Memorial University of Newfoundland
Faculty of Engineering and Applied Science

ENGI 980B: Computer engineering project

Project Report

"The survey of Space-Air-Ground Integrated network"

Instructor: Dr. Cheng Li

Ziyang Li

#201893331

Date: December 21, 2020

1. Introduction

With the rapid development of science and technology, it is generally recognized that traditional communication technology is facing significant challenges. The increase of user accesses and the improvement of user accuracy need to be solved. The networks of the future need to accommodate hundreds of times more than today's network throughput. As a result, the limitations of ground communications have increased significantly. At the same time, reliable, high-speed Internet access is not available in extreme environments such as oceans and mountains. Therefore, new network systems have become the primary solution to propose and implement next-generation network technologies and standards. The concept of space, air, and ground integration (SAGIN) network system has been submitted and attracted scholars' attention.

The advent of SAGIN has dramatically improved data connectivity. Satellites can provide seamless connectivity for extreme areas, air networks can increase the area covered, and the intensity of the ground network determines access to high-speed networks. SAGIN is particularly outstanding in many functional areas, such as mapping maps, military missions, disaster relief, etc.

The main challenge of the existing research on the SAGIN network is integrating the three-part network, that is, how the three-part network works as a whole part. Meanwhile, Satellite networks have very high latency, and the maintenance and use costs are too high. Furthermore, the guarantee of QoS and security between multi-layer transmissions are significant challenges.

The first part of this article introduces the current situation of the SAGIN system, and the second part adds the vehicle network to the system to form the basic SAGVN system. In the third part, the civil airliner network expands the structure of the system. The fourth part summarizes the existing SAGIN system and its extension application.

2. SAGIN system

2.1 SAGIN normal architecture

Figure 1 shows the main components of SAGIN, space networks, air networks, and ground networks. These three parts can work interrelatedly or independently.

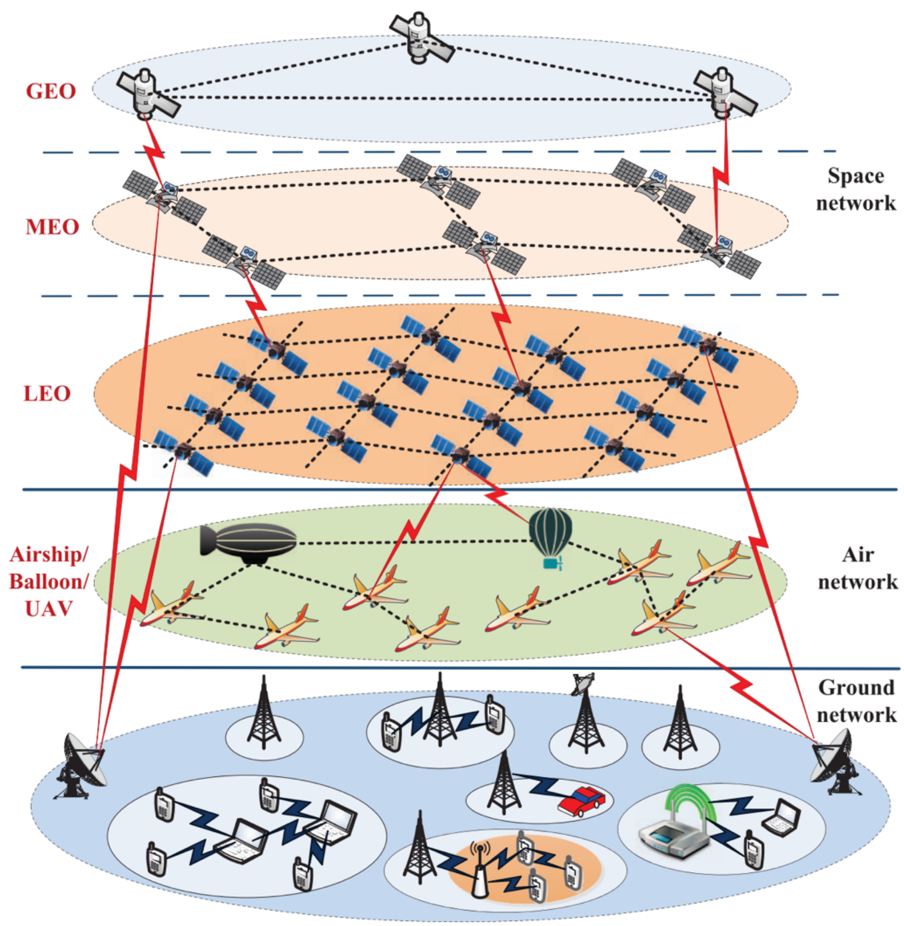

Figure 1. The normal architecture of SAGIN [1]

Space networks are made up of satellites, constellations, and space network infrastructure. Depending on the location of the Earth, satellites can be divided into GEO, MEO, and LEO. LEO and MEO satellites can be called narrow-band satellite networks, mainly providing users with lower-rate data services. GEO is also called a broadband satellite network that provides faster data transmission. The interconnectedness of the various layers of satellites forms a multi-layer satellite network (MLSN).

Air networks use airborne mobile equipment, such as drones, airships, hot air balloons, as carriers for information collection and transmission. The air network has the advantages of low energy consumption, low cost, easy deployment, wide range, etc.

The ground network is mainly composed of cellular networks, WLAN, and other ground communication systems. Cellular systems are already in the fifth generation of network systems (5G). Ground networks can provide users with data rates, but network coverage is also limited in extreme areas.

Table 1 compares the primary data for these three networks. Space satellite networks can achieve network coverage across the earth, but the transmission delay is high. Ground network layers are vulnerable to natural or human-made damage. Even if the delay is low and the coverage is extensive, air networks need to consider the air carrier capacity, link stability, and other issues.

Segment	Objects	Hight above earth	One way delay	Data rates	Advantages	Disadvantages
space	GEO	35,786km	about 270ms	least performance	large coverage, broadcast/multicast	long propagation latency, limited capacity, high mobility
	MEO	2000-35,786km	about 110ms	up to 1.2Gbps		
	LEO	160-2000km	less than 40ms	up to 3.75Gbps		
air	airship balloon UAV	17-30 km (HAP), less than 10 km (LAP)	medium	high data rates	wide coverage, low cost, flexible deployment	less capacity, unstable link, high mobility
ground	cellular Ad Hoc WiMAX WLAN	N.A.	lowest	high data rates	rich resources, high throughput	limited coverage, vulnerable to disaster

Table 1. Comparison among SAGIN different network layers

2.2 Existing SAGIN systems

Several SAGIN systems have been constructed over the past few decades, consisting mainly of two parts, using the geostationary orbit (GEO) satellite system and the non-GEO (NGEO) system, as Table 2.

	Name	Satellite system	Features
GEO System	Global Information Grid (GIG)	GEO	ground layer, space layer, near-earth space layer, satellite layer, including seamless global communication nodes and equipment
	Transformational Satellite System (TSAT)	GEO	TSAT consists of five GEO satellites and forms a high-speed network between them, giving the ground terminal real-time access to optical and radar images captured by the air network and the satellite.
NGEO System	O3B	MEO	O3b is mainly designed to help 3 billion people in Africa, Asia, and South America access the network
	Iridium	LEO	The primary purpose of Iridium is to provide voice services with global coverage.
	Globalstar	LEO	Globalstar is used to provide seamless satellite telephone services around the world.

Table 2. The summary of existing SAGIN

GIG and TSAT are typical GEO systems. The Global Information Network (GIG) is a full-size communications project designed by the U.S. Department of Defense, consisting mainly of four parts: ground layer, space layer, near-Earth space layer, and satellite layer. At the same time, GIG includes seamless global communication nodes and devices. Transformational satellite system (TSAT) is a satellite system developed by NASA, the U.S. Department of Defense, and the Central Intelligence Agency in applications and military fields. TSAT consists of five GEO satellites and forms a high-speed network between them, giving the ground terminal real-time access to optical and radar images captured by the air network and the satellite.

O3b, Iridium, and Globalstar are representatives of NGEO systems. O3b is mainly designed to help 3 billion people in Africa, Asia, and South America access the network, primarily using the Medium Earth Orbit (MEO) Satellite. O3b uses 12-20 MEO satellites to form a constellation network, and now four satellites are launched. The primary purpose of Iridium is to provide voice services with global coverage. The constellation network consists of 66 low earth orbit (LEO) satellites with the same processing capacity and routing. Globalstar is used to provide seamless satellite telephone services worldwide, and its constellation network consists of 48 LEO satellites and eight satellite orbits.

2.3 Physical layer features

When designing and optimizing wireless networks, the three primary characteristics of its physical layer should be fully considered.

