_{c_k} \Leftarrow SORT(I^*_{c_k})$;

$c^* \Leftarrow I^*_{c_k}(n)$;

Appendix C Experiments

To validate the LQSI model, we develop a simulator using MATLAB tools to perform simulation programs according to the simulation environment. Numerical results that demonstrate the impact of network parameters on link quality will be given out in this section. Apparently, these results could help selecting an optimal link, c^*, from link set C according to different QoS link requirements scenarios. Different requirements with transmission successful probability and transmission delay are reflected by weight factors. The vehicular environment used in this section is depicted as follows. The simulation scenario considers a unidirectional highway link between the source vehicle v_a and the destination vehicle v_b, as Figure A1. The distance between two related vehicles (vehicle v_a and vehicle v_b) is $L = 3000m$. We assume there are 3 lanes on the highway and vehicles that locate between two related vehicles (vehicle v_a and vehicle v_b) keep their steady velocities. Some other parameters are fixed as Table C1 [1] [2].

Figure C1 details that the connection probability of link c_k increases as the number of vehicles increases, and saturates at a certain network size for different transmission ranges. The analysis results in Figure C1 are obtained from (7). To understand this, the connection probability can be taken as time portion of vehicular network links connection during observation. In addition, Figure C1 also shows us detailed results on the statical characters of network links connectivity as follows. If the link c_k is composed of 60 vehicles with $R_T = 200, 300, 400\,m$ transmission ranges, the link c_k will be fully connected about $68\%, 85\%, 97\%$, respectively. On the other hand, the connectivity of link c_k can be improved as transmission range R_T increases for fixed number of vehicles.

The transmission delay with V2V multi-hop link is plotted with respect to different number of vehicles in Figure C2. The results correspond to the transmission distance of 200, 300, 400 meters, respectively. With the increasing number of vehicles, the transmission delay of link c_k also increases gradually. That is because large number of vehicles reduce the distance among adjacent vehicles and the transmission successful probability of millimeter wave link c_k is enhanced correspondingly. As of increasing number of vehicles, the transmission delay for messages in link c_k mainly depends on the messages retransmission delay in every hop link among adjacent vehicles. In this case, the more the number of vehicles is, the more the number of relay hops the link c_k induces. Hence, the total retransmission delay is increased.

Figure C3 shows the V2V link quality as a function of the number of vehicles n between the adjacent related the source vehicle v_a and the destination vehicle v_b when transmission ranges of vehicle are $R_T = 200m$, $300m$ and $400m$ respectively for the situation of fixed weight factors $\alpha = 0.5$, $\beta = 0.5$. The results in Figure C3 indicate that link quality I^* is a monotonous increasing function before declining with the increasing number of vehicles n. The LQSI reaches to the corresponding an

Table C1 SYSTEM PARAMETERS DEFINITION

Parameter	Value
Transmission Power $P_{tr}(dBm)$	30
Millimeter wave Bandwidth $B_{mW}(MHz)$	200
Noise power spectrum density $N_0(dBm/Hz)$	-174
Slot time $t_{slot}(\mu s)$	50
Transmission time $T_t(\mu s)$	20
Toleration time $T_{toler}(ms)$	20

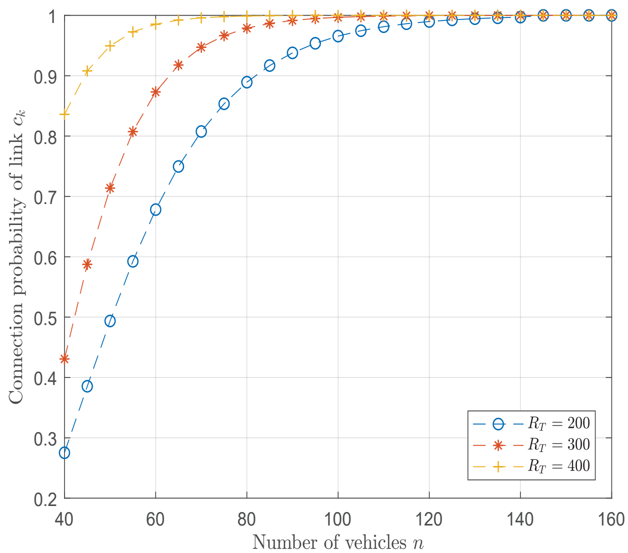

Figure C1 V2V multi-hop link c_k connection probability with respect to different number of vehicles.

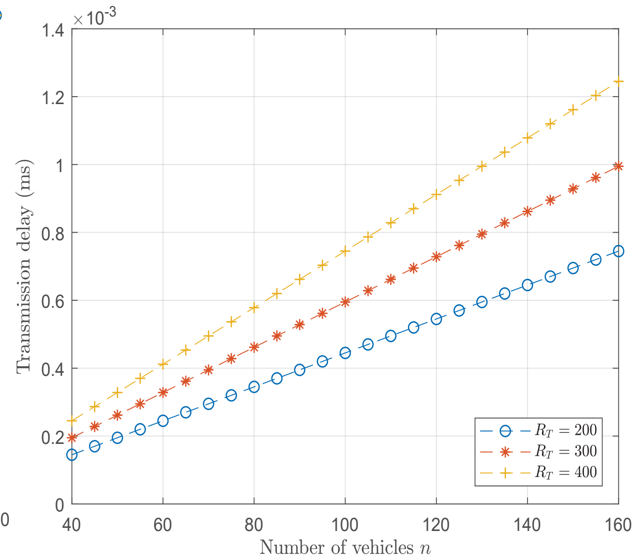

Figure C2 V2V multi-hop link c_k transmission delay with respect to different number of vehicles.

