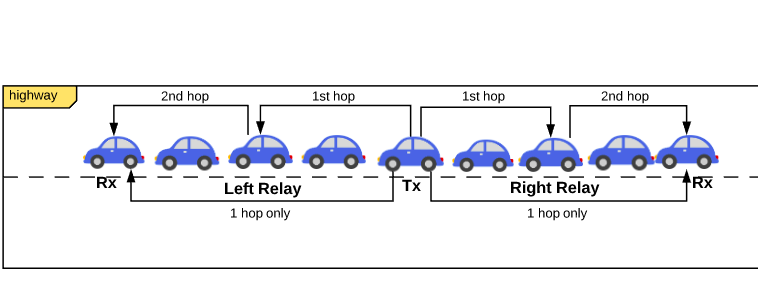
**Chapter 4 Two-hop network and resource allocation**

Over the past few years, single-hop vehicular transmission or multi-hop vehicular transmission in direct V2X communication has be widely used to deliver messages, such as hazardous situation information, road congestion information and traffic warning messages in direct V2X communication. These are all safety-related applications in order to reduce the possibility of vehicle trashes. So the transmission range and time delay concerned messages transmitting between transmitter and receivers count.

****

**Figure.1 single-hop network VS twice-hop network**

**4.1 Single-hop network**

Figure.1 illustrates the two concepts for a basic highway scenario where just two dissemination directions are considered. One concept is single-hop network, which is consisted of the transmitter and receivers in the proximity of the transmitter. The periodic status messages are transmitted by the only transmitter to other vehicles in the transmission range of the transmitter directly. Radio propagation only depends on the distance between transmitter and receiver. Single hop network can also deliver the messages to all intended receivers. But the successful transmission ratio matters.

**4.2 The limitation of single-hop network**

In the literature, the performance of V2X communication under cellular network control is restricted by using a single-hop direct V2X communication. Because single-hop direct V2X communication cannot fulfill the ultra-high reliability requirement of V2X communication in certain scenarios. For instance, as mentioned before, a V2X communication range up to 1000 meters should be achieved on a highway scenario in order to obtain a good perception of the environment and avoid accidents. [3GPP document, TR 22.886, *Study on enhancement of 3GPP support for 5G V2X services*, March 2017.]

However, packets transmission over single-hop direct V2X communication will reach the receivers far away from the transmitter with a bad signal quality. Because of the bad-quality of the receiving signals, the receivers have a high probability to not successfully receive the packets and therefore the reliability of the V2X communication is decreased.

**4.3 The limitation of multi-hop (more than two hops) network**

Also, the use of multi-hop transmission in V2X communication is spectrally inefficient as, in most cases, they need to transmit on orthogonal channels. And the performance of relaying processes along multiple-hop is unsuitable. [A. Bletsas, A. Khisti, D. P. Reed and A. Lippman, “A simple cooperative diversity method based on netwrok path selection”, *IEEE J. Sel. Areas Comm.*, Vol. 24, No. 3, pp.659-672, Mar. 2006.] In a multi-hop network, the same problem can be defined as hop selection and a related scheme is proposed in L. Ruan and V. K. N. Lau, [Decentralized dynamic hop selection and power control in cognitive multi-hop relay systems”, *IEEE Trans. on Wireless. Comm.*, Vol. 9, No. 10, pp. 3024-3030, Oct. 2010.] which involves power control as well to co-exist with the primary users. A common denominator in all these papers is that the secondary nodes are assumed to adapt their transmission power in order to always satisfy the interference constraint in underlay settings. However, this may not be the case in every network and the secondary nodes may have fixed transmission power. [Hussain S I, Alouini M S, Qaraqe K, et al. Reactive relay selection in underlay cognitive networks with fixed gain relays[C]//Communications (ICC), 2012 IEEE International Conference on. IEEE, 2012: 1784-1788.]

**4.4 Two-hop transmission network**

To improve traffic safety and efficiency, each vehicle on highway is required to broadcast its information like geometrical location, mobility pattern and its sensed environment information to other traffic participants within certain radius. And the radius is often referred to as the transmission range and its value is related to detailed service requirements. On this highway scenario, a communication range of 1000 meters is required. But the signal propagation loss can be quite high with such a large transmission distance. Also, the direct V2X communication over side link corresponds to a point-to-multi-point multicast transmission. [3GPP document, TS 23.303, *Proximity-based services (ProSe); Stage 2*, June 2017]. The transmitter of the single-hop direct V2X communication cannot be aware of the channel condition to all receivers. So the single-hop direct V2X cannot be guaranteed that all receivers can receive transmission packets with a good quality for successful packet decoding. In order to increase packet transmission range and increase V2X communication reliability, we propose a two-hop direct V2X communication over side link in this work. The packet transmission range is defined in this work as the range over which a packet can be successfully received. As figure.1 shows, two selected relays retransmit the messages received from the transmitter and consist the twice-hop communication network with the transmitter. The transmitter generates the packets and transmits over the side link. After the first-hop transmission, a selected vehicle which has successfully received the packets from the first-hop can be triggered as a relay and retransmits the received packets to other receivers that have not received the packets successfully in the proximity of the relay. So the transmission link between the relay and its receivers is called as the second hop. Therefore, all receivers under the transmission range of the transmitter try to receive the packets successfully from at least one of the two hops. In the two hops transmission network, messages are transmitted with a low frequency or a low transmit power in the first hop, and then retransmitted by selecting relays until the desired dissemination range is covered. [Mittag J, Thomas F, Härri J, et al. A comparison of single-and multi-hop beaconing in VANETs[C]//Proceedings of the sixth ACM international workshop on VehiculAr InterNETworking. ACM, 2009: 69-78.] The fundamental purpose of this work is to maximize the performance of the communication systems with limited frequency and time resources.

**4.5 Transmission Range Maximization for Two-Hop Direct V2X Communication**

As mentioned before, the two-hop direct V2X communication over side link can be applied to extend packet transmission range. The amount of resource allocated to the first hop and second hop should be adapted by the network in an efficient way in order to maximize the overall packets transmission range.

So the problem about the maximum transmission range shows as following,

Maximize (1)

Subject to (2)

(3)

(4)

Eq. (1) represents the maximization of the transmission range by allocating bandwidth and for the two hops respectively. The function represents as the transmission range function and used to calculate the packet transmission range if bandwidth resources are allocated to the direct V2X hops. So and

stand for the packet transmission range for the first and second hop correspondingly. Also, and stand for the bandwidth allocated to the two hops. Eq. (2) - (4) present the constraints, which mean allocated bandwidth resource cannot exceed the overall available bandwidth.

**4.5.1 Maximize the packet transmission range**

in order to get the maximum transmission distance, a general formula to calculate the path loss is used here, as:

(5)

is the amplitude which is a constant value and is the distance between transmitter and receiver. Empirically, the relation between the average received power and the distance is determined by the expression where is called the path loss exponent that is related with the concrete communication signal.

Therefore, we calculate the receiving power at the -th receiver for a packet transmitted by -th transmitter, as:

(6)

is the transmission power and is the distance between the-th transmitter and -th receiver. And we assume that all transmitters use the same transmission power with . Furthermore, the Signal to Interference plus Noise Ratio (SINR) of-th receiver is expressed as:

(7)

where the stands for the interference from the transmitters that transmits the packets over the resource of the -th transmitter. And represents the noise power. For simplification, is used to present the interference power, if the -th receiver is trying to receive a packet from

-th transmitter, as:

= (8)

Therefore, Eq. (7) can be represented as

(9)

In order to receive packets successfully from the -th transmitter, the SINR value of the -th receiver should be better than a threshold value. We can calculate the threshold SINR value from Shannon-Hartley theorem which represents the maximum rate at which information can be transmitted over a communications channel of a specified bandwidth in the presence of noise, as:

(10)

is the capacity and is also the maximum rate of information. is the transmission bandwidth. Therefore, the SINR threshold value for successful receiving a packet can be calculated as:

(11)

So the calculated value should be greater than the , as:

(12)

therefore,

(13)

In order to fulfil the equality in Eq. (13),

(14)

Therefore, the maximum distance where a packet can be successfully received can be derived as:

(15)

From Eq. (15), the transmission range of a single hop direct V2X over side link is not only affected by the allocated resource but also it has the relation with the interference. The interference of the first hop transmission is impacted by the allocated resource scheme.

In addition, the capacity of the transmission system can be derived from the real V2X communication scenario, as:

(16)

where vehicles in total are in coverage of a base station, and each vehicle tries to transmit a packet with size of bits periodically with a frequency packets per second.

From Eq. (1) and Eq. (15), we get the equation as:

(17)

So Eq. (17) represents the maximal transmission range between two hops direct V2X communication over side link. Also the maximum transmission range is the radius of transmission.

**4.6 Resource allocation between two hops**

As mentioned before, the resource allocation between the first hop and the second hop transmissions should be adapted to increase the packet transmission range. As Eq. (17) shows that the maximum transmission range is also related with the sum of the interference power and noise power. Noise power is affected by resource allocation. Because we take thermal noise into consideration which is -174 dBm/Hz. For example, if the allocated bandwidth is 10MHz, and then the noise power is -97 dB. Also, the interference power is not constant and related with the position of the transmitters which transmit the packets on the same radio resource.

**4.6.1 Resource Allocation Modes**

V2X side link transmission mode 3 and V2X side link transmission mode 4 which are used to allocate the resource to a V2X transmitter in LTE 14[3GPP document, TS 36.213, *Evolved Universal Terrestrial Radio Ac- cess (E-UTRA); Physical layer procedures*, September 2017.]

* V2X side link transmission mode 3: The transmission resource is scheduled by network and therefore network can allocate the same radio resource to different transmitters.
* V2X side link transmission mode 4: a V2X transmitter autonomously selects a resource from a resource pool which is either configured by network or pre-configured in the user device.

Network can allocate the same resource to different zones if they are satisfied with a distance larger than a threshold. The distance threshold value for both modes should be decided in a way that the mutual interference power is small enough. In order to estimate the interference, so the network should be aware of the path loss model of the communication system.

in this work, the distance threshold value is large enough, so the mutual interference power is much lower than the noise power. Therefore, the Eq. (17) can be simplified as:

(18)

To differentiate the objective function as:

(19)

with the constraint function in Eq. (2) – Eq. (4), the objective function will be maximized if Eq. 20 is satisfied, as:

(20)

so (21)

when , the transmission range is maximized.