Journal of Southeast University (English Edition) Vol. 28, No. 2, pp. 135 – 139 June 2012 ISSN 1003—7985

Satellite and high altitude platform-based inter-vehicle communications in vast and desolate areas

Lin Yuanguai[1, 2] Wang Lin[1] Shen Lianfeng[1]

([1] National Mobile Communications Research Laboratory, Southeast University, Nanjing 210096, China)

([2] College of Electronics Information and Engineering, Qiongzhou University, Sanya 572022, China)

Abstract: In order to solve the problem of inter-vehicle communication (IVC) in vast and desolate areas such as the desert and the Gobi, two vehicle network models are proposed. One is based on satellite communication and the other is based on high altitude platform (HAP) communication. The system outline and networking modes of the two models are described. In the satellite communication based model, all the vehicles are equipped with vehicle-bone satellite communication on the move terminals and the communication signals between vehicles are forwarded by satellite. In the high altitude platform-based model, the HAPs are equipped with base station facilities to form aerial base stations, and vehicles can communicate with each other via common terrestrial mobile communication devices. Some key parameters such as path loss, link loss and system capacity are also computed. The analysis shows that both the two models can satisfy the requirement of IVC in the descriptive environment.

Key words: inter-vehicle communication; satellite communication; high altitude platform communication; terrestrial mobile communication device; system capacity

doi: 10.3969/j.issn.1003 – 7985.2012.02.001

In vast and desolate areas such as the desert or the Gobi and so on, few communication infrastructures are available due to the extreme climate and the low density of population. Therefore, communication among vehicles traveling in those areas becomes quite difficult. Drivers, who are usually unfamiliar with the road conditions there, are easy to get lost and be in danger. In this case, researches of inter-vehicle communication (IVC) in vast and desolate areas are very essential, especially for activities such as military affairs, scientific expeditions and explorations.

In recent years, vehicular ad hoc network (VANET), which provides IVC capability, has received remarkable attention. Most of the VANET researches have focused on urban roadway conditions[1–2], where the inter-vehicle space is small; the number of vehicles is large; the roads have already existed and been regular; and all kinds of terrestrial communication infrastructures are available. There are also some researches about VANET on highways[3]. Compared with the urban areas, the vehicles on highways are relatively sparse and the terrestrial communication infrastructures available are fewer. But the vehicles there still travel on the existing roads and can improve the capability of VANET with the help of some roadside units[3]. However, in the desert or the Gobi, vehicles cannot move along regular roads. What's more, there are no available terrestrial communication infrastructures. So the theories of the two scenarios mentioned above are not suitable for IVC in the desert or the Gobi.

Satellite communication is well known for its long communication distance, large coverage area, fast networking as well as no limitations on the application environment. Recently, vehicle-bone satellite communication on the move (COTM) technique has improved a lot[4]. Despite all the advantages mentioned above, satellite communication also has some evident disadvantages, such as expensive devices, pretty high fees and limited communication resources. Therefore, another vehicle network model which is based on the high altitude platform (HAP)[5] is proposed. In this model, base station (BS) facilities are carried to the space of the desert or the Gobi by the HAP to form aerial BSs. Thus vehicles can communicate with one another by using common terrestrial mobile communication devices. This kind of model can effectively overcome the shortcomings of the satellite communication.

1 System Outline

1.1 Vehicle network based on satellite communication

There are three assumptions of the application scenario of the vehicle network based on satellite communication as follows:

Received 2012-01-13.

Biographies: Lin Yuanguai (1972—), female, associate professor, graduate; Shen Lianfeng (corresponding author), male, professor, lfshen@seu.edu.cn.

Foundation items: The National High Technology Research and Development Program of China (863 Program) (No. 2008AA01Z205), the Specialized Development Foundation for the Achievement Transformation of Jiangsu Province (No. BA2010023), the Natural Science Foundation of Hainan Province (No. 609008), Sanya University and Local Government Technological Cooperative Project (No. 2010YD29).

Citation: Lin Yuanguai, Wang Lin, Shen Lianfeng. Satellite and high altitude platform-based inter-vehicle communications in vast and desolate areas[J]. Journal of Southeast University (English Edition), 2012, 28 (2): 135 – 139. [doi: 10.3969/j.issn.1003 – 7985.2012.02.001]

1) Vehicles travel in the desert or the Gobi, with no access to any terrestrial communication infrastructure.

2) All the vehicles are equipped with vehicle-bone satellite COTM terminals, which can ensure stable and effective two-way communication between vehicles and satellites while vehicles are moving at a high speed.