The first is the frequency band. The frequency of air-to-ground and space communications is mainly assigned by the International Telecommunication Union. Table 3 lists the prominent frequency bands and their characteristics.

Frequency band	Frequency range (GHz)	Intended services
L	0.39 - 1.55	GPS, satellite phone, space-air and air-ground communications
S	1.55 - 3.4	weather radar, NASA, deep space research
C	3.4 - 8	full-time satellite TV, air-ground communications
X	7.925 - 12.5	radar applications
Ku	12.5 - 16	broadcast satellite services
K	18 - 26.5	broadcast satellite services
Ka	26.5 - 36	close-range targeting radars on military aircraft
Q	36 - 46	high throughput satellite services
V	46 - 56	high throughput satellite services
W	75 - 110	high throughput satellite services

Table 3. Frequency bands in SAGIN communications

The second factor is the propagation channel. SAGIN is different from traditional ground communication, the transmission distance of each layer network is long, and the error rate is high. Therefore, the optimization of transmission channels becomes essential.

The third factor is that SAGIN is a multi-layer network structure, so the impact of cross-layer transmission on other layers should be summed up in the network's design idea. Any change in the system between the three segments will affect the channel of the physical layer, and even affect the traffic and routing control of the upper layer, which in turn affects the whole network structure.

2.4 The applicability of existing network architecture

The ad hoc network, also known as the wireless ad hoc network, is a temporary, non-standard wireless mobile terminals network. In this network, a single node can dynamically discover other nodes that it can connect directly. Examples of ad hoc are emerging, such as the vehicle ad hoc network (VANET), the flying ad hoc network (FANET), and so on. The ad hoc network is suitable for network construction in exceptional cases, such as geological disaster relief. It is characterized by the fact that the infrastructure cannot be relied upon under certain circumstances. Connecting the ad hoc network to SAGIN can effectively improve the efficiency of network utilization. Combined with satellite and aviation networks, VANET will provide reliable communications with the advantages of extensive coverage and flexibility. As an emerging technology, Drone communication has the characteristics of flexible deployment, broadband wireless access, and dynamics. Drone enhancement VANET not only improves infrastructure coverage and car-to-car connectivity but also provides better road safety.

2.5 The challenges faced by SAGIN

SAGIN is not perfect, and it is also facing problems in the process of development. Satellite networks have very high latency, and the maintenance and use costs are too high, the guarantee of QoS between multi-layer transmissions, the choice of gateways, and how to choose the right channel. And the security and privacy of the cross-layer transfer. These are all problems that cannot be ignored in the development of the SAGIN network.

3.SAGVN

3.1 V2X communications

3.1.1 Introduction

In the past decade, vehicular networks have attracted broad interests from academia, industries, and governments due to their potential colossal impact on our daily lives. Notably, in 1999, FCC has allocated a specific spectrum band for the exclusive use of vehicular networks. In 2010, IEEE also approved a new standard, IEEE 802.11p, to enable wireless access in vehicular environments, namely WAVE.

For vehicle network, different types communications are combined the V2X communications. Table 4 is an integration.

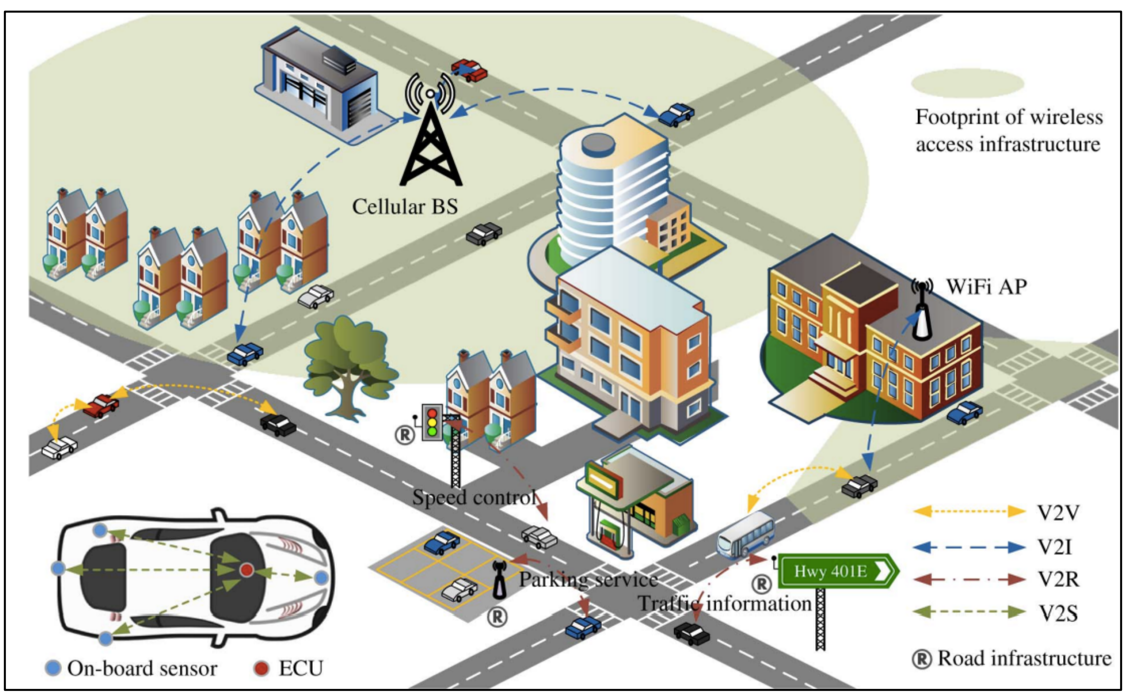

Figure 2. The structure of V2X communications [2]

Type	Abbreviation	Description
Vehicle to vehicle communications	V2V	communication between vehicles, for safety applications.
Vehicle to infrastructure	V2I	communication between vehicles and wireless access infrastructure.
Vehicle to pedestrian	V2P	Communication between vehicles and pedestrians on the road.
Vehicle to cloud	V2C	Communication between vehicles and cloud services.
Vehicle to sensor	V2S	Communication between vehicles and sensor units.
Vehicle-to-Roadside	V2R	communication between vehicles and ITS (roadside) infrastructure.

Table 4. The summary of V2X communications

3.1.2 Advantages and challenges

V2X communications enhance road safety. V2V communication can effectively detect blind spots, vehicle lane changes, and early warning of collisions in front of the vehicle, thus playing a role in avoiding collisions. V2P communication can effectively identify the location of passers-by to avoid hitting pedestrians.

V2X communication reduces traffic congestion. The V2X can help control the traffic at intersections by manipulating the traffic lights, which dramatically increases the efficiency of traffic throughput. Meanwhile, V2X communication can also play a role in the protection of the environment. The V2X helps protect the planet's ecology by reducing traffic congestion and providing vehicles with the most efficient route planning, which has led to a sharp drop in vehicle carbon dioxide emissions.

V2X communications can provide practical assistance for road services. V2C communication is integrated into smart parking, on-road entertainment, EV charging management, location-related advertisement, etc.

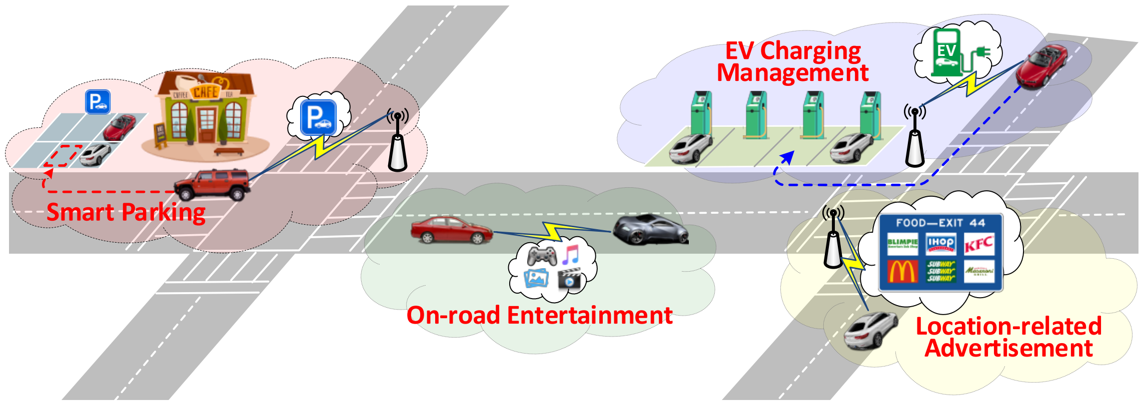

Figure 3. V2X for road services

However, V2X communication is a typical heterogeneous machine- and human-type coexisted scenario. Thus, it faces the challenges of both machine-to-machine (M2M) and human-to-human (H2H) communications.

The M2M communications are the most critical part, and present follows features.

(1) Sensor-rich. Currently, each car has 40-150 sensors, and this number is expected to double in the coming years.

(2) Big data. For example, each google car can generate 750MB of data per second in 2013. This number can further increase as the car becomes more intelligent with more sensors.

(3) Frequent interactive. The context information needs to be updated ten times per second at least.

The human-type traffic keeps increasing due to the requirement of on-road infotainment and location-based services. Thus, the vehicular networking system will present massive connections with high throughput. Meanwhile, the enormous link will lead to a lack of bandwidth. Due to the high mobility of vehicles, unreliable channels and frequent handover are challenges for the network.

3.2 Automated Driving

3.2.1 Introduction

With the development of V2X communication, the concept of automated driving came into being. First of all, we analyze normal human driving behavior from a system point of view. The driving system's inputs is the information of the driving environment obtained through perception (e.g., road condition, traffic, pedestrians), which is obtained through eye observation for human drivers. With this information, human drivers use the brain based on the driving skills learned from training schools and daily experiences. Then human drivers take actions based on their decisions to control the car, including speed, braking, and steering.

Figure 4. The sample for human driving

Like human driving patterns, automated driving can be analyzed at the system level. The perception is conducted through high techniques: camera, radar, GPS, and HD maps are all implemented to help the car to know the driving environment. The sensed information is input into automated driving software. The software makes decisions through machine learning technologies and outputs the control information directed to the engines through in-car wired networks. Extensive training is required to obtain a mature automated driving system, such that the driving software can make the right decisions based on historical experience, just like a human driver. But the difference is that humans and machines learn and understand in different ways.

Figure 5. The sample for automated driving

3.2.2 Automated driving with V2X communication

V2X communication makes automated driving safer, more comfortable, and smarter. With the help of vehicular networks, vehicles can get global traffic information and make global optimization together through cooperation. This way can significantly improve sensing ability, accuracy, reliability, as well as traffic efficiency.

Swarm intelligence (SI) is the collective behavior of decentralized, self-organized systems, natural or artificial. As the proverb says, “A single ant or bee isn’t smart, but their groups are.” V2X enabled swarm intelligence on-road in two ways, information sharing and cooperative driving with communications. For information sharing, a vehicle can have a bird view even when it is blocked by oversize vehicles (global information in the special domain). A vehicle can also instantly know other car’s actions and prepare to response (global information in the temporal domain). Cooperative driving with communications is used to improve safety, efficiency and reduce energy consumption and traffic jam.

Except for swarm intelligence, vehicles' sensing intelligence can relive the V2X communication workload cause to enhance communication reliability and efficiency. The benefits of sensing intelligence are (1) Reduced message interaction. Automated driving vehicles can obtain lots of information locally, which can significantly reduce the workload of V2X communications. These safety-related messages require frequent interaction (at least 10/s) with extremely low transmission delay (milliseconds) and high reliability. Which means, these message interactions will consume huge communication resources, especially in dense vehicle scenarios. With sensing intelligence reducing these transmissions, the saved resources can be better utilized to serve other on-road mobile applications. (2) Reliability, safety, and privacy. Compared with V2V/V2X message transmission, local message sensing is more reliable, considering the transmission delay and potential communication attacks. Besides, with less message transmission and sharing, privacy can be better protected. (3) Regulated mobility. Different from human drivers, automated driving is more regulated and can be controlled. Thus, in both macro (like vehicle density) and micro scales (like headway and speed), the mobility of vehicles is more regulated with less randomness, which can also be accurately predicted. In communication networks, communication resources are usually wasted to deal with traffic randomness, especially when the QoS requirements are strict. Therefore, with more regulated and predicted vehicle mobility, we can make better scheduling to improve communication resources and enhance network performance.

If V2X communication and autonomous driving can be perfectly integrated, individual users will enjoy the safest and most convenient driving experience. All impaired driving will cease to exist. All people, young and old, can drive their cars with peace of mind. At the same time, for users across the city, there will be no late delivery. All driverless cars have cloud brain control and reach real accurately.

3.2.3 Automated driving levels and challenges

SAE (Society of Automotive Engineers) of American proposed the 6-level of automated driving.

In level 0, there is no automation. The human driver performs driving the full-time. In both level 1 and 2, the human driver must monitor the driving environment, and the driving assistant system acts passively. However, in level 3, 4, and 5, the automated driving system monitors the driving environment and works actively.

Level	Level name	Description
Level-0	No automation	The human driver performs driving the full-time
Level-1	Driver assistance	Under some specific driving mode (e.g., Adaptive Cruise Control (ACC)), there is a driver assistance system performing either steering or acceleration/deceleration using information about the driving environment, and with the expectation that the human driver performs all remaining aspects of the dynamic driving task
Level-2	Partial automation	Under specific/simple driving mode, the automated driving system takes full control of the vehicle (including accelerating, braking, and steering). The driver must monitor the driving and be prepared to take control immediately when automation fails.
Level-3	Conditional automation	The automated system can monitor the driving environment; drivers can turn their attention away but be prepared to intervene within some limited time. In level-3, the driver can watch a movie or text.
Level-4	High automation	No driver attention is ever required for safety, i.e., the driver may safely go to sleep or leave the driver's seat. However, automotive driving is only supported in limited areas or specific circumstances, like traffic jams. Outside of the area, the car will bake, and the human driver is required to perform driving.
Level-5	Full automation	No human driver is needed.

Table 5. Automated driving levels

Currently, most cars can realize the level-2 self-driving, like Tesla autopilot, produced in Sept. 2016. The Distronic Plus, produced by Mercedes-Benz in Sept. 2016, can realize level-3 automation. Google/Baidu car is an example of level-4 automation, which is now under on-road testing. In the next two years, Tesla will realize level-5 full automation; In 2021, Ford will produce the level-4 car, and Mercedes-Benz will realize level-5.

Due to the unique nature of autonomous driving, Connected and Automated Vehicles (CAV) has a very high demand for networks to achieve full automation. There are two main aspects: seamless network coverage and high-quality service (in different spaces and times). Between them, the quality-of-service requirements of autonomous driving include high reliability and low delay, mobility support, and high throughput. However, for remote areas, coverage of existing networks remains inadequate. Another critical challenge is because traffic flow and vehicle density often change with time and place, due to the demand for vehicle data are not equal in time and space. Fixed network deployments are challenging to resolve for this problem: over-tight deployments increase overhead and reduce resource utilization; too-poor deployments do not meet sudden business needs. Ground network deployment often results in network performance decline due to obstruction and other reasons.

3.3 SAGVN

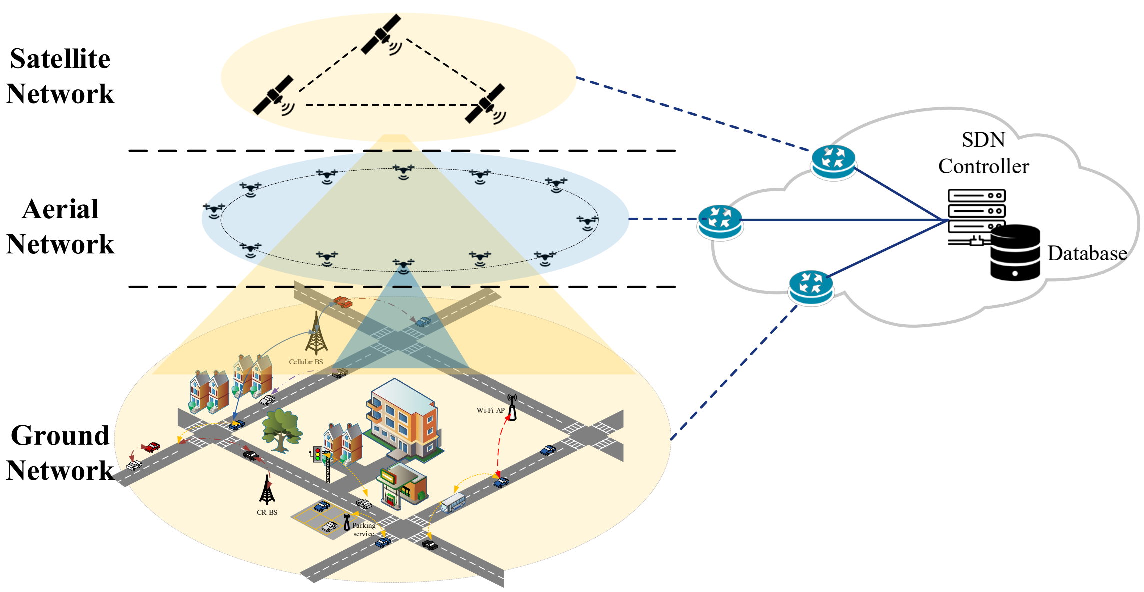

Figure 6. The structure of SAGVN

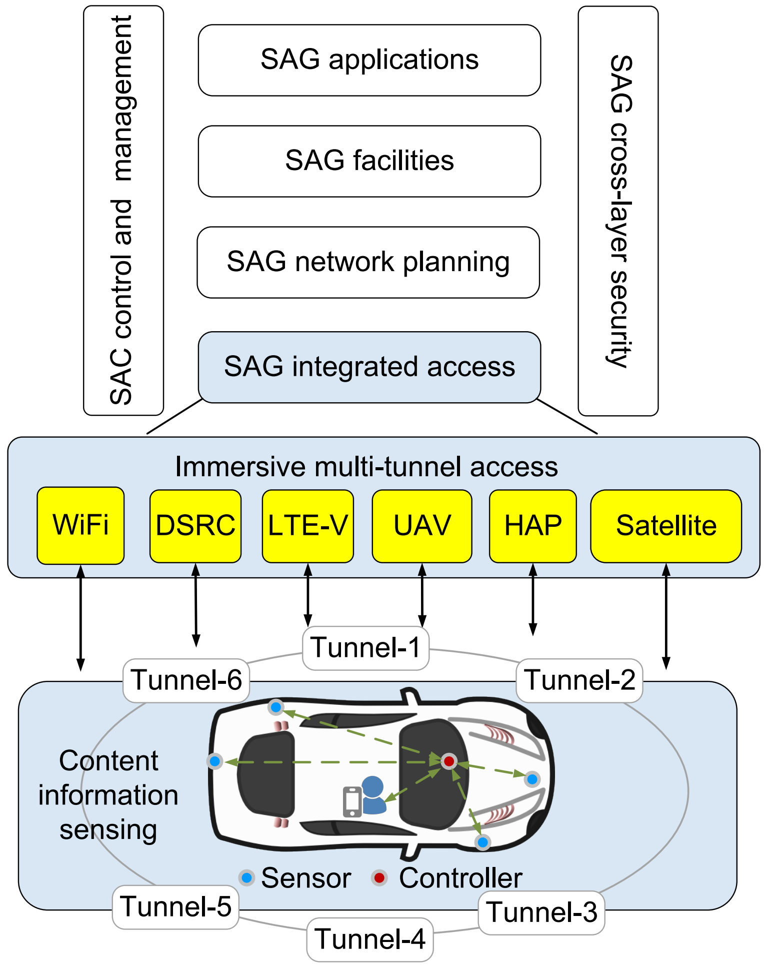

Figure 7. The interior and exterior structure of SAGVN

Building a multi-tunnel space-air-ground integrated communication system, to make use of the advantages of different networks. The system is dominant by ground communication systems, with the assistance of space-air facilities.

The ground vehicular network mainly provides massive access with high-rate transmission, including 3 communication tunnels. (1) in-car communication, which connects sensors (wired) and passengers (wireless, through WIFI or Bluetooth). (2) V2V communications, which mainly transmit low-latency driving-assisted road-safety context information (through DSRC). (3) V2R communication, which can provide mostly high data rate internet access (using 802.11p or LTE-V). The most critical problem for ground vehicular networking is to design efficient and reliable MAC mechanism and resource allocation algorithms to make full use of radio resources.

The space-air-assisted vehicular networking is responsible to enhance the coverage and vehicular mobility. (1) The UAVs (or drones) can form moving cells to keep pace with the movement of vehicles, to better support the high mobility by avoiding frequent handover. (2) The HAPs (High-altitude platform) can conduct wide-area high-efficient broadcasting (or multicasting), like the traffic and weather information. (3) satellite is responsible for location and navigation, and also cover the area without ground network access.

3.4 Some simulation for SAGVN

3.4.1 Simulation software

The Table 6 is a description of the functionality of the simulation software used in this paper.

Logo	Name	Function
	System tool kit	• Satellites, sensors modules • Data analysis and visualization • Satellite orbit, Ground station • Communication parameters: Power, antenna gain, Path loss, etc. • Access time, signal-to-noise ratio, bit error rate • Offer MATLAB interface
PTV VISSIM the mind of movement	VISSIM	Advanced and flexible traffic simulation software, complex vehicle interactions, mobility, traffic planning
	MATLAB	Communications System Toolbox: Channel Modeling and RF Impairments, Simulate link-level models

Table 6. Simulation software [3][4][5]

3.4.2 Satellites

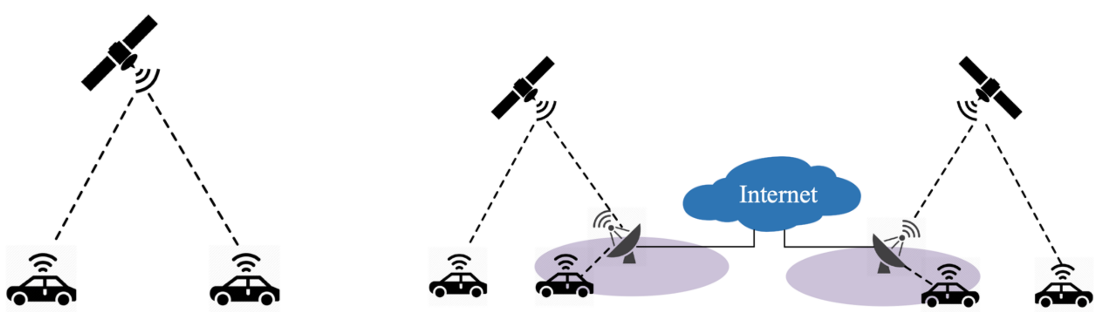

Figure 8. Satellites for serving vehicle

The satellite is connected to the Internet through a ground station. Therefore, by using satellite communication, a device can communicate with any other devices worldwide, even though it is a noncellular or non-fix network deployed. In the left half of Figure 8, two vehicles are within the coverage area of one satellite. For this case, the satellite can relay the transmissions between the vehicles. In the right half of Figure 8, two remote vehicles (e.g., one in the US, another in China) communicate via a satellite system. Note that if a vehicle is within the coverage area of the ground station or it does not have a satellite communication module, it can directly communicate with the ground station with LTE/WiFi. Otherwise, it can communicate with the satellite. The communication route is a vehicle-(satellite)-ground station-Internet-ground station-(satellite)-vehicle.

We simulate a given location that requires at least 7 MEOs to guarantee 100% coverage. Figure 9 is a screenshot of STK simulated satellite trajectory. Figure 10 is MATLAB simulates the segment cover curve of seven satellites. Figure 11 is STK satellite coverage analysis. Higher communication performance can be obtained by using low-orbit satellites, but more satellites are needed to provide the same coverage.

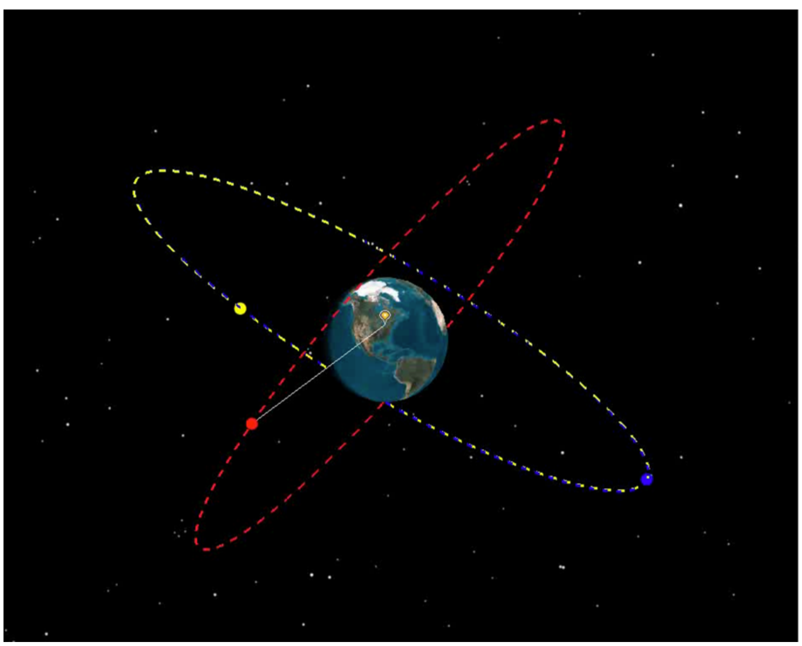

Figure 9. Screenshot of STK simulated satellite trajectory [3]

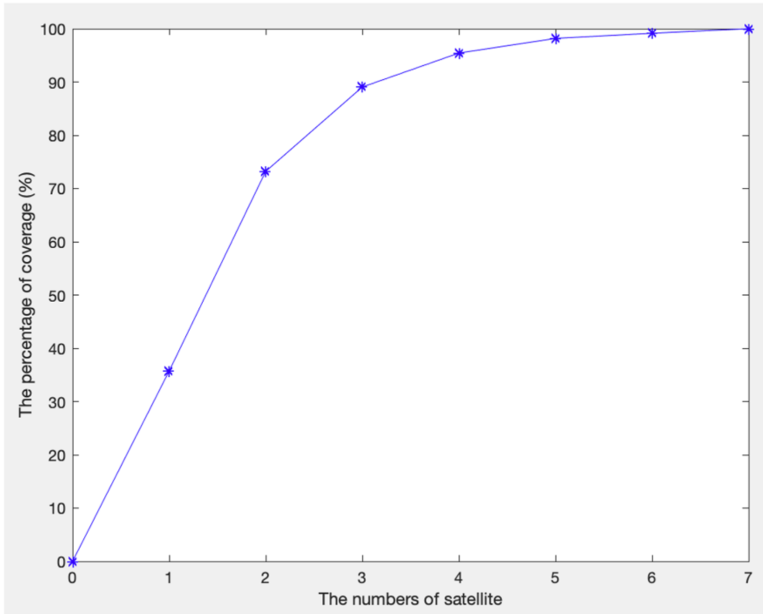

Figure 10. MATLAB simulates the segment cover curve of seven satellites [4]

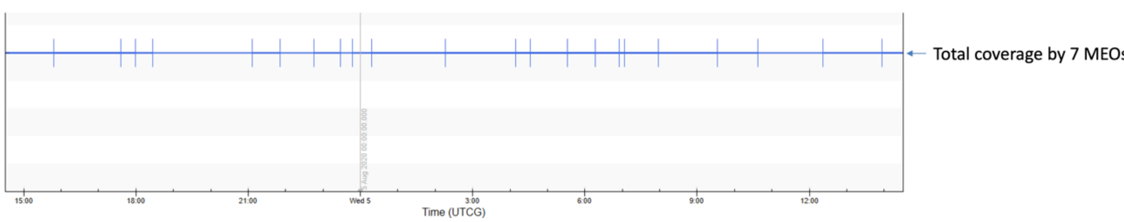

Figure 11. STK satellite coverage analysis [3]

Simultaneously, we found that by simulating, we could reduce the number of satellites to three to achieve approximate effects. The satellite network at this time consists of two MEOs and one inclined orbit satellite. Figure 12 shows a screenshot of the STK simulation. Figure 13 shows the satellite coverage analysis. As can be seen from the simulation results in the Figure 13, the coverage time of each satellite is different, but if three satellites are used, the overall coverage time is negligible.

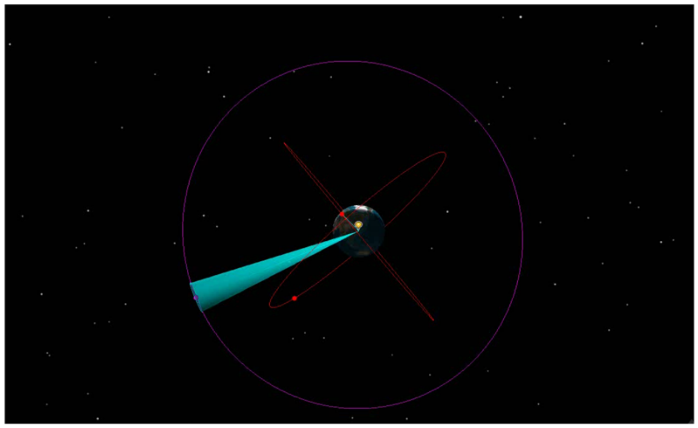

Figure 12. Screenshot of the STK simulation [3]

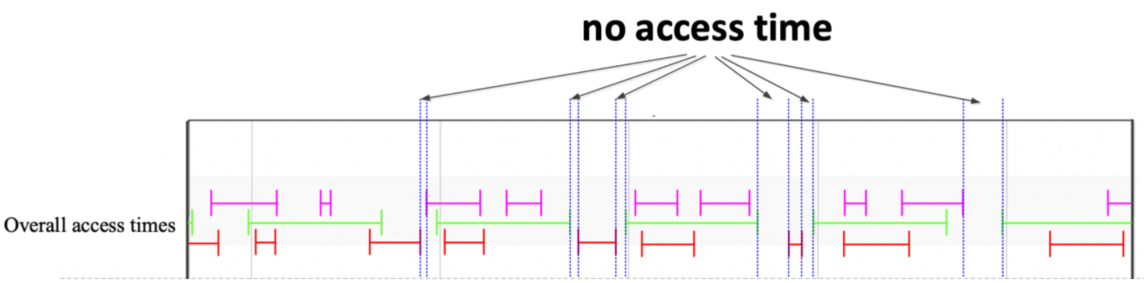

Figure 13. The satellite coverage analysis [3]

3.4.3 UAV

China Mobile has carried out the test of the emergency high-altitude base station of the system-held UAV in Hunan and Beijing. The drone's emergency high-altitude base station covers up to 50 square kilometers and provides instant messaging to 5,400 mobile phone users at the same time. It can be quickly lifted to 100 meters in 5 minutes, 24 hours non-stop for the disaster area to provide VoLTE and data services. And it also offers other communications support, rapid response, easy to operate, flexible coverage, long delay time, robust scalability, etc. At present, the high-altitude base station of emergency communication of the system-retained UAV has the commercial conditions of scale. [9] EE, the UK's largest 4G operator, is testing the Air Mask system, which uses drones, balloons, and other carriers as flight base stations to provide temporary communications connectivity to areas where ground communications are under-resourced. The project is currently in the prototype validation phase, and all tests are carried out by drones or balloons carrying a 5watt small cell solution from Nokia.

Figure 14 simulation results show the optimal deployment of a defined number (5) of UAV base stations. The figure on the left is a 3D view angle of view, and the figure on the right is a top view projected in the direction of the z-axis (height). Ground block points represent vehicle nodes, aerial dots represent drones, and black triangles represent base stations. Drone nodes of the corresponding color represent vehicle nodes of different colors, and purple vehicle nodes represent nodes that are not covered. As can be seen from the figure, to maximize user coverage, five drones' deployment results cover exactly the denser intersection areas of all vehicle nodes.

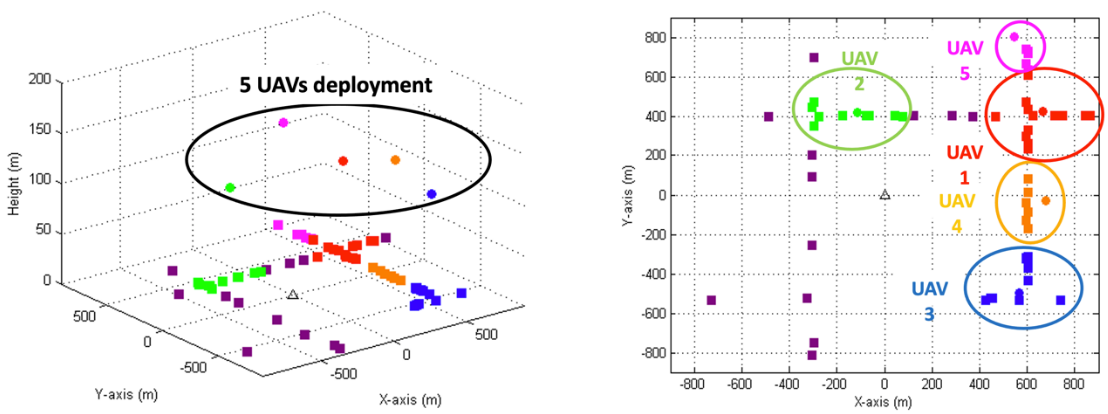

Figure 14. The results for UAV deployment [4]

4. SCAGIN

4.1 The necessary to develop the air network layer

With the development of the 5G network, the throughput required by the network system increases about 2.6 times that of the 4G era. As communications data explodes, service quality has taken it to a new level. Meanwhile, the scope of human activity is growing. At present, the range of human activity is not limited to urban areas, and more remote areas are also involved in social activities. Human activities such as offshore oil fields and Antarctica expeditions make remote areas need network communications. Furthermore, set up a seamless global communication network, upgrade scholars' research direction from ground communication to the study of the air network, and improve and upgrade the existing SAGIN system.

4.2 SCAGIN architecture

The same as the SAGIN network structure in the first part, SCAGIN adds aircraft to the air network layer, significantly reducing reliance on LEO satellites.

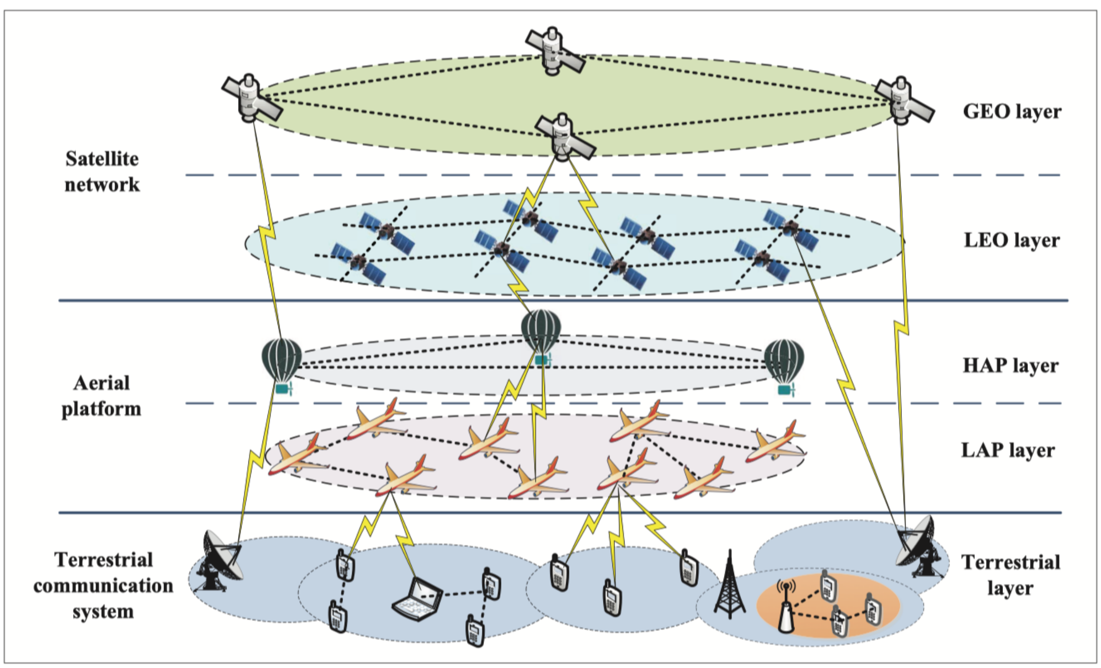

Figure 15. The simple architecture for space-terrestrial integrated network [6]

Figure 15. shows a similar diagram of the temporary SCAGIN structure, and the traditional space structure is the LEO satellite system, the aerial form is UAV. LEO and UAV have problems they can't avoid.

LEO satellites have low propagation delays and path loss due to their proximity to the surface. At the same time, LEO satellites can withstand high-frequency use. The LEO satellite is, therefore, an essential satellite system in the field of space network communication. However, LEO satellites also have unavoidable defects, short life cycles, short replacement cycles, high maintenance costs, and limited actual communication capabilities.

With the development of drones, more and more people are coming into contact with drones. UAV is the collective name for all types of drones. Because of its high portability, flexibility, low cost, and high-like visible-light communications for air-to-ground transmission, scholars have used it as an aerial carrier built into traditional SAGIN networks. However, as the number of UAVs increases, so makes the regulation of UAVs in various countries. More and more states are asking for UAV driver's licenses. From the UAV itself, battery limitations are its inevitable problem, the average full-charge flight time of UAVs sold on the market is about 30 minutes, so in practice, UAVs are often used in emergencies.

4.3 Analysis of civil aircrafts

Figure 16 shows the aircraft radar capture. At this moment, the Earth's major continents and oceans are covered by dense civil airliners. As a result, civil aircraft can provide a large amount of data and ensure diversity, security, and confidentiality.

Figure 16. Global Cas flight tracking [7]

Figure 17 simulates the area covered by a single aircraft flying. The angle between the aircraft and the ground determines the area of the earth that can be covered during flight.

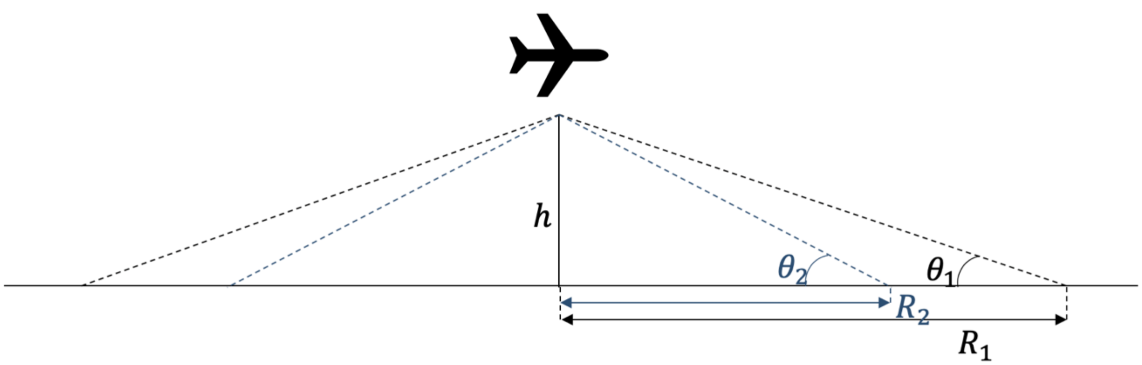

Figure 17. Schematic diagram of single CA covering the ground

The coverage radius of one single CA is

$$R = r \cdot (\arccos\left(\frac{r}{r+h} cos\theta\right) - \theta)$$

The furthest communication distance is

$$l = \frac{r \cdot sin(\arccos\left(\frac{r}{r+h} cos\theta\right) - \theta)}{cos(\arccos\left(\frac{r}{r+h} cos\theta\right) - \theta)}$$

Where h is the flight height, θ is the elevation, r is the radius of earth approximate 6371 km.

According to the above mathematical formula, Table 7 gives a practical example between elevation and the two distances.

Elevation θ(°)	Coverage radius R(km)	Furthest Communication Distance $l(km)$
0	356.7	357.1
5	104.3	104.9
10	55.2	56.2
15	36.9	38.2

Table 7. Relationship between elevation and coverage

Suppose the earth is a perfect sphere because the curvature of the earth's elliptical shape is negligible. When elevation is 5, the aircraft covers a radius of about 104 km and covers an area of about 34,000 square kilometers. The result is imposing for a single aircraft. In turn, international flights can cover most of the earth's surface.

Furthermore, the link budget for civil aviation aircraft is analyzed. SpaceX's two satellites were introduced, the first in the 1100km Ku and Ka-band, and the second in the V band at 340km. Because the aircraft's frequency band is unknown, the satellite's frequency band is applied to the plane for comparison accuracy. Table 8. then provides the key parameters to compare and explains the parameters.

	SpaceX				
Type of SAP	Satellite #1	Satellite #2	CA		Description
Height(km)	1100	340	10		Height from the surface
Elevation(°)	45	45	20		The elevation between the surface
$f(GHz)$	15	60	15	60	Service frequency
$G_T(dB)$	40	53	40	53	Transmitting antenna gain
$G_R(dB)$	3				Receiving antenna gain
$L_a(dB)$	6				Additional loss
Guaranteed BER	10^{-4}				Bit error rate

Table 8. Key parameters of link budget

According to Table 8, three of the comparisons are designed to be similar to Figure 17's schematic diagram in Figure 18.

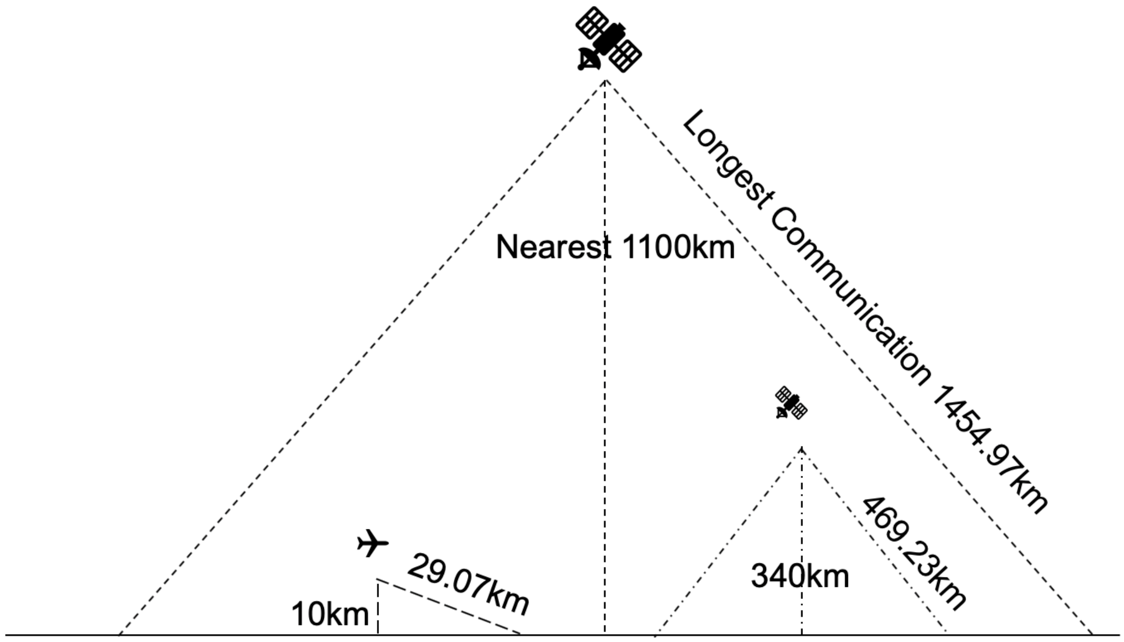

Figure 18. Schematic diagram of multi-layer SAP coverage

The link budget for three comparisons is simulated using MATLAB. Assuming that the transmission rate is 10Kbps and 10Mbps, the modulation demodulation means QPSK and 16QAM, the value of $\frac{E_b}{N_0}$ can be derived according to BER and SNR, and then according to the following formula

$$\frac{P_R}{N_0} = \frac{RE_b}{N_0}$$

$$P_R = P_T G_T G_R L_S L_a \ (L_S = (\frac{c}{4\pi df})^2)$$

$$EIRP = P_T - \mathrm{L} + \mathrm{G}$$

Where

L_S	The signal propagation between sap and user is LoS
d	Distance between user and SAP
$EIRP$	Effective isotropic radiated power
E_b	Average energy/bit of every pulse
N_0	PSD of noise

Table 9. Noun interpretation of above formulas

Figure 19. is an analog diagram of transmission power and EIRP after the use of MATLAB.

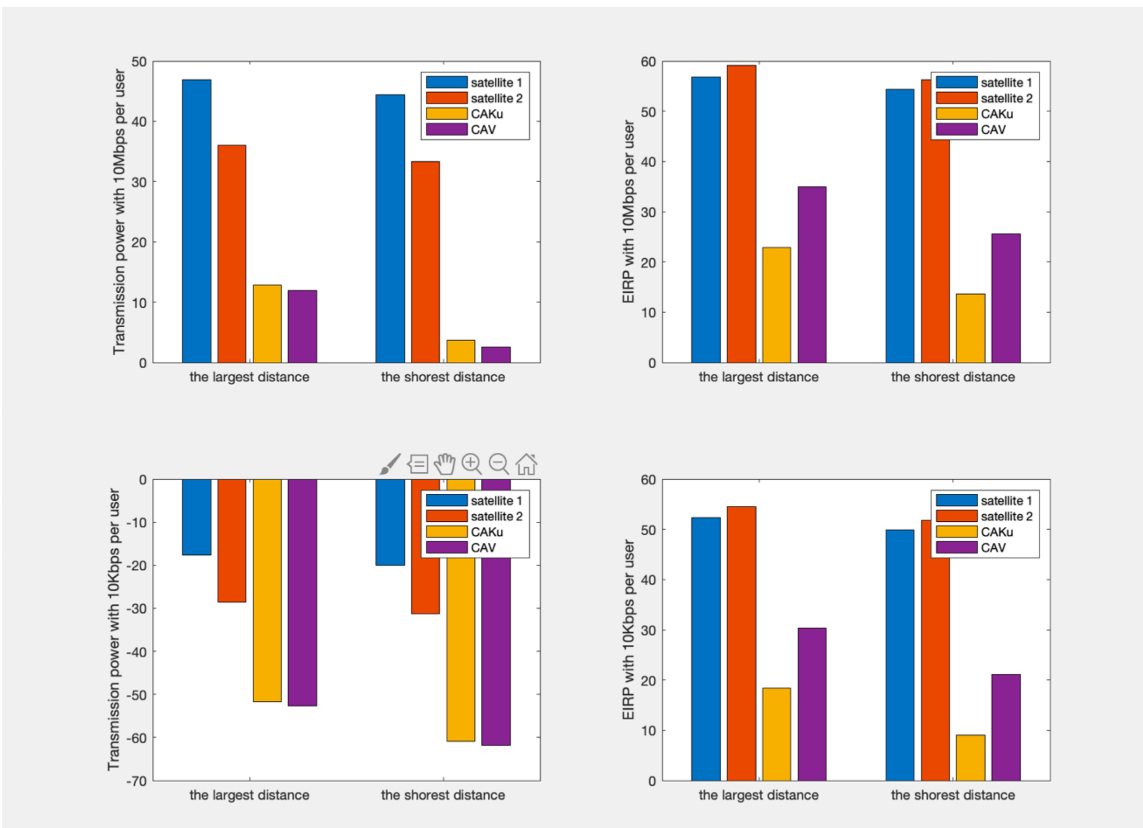

Figure 19. Comparative images of transmission power and EIRP [4]

As shown in Figure 19, the transmission power of civil aviation aircraft and EIRP is less than two satellites. With the experiment, when the transmission rate increases to 20Gbps, civil aviation aircraft's transmission power will be significantly reduced, but EIRP is higher than in Figure 19. Therefore, civil aircraft are more suitable in the system.

4.4 Shortcomings and improvements

Like Figure 20, the intensity of civil aircraft varies over time, which means that the more passengers travel at a particular time, the denser the aircraft at that point. Therefore, the intensity of the aircraft is related to the number of aircraft allocated at any time. At the same time, we observed how small aircraft density was at the same point in time. For example, in Canada's north and northwest, few planes fly by, and more densely populated cities such as New York are denser. As a result, the city's population size and flight time can strongly affect the aircraft's intensity.

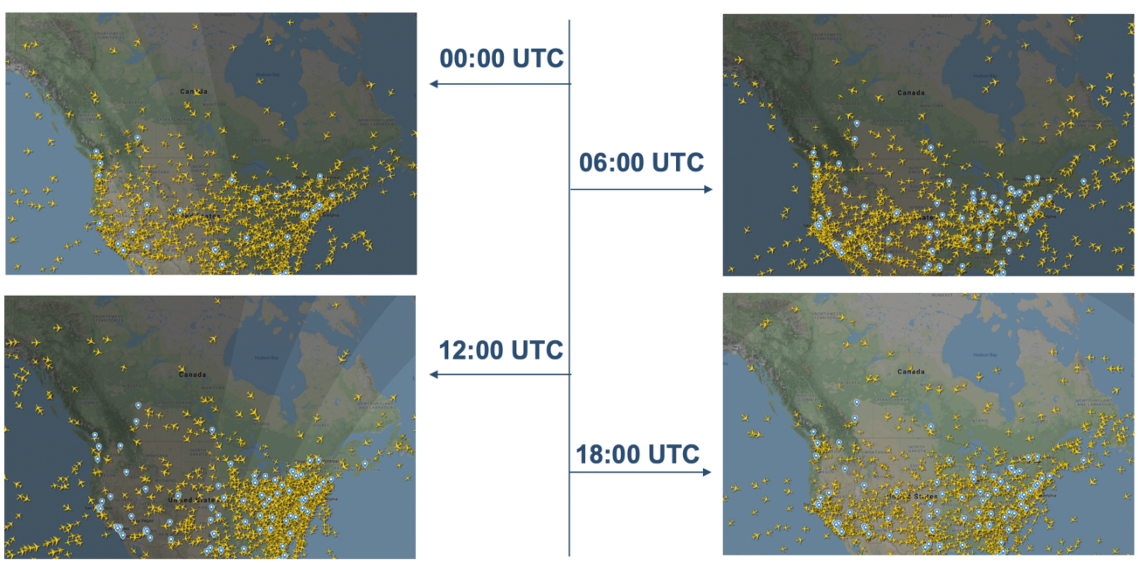

Figure 20. Flight coverage at different times [7]

Table 10. shows a comparison between ground base stations, LEO satellites, UAVs, and civil aircraft. Because of civil aircraft's above shortcomings, it is necessary to combine LEO satellites with civil aircraft into network systems. In this way, civil airliners can receive satellite signals while reducing the

satellite's energy consumption.

Category of BSs	Terrestrial BS	LEO Satellites	UAV	CA
Height	5~200m	500~2000km	<500m	About 10km
Service life	24 hours <15 years	24 hours 3~5 years	each flight lasts less than 30 min	10~12 hours Flying service per day
Capacity	High	Low	Low	High
Coverage	Low	High	Low	Medium
Delay	Low	High	Low	Medium
Velocity	Quasi-static	High	Low	Medium
Flight route	None	Fixed	Controllable	Fixed

Table 10. Performance of different base stations

4.5 The breakthrough and challenges

SCAGIN has four notable breakthroughs compared to SAGIN.

First, the most obvious is that SCAGIN expanded the variety of Sky Access Platform (SAP), civil aircraft as a new air carrier was added to the network. Promote seamless global connectivity by increasing the scale of the system.

The second point is the joint association [11]. According to the above content, a single development of a carrier cannot efficiently achieve a seamless global connectivity system. Even the new civil aircraft that we add to are the same and need to be affected by time and population density. Therefore, we need LEO satellites and aircraft to connect to achieve a win-win outcome, which is what the joint association meaning is.

The third point is that SCAGIN is a kind of standard architecture. Due to UAV's limitations, in the UAV section, make it is generally used in emergencies. For SCAGIN, it should exist as standard network architecture, not just in a crisis. The typical architecture is also conducive to the rapid development of the Internet of Things (IoT) and a seamless global coverage network.

The last point is service-oriented. Before SCAGIN was proposed, communication networks were allocated according to demand, known as "on-demand." As a result, traditional communication networks are no more than large-scale access data. For example, at a large stadium event, when spectators take out their phones to share the joy of the moment with their friends, they find that they don't have a signal. Too much data cause long delays to access the ground base station at the same time. In the SCAGIN system, "just in time (JIT)" was born out as a new concept. It allows users to access the network of any platform with permissions according to their own needs. Still, based on the above example, if the audience can access the base station in the air, it will significantly reduce the ground base station's pressure. At the same time, network traffic can be allocated according to the remaining platforms' carrying capacity.

SCAGIN also faces problems that need to be addressed. For example, the physical layer studied how MIMO and SCAGIN worked effectively, how network slicing was implemented in SCAGIN, how many gateways for civil airliners needed to be selected and deployed, and the security of SCAGIN cross-layer communication. Future research on how to construct a seamless coverage network cannot be stopped.

5. Current research on the Integrated network

5.1 Software-defined reconfigurable implementation methods

SAGVN or SCAGVN has multi-level dynamic characteristics. The one is because the vehicle communication node is in continuous movement. The other is because the specific vehicle networking application sits on updates, forming dynamic communication, and computing resource requirements.

The reconfigurable network of the software East One can be reconfigured simultaneously on a large space-time scale and adapt dynamically to the different needs. When application requirements change, network functions can be refactored simply by updating the software. Devices at the space and air network layers can change their routes and other states in a software-defined manner to make them more suitable for vehicle gathering hotspots.

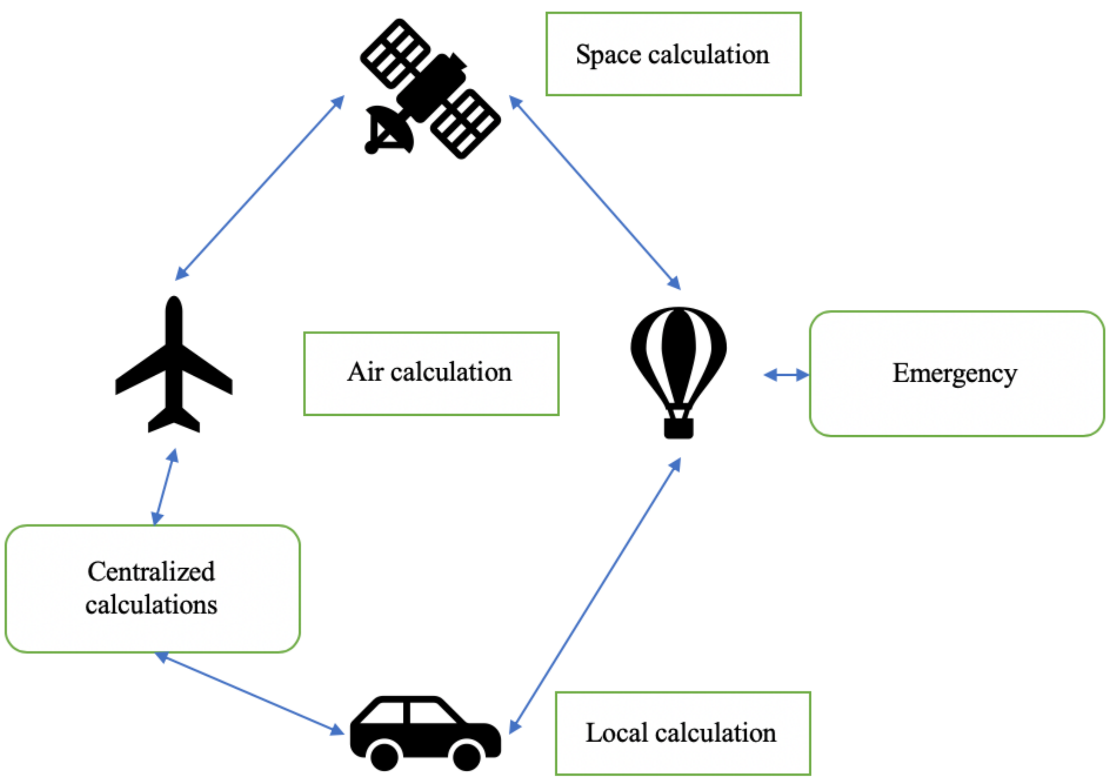

Figure 21 . Example diagram of software definition refactorable S(C)AGVN network

5.2 Vehicle networking for the capture of situational information

The first analysis is the acquisition method of vehicle location information in a complex dynamic environment. As far as intelligent driving is concerned, it is one of the most critical issues in confirming the surrounding object's relative position and position. There are two ways to discuss this. One is based on the positioning method of vehicle collaboration, and the other is the positioning tracking method based on the fusion of external measurement and internal information [10]. Figure 22. explains the first approach.

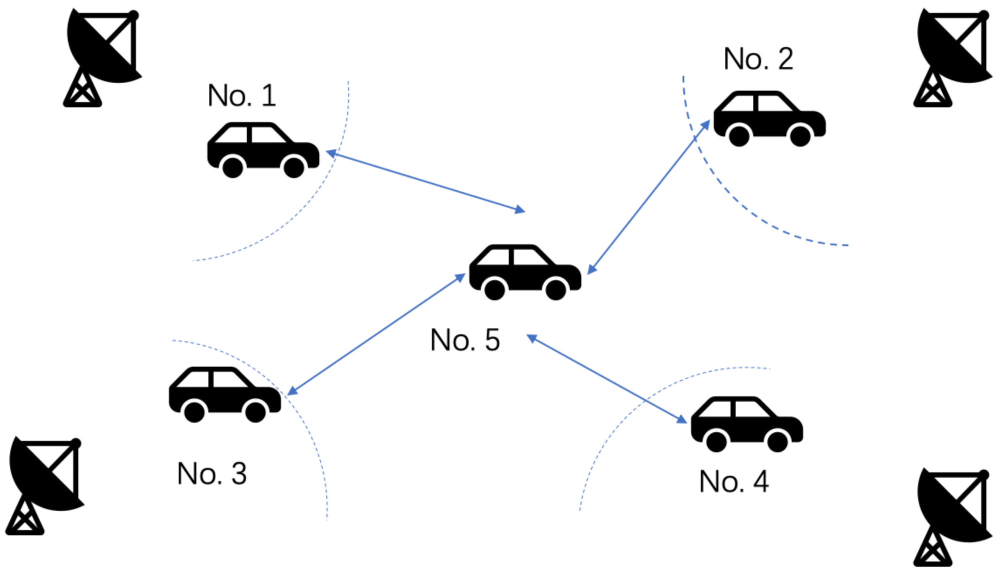

Figure 22. positioning method of vehicle collaboration

As shown in Figure 22, number 5 is not covered by the base station, but the location of the vehicle can still be obtained through the synergy of the number 1 to 4 cars.

The most common method of location tracking, which combines external measurement with internal information, is to use map information for location correction, which can be provided by spatial information platform. Fusion information is fast and straightforward, but the real-time is not good, the accuracy is not enough.

Figure 23. shows the composition and representation of location situation information. In addition to

other vehicles, the obstacle position is also one of the vital information to be detected while driving. Other methods are emerging, such as the theory of discrete mathematics, which deals with the fusion of macro or micro situational information from graph theory.