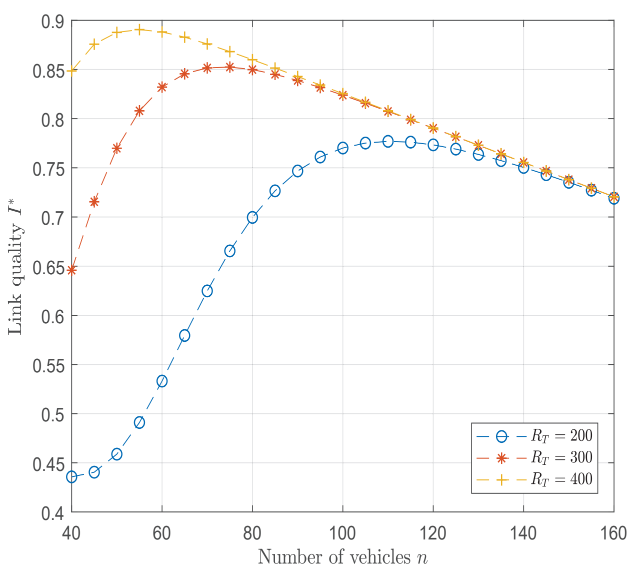

Figure C3 V2V multi-hop link quality with respect to different number of vehicles.

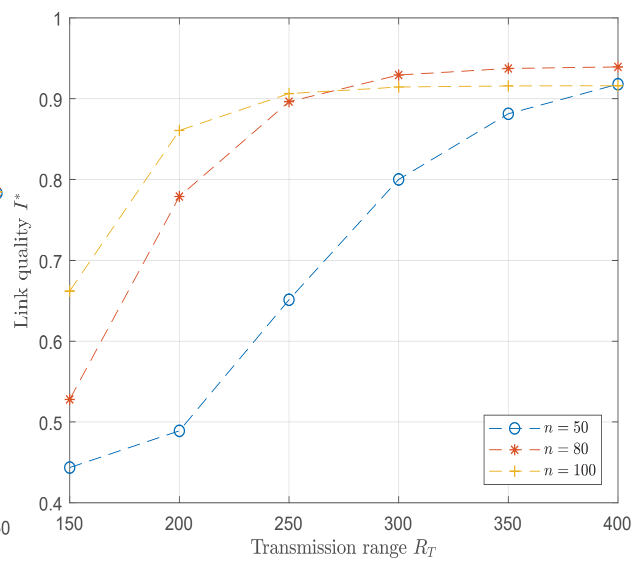

Figure C4 V2V multi-hop link quality with respect to different transmission ranges under different number of vehicles n.

optimal value I^* for different R_T with the increasing of number of vehicles. The reason is the improvement of performance in terms of link connectivity with the increasing of number of vehicles. Meanwhile, the link quality deteriorate gradually with the increasing number of vehicles. This is caused by the increasing inference among vehicles.

From Figure C4, we can see that the V2V link quality with different transmission ranges of vehicle in the case of different number of vehicles, $n = 50$, 80 and 100. We set weight factors for transmission successful probability and transmission delay as $\alpha = 0.5$ and $\beta = 0.5$, respectively. For different number of vehicles, there is an optimal transmission range R_T to achieve the best link quality. For the larger transmission range, the connectivity of link for fixed number of vehicles is improved. Relay vehicles will communicate with one vehicle at the way of close distance with a relatively large number of vehicles. So the link quality is enhanced. The link quality will decrease on account of burden from the large number of vehicles with the increasing of transmission range.

Figure C5 presents the V2V multi-hop link quality in terms of different weight factors α and β. In Figure C5, different weight factors corresponding to transmission successful probability and transmission delay reflect different service requirements. This results indicate that V2V multi-hop link quality and the optimal number of vehicles are different due

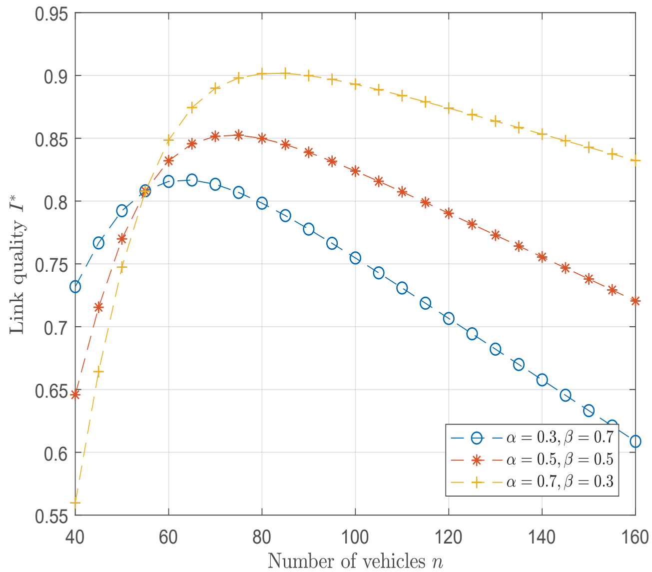

Figure C5 V2V multi-hop link quality with respect to different weight factors α and β.

to different service requirements of vehicular network on data transmission successful probability and transmission delay.

References

1 Ghosh A, Thomas T A, Cudak M C, et al. Millimeter-wave enhanced local area systems: A high-data-rate approach for future wireless networks. IEEE Journal on Selected Areas in Communications, 2014, 32(6): 1152-1163.

2 Zhang W, Chen Y, Yang Y, et al. Multi-hop connectivity probability in infrastructure-based vehicular networks. IEEE Journal on Selected Areas in Communications, 2012, 30(4): 740-747.