3) There are no existing roads in the desert or the Gobi. So the directions of vehicles are random.

The satellite communication is the only way of communication among vehicles in this scenario. The coverage area of a satellite is so large that one satellite can cover the entire desert. Take the Iridium system as an example[6]. It is one of the low earth orbit (LEO) satellite systems, which has 66 satellites at an altitude of 780 km above the earth. Every single satellite has 48 spot beams. Each of them corresponds to a cell of 667 km in diameter on earth. So the diameter of the total coverage area of each satellite is about 4 000 km. The largest desert in China is the Taklimakan Desert, which is about 1 000 km in length and 400 km in width. Therefore, two cells of the Iridium satellite can cover the whole desert. The coverage areas of the middle earth orbit (MEO) and the geostationary earth orbit (GEO) satellite are much larger than those of the LEO satellite, as their orbit heights are much higher. As a result, only one satellite is needed in this model. The vehicle network model based on a satellite is shown in Fig. 1. All the vehicles communicate with one another via the satellite. They can also get access to the terrestrial core networks outside the desert or the Gobi like Internet and the public land mobile network (PLMN) through the gateway of the satellite.

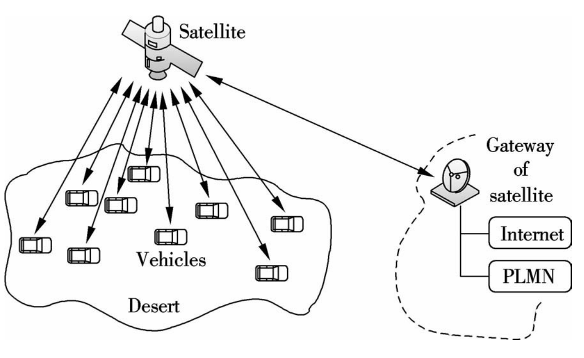

Fig. 1 Vehicle network model based on satellite

1.2 Vehicle network model based on HAP

Because of its large coverage area and almost no limitations on the environment, satellite mobile communication has become one of the most important methods in researching the vehicle network in the desert or the Gobi. But it also has many shortcomings. Satellite communication always has a big problem of long delay and large path loss. What's more, in the desert or the Gobi scenario mentioned above, the vehicle network based on a satellite has problems as follows:

1) All the vehicles should be equipped with satellite COTM terminals which are quite expensive. Therefore, the cost for equipment installation will be very high as the number of vehicles increases.

2) Compared with common terrestrial mobile communication, fees of satellite mobile communication are much higher.

3) Sources provided by satellite mobile communication are very limited. The broadband transmission is very difficult. For example, the data transmission rate of the Iridium system is only 2.4 kbit/s[6] and that of the GlobalStar system is 7.2 kbit/s[7]. Even for the Inmarsat system which has developed quickly in recent years, the two-way data transmission rate of its widely used M4 standard is only 64 kbit/s[8].

Due to the problems of satellite communication mentioned above, another vehicle network model based on the HAP is presented. A suitable HAP is usually considered to be a quasi-stationary unmanned vehicle in the stratosphere at an altitude between 17 and 20 km[9]. It should maintain its position within a sphere having a radius of 0.5 km[10]. As an aeronautical platform, HAPs can take different forms, such as unmanned airships and hot balloons. HAPs combine the advantages of both the satellite and the terrestrial mobile communications, which has brought it considerable attention in recent years. They have lower free space loss (FSL) and less transmission delay when compared to satellites. They provide larger coverage when compared with terrestrial networks. What's more, the position of HAPs can be changed according to the communication requirements so that the network can be reconfigured flexibly.

The assumption of the aerial BS presented in this paper will use HAPs to carry the BS facilities into space. In this way, vehicles travelling in the coverage area of the aerial BSs can communicate with one another via common terrestrial mobile communication devices. The network of aerial BSs, such as the third generation (3G) cellular network, can provide broadband transmission. For example, the data transmission rate of TD-SCDMA is 384 kbit/s while travelling at a high speed. In conclusion, the vehicle network model based on the HAP can solve the problems of satellite mobile communication effectively.

There are four assumptions of the application scenario of the vehicle network based on the HAP as follows:

1) Vehicles travel in the desert or the Gobi, with no access to any terrestrial communication infrastructure.

2) HAPs, carrying BS facilities within them, stay in space at an altitude of 20 km. The influences of slow movements of HAPs are ignored. That is, the HAP maintains its position within a sphere having a radius of about 0.5 km. Compared with the high speed of the vehicles in the desert or the Gobi, the influences of HAPs' slow movements can be ignored.

3) In the coverage area of the HAP, vehicles can communicate with one another via common terrestrial mobile communication devices such as a 3G network.

4) There are no existing roads in desert or Gobi. So the directions of vehicles are random.

The vehicle network model based on the HAP is shown in Fig. 2. In the coverage area of the aerial BS, vehicles in desert or Gobi communicate with each other through the BS. Vehicles can also connect with terrestrial core networks via satellites or microwave links of aerial BSs. If broadband data transmissions are needed between vehicles and terrestrial core networks, data should be transmitted via the microwave links of aerial BSs. Otherwise, data can be transmitted through the satellite.

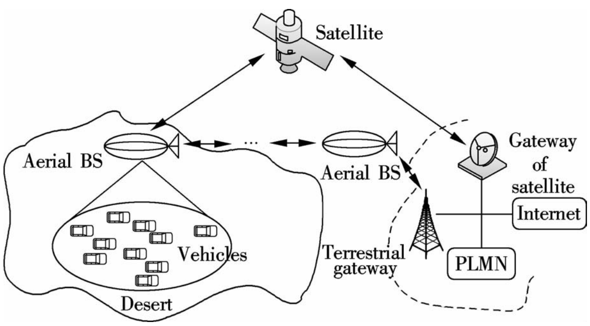

Fig. 2 Vehicle network model based on HAP

2 Networking Modes

2.1 Networking modes of vehicle network model based on satellite communication

The networking modes of the vehicle network model based on satellite communication can be divided into two kinds according to the existence of on-satellite handling technique as follows:

1) On-satellite handling technique based On-satellite handling technique means that satellites are equipped with on-satellite handling facilities which can demodulate, read addresses, etc. There are inter-satellite links in this kind of system. In this case, users can start the call with a satellite mobile communication device at any place on the earth. The call request can be forwarded to the called device far away via the inter-satellite links. In this process, no terrestrial facilities are needed. This kind of system is almost independent of terrestrial networks and gateways. The communication data among vehicles are forwarded by the satellite, which is shown in Fig. 3(a).

2) Transparent forwarding based Transparent forwarding on the satellite means that the received data only get the necessary easy handling and then are forwarded to earth by the forwarding devices. There are no links between satellites. All the handling and switching processes are performed by terrestrial facilities. In this case, a fair number of terrestrial gateways are required. In this system, there must be two hops while two vehicles try to connect. First, the vehicle which starts the call should establish a link between the satellite and itself. Then the satellite forwards the call request to its terrestrial gateway. Finally, the gateway forwards the request to the target vehicle through the satellite. The process is shown in Fig. 3(b). The delay of this system is evidently much longer than that of the satellite system based on the on-satellite handling technique.

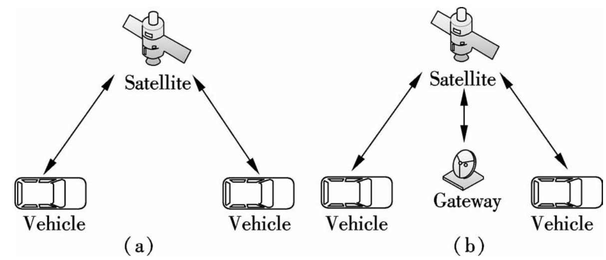

Fig. 3 Networking modes of the vehicle network model based on satellite communication. (a) Communication only by the satellite; (b) Communication by the satellite and the gateway

2.2 Networking modes of vehicle network model based on HAP

The coverage area of the HAP should be discussed first. Assume that the HAP stays in an altitude of 20 km and the minimum elevation angle of the user is 5°. Then it can be calculated that the radius of the coverage area of the HAP is 229 km, as shown in Fig. 4.

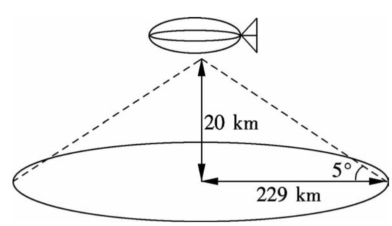

Fig. 4 Coverage area of HAP

Therefore, when all the vehicles travel in an area with a radius of 229 km, only one HAP is needed in the system and it is shown in Fig. 5(a). When the number of vehicles is extremely high and their travelling area is rather large, several HAPs are needed to form an aerial cellular network, and it is shown in Fig. 5(b). Actually, in practical applications, such as military affairs, scientific expeditions and explorations in the desert or the Gobi, the distribution of vehicles is relatively concentrated and an area with a radius of 229 km can cover all the vehicles. The situation shown in Fig. 5(a) will be studied in detail.

3 Key Parameters

3.1 Path loss and link loss

The link loss in free space is discussed first. The power P_r absorbed by the receiving antenna in free space is[11]

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 = P_t G_t G_r \left(\frac{c}{4\pi d f}\right)^2 \tag{1}$$

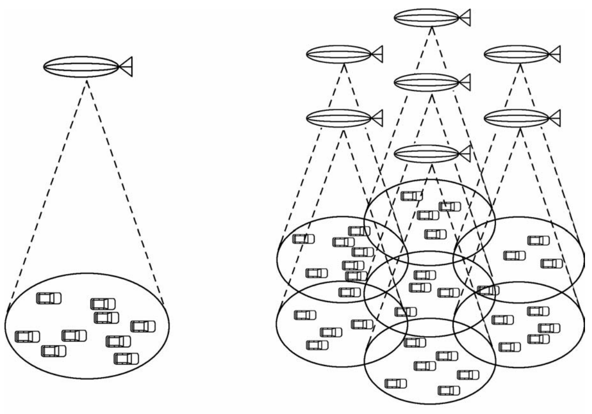

Fig. 5 Networking modes of the vehicle network model based on HAP. (a) Only one HAP in the system; (b) Several HAPs to form an aerial cellular network

The link loss L_{link} is

$$L_{\text{link}} = 10\lg\left(\frac{P_t}{P_r}\right) = 32.4 + 20\lg f + 20\lg d - G_t - G_r \quad (2)$$

The path loss L_{path} is

$$L_{\text{path}} = 32.4 + 20\lg f + 20\lg d \quad (3)$$

where P_t is the transmitting power; P_r is the receiving power; G_t is the gain of the transmitting antenna, dB; G_r is the gain of the receiving antenna, dB; f is the carrier frequency, MHz; and d is the distance between the terminal and the satellite or HAP, km. Take the downlink as an example. Here, the Iridium system is taken as an example of the LEO satellite systems, the Inmarsat system as an example of the GEO satellite systems and the GSM 900 system as an example of the BS in the HAP. The values of the variables in the equation of L_{link} and L_{path} are shown in Tab. 1.

Tab. 1 Values of variables in the equation of L_{link} and L_{path}

Type of model	G_t/dB	G_r/dB	f/MHz	d/km	
				The shortest distance	The longest distance
GEO (Inmarsat)	42	1.7	1 538	36 000	38 380
LEO (Iridium)	23.1	1.0	1 616	780	1 696
HAP (GSM 900)	7	0	935	20	229.5

The calculation results of L_{link} and L_{path} is shown in Tab. 2. It is seen that the path loss of the vehicle network model based on the satellite is much higher than that of the vehicle network model based on the HAP. In order to obtain a relatively close link loss, the gain of the antenna on satellite should be much larger.

Tab. 2 The calculation results of L_{path} and L_{link}

Type of model	L_{path}/dB		L_{link}/dB	
	The shortest distance	The longest distance	The shortest distance	The longest distance
GEO (Inmarsat)	187.265 2	187.821 2	143.565 2	144.121 2
LEO (Iridium)	154.410 7	161.157 3	130.310 7	137.057 3
HAP (GSM 900)	117.836 8	139.031 9	110.836 8	132.031 9

3.2 Capacity of system

The capacity of the FDMA and TDMA cellular system is[11]

$$m = \frac{B_t/B_c}{K} \quad (4)$$

where m is the capacity of the system; B_t is the total bandwidth assigned to the system; B_c is the channel bandwidth; and K is the number of cells in the area.

If the vehicles travel within an area having a radius of 229 km, only one HAP is required. Thus, $K = 1$. Still, take the GSM 900 system as an example of the BS in the HAP. The uplink frequency is from 890 to 915 MHz, while the downlink frequency is from 935 to 960 MHz. Therefore, the total bandwidth of the GSM 900 is 25 MHz. The channel bandwidth is 200 kHz. Then the capacity of the GSM 900 system is

$$m = \frac{25\ 000/200}{1} = 125 \text{ channels/cell}$$

The capacities of the different systems are shown in Tab. 3.

Tab. 3 The capacity of different systems

Type of model	Capacity/(channels · cell^{-1})
GEO (Inmarsat)	25
LEO (Iridium)	80
HAP (GSM 900)	125

It can be seen from Tab. 3 that the capacity of the vehicle network based on the HAP is much larger than that of the vehicle network based on the satellite. Actually, the area of one cell of the satellite is several times larger than that of one cell of the BS in the HAP, which means that the capacity difference of the different systems is actually greater than that shown in Tab. 3.

From the calculation results of the important parameters such as path loss, link loss and the system capacity, the vehicle network based on the HAP is better than the vehicle network based on the satellite in several different aspects. Therefore, it is of high value and deserves considerable attention.

4 Conclusion

In this paper, two vehicle network models based on satellite and the HAP for IVC in the desert or the Gobi are proposed. The most outstanding characteristic of the vehicle network model based on the satellite is large coverage area. The vehicles can connect with one another via satellite at any place in the desert or the Gobi. On the other hand, the vehicle network model based on the HAP is established on the theory of the existing cellular network. Vehicles can access one another by using common terrestrial mobile communication devices. The path loss, link loss and capacity of the two models are computed. To conclude, both of the models can effectively satisfy the need of IVC in the desert or the Gobi.

References

[1] Wu Y, Shen L F, Shao Z H, et al. Power control algorithm based on vehicular probe message in vehicular ad hoc network [J]. *Journal of Southeast University: Natural Science Edition*, 2011, **41**(4): 659 – 664. (in Chinese)

[2] Wu Y, Yang Q, Wu Q X, et al. A networking algorithm based on self-organizing map neural network for VANET [J]. *Journal on Communications*, 2011, **32**(12): 136 – 145. (in Chinese)

[3] Sou S I, Tonguz O K. Enhancing VANET connectivity through roadside units on highways [J]. *IEEE Transactions on Vehicular Technology*, 2011, **60**(8): 3586 – 3602.

[4] Farinelli P, Chiuppesi E, Di M F, et al. Development of different K-band MEMS phase shifter designs for satellite COTM terminals [C]//*Proceedings of the 4th European Microwave Integrated Circuits Conference*. Rome, Italy, 2009: 515 – 518.

[5] Mohammed A, Mehmeed A, Pavlidou F, et al. The role of high-altitude platforms (HAPs) in the global wireless connectivity [J]. *Proceedings of the IEEE*, 2011, **99**(11):1939 – 1953.

[6] Pratt S R, Raines R A, Fossa C E, et al. An operational and performance overview of the IRIDIUM low earth orbit satellite system [J]. *IEEE Communications Surveys & Tutorials*, 1999, **2**(2): 2 – 10.

[7] Dietrich F J, Metzen P, Monte P. The globalstar cellular satellite system [J]. *IEEE Transactions on Antennas and Propagation*, 1998, **46**(6):935 – 942.

[8] Ilcev S D. Inmarsat satellite-based global business solutions for remote and rural communications [C]//*The 7th AFRICON Conference in Africa*. Gaborone, Botswana, 2004: 31 – 37.

[9] Kandus G, Svigelj A, Mohorcic M. Telecommunication network over high altitude platforms [C]//*The 7th International Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Services*. Serbia and Montenegro, Yugoslavia, 2005: 344 – 347.

[10] Holis J, Pechac P. Elevation dependent shadowing model for mobile communications via high altitude platforms in built-up areas [J]. *IEEE Transactions on Antennas and Propagation*, 2008, **56**(4):1078 – 1084.

[11] Simon H. *Communication systems* [M]. Beijing: Publishing House of Electronics Industry, 2003.

基于卫星和高空平台的广袤荒漠场景集团车辆通信

林元乖[1,2]　王　琳[1]　沈连丰[1]

([1] 东南大学移动通信国家重点实验室, 南京 210096)
([2] 琼州学院电子信息工程学院, 三亚 572022)

摘要:为了解决诸如沙漠、戈壁等广袤荒漠场景集团车辆通信问题,提出了基于卫星通信和基于高空平台通信2种车辆间组网模型,并给出了这2种模型的系统框架和组网模式. 在基于卫星通信模型中,所有车辆均配备车载“动中通”卫星通信终端,车辆间通信信号由卫星转发. 在基于高空平台通信模型中,装载基站设备的高空平台形成了空中基站,车辆使用普通地面移动通信设备即可通信. 此外,对路径损耗、链路损耗和系统容量等关键参数进行了计算. 分析结果表明,所提出的2种模型能够满足所述场景车辆间的通信需求.

关键词:车辆间通信;卫星通信;高空平台通信;陆地移动通信装置;系统容量

中图分类号:TN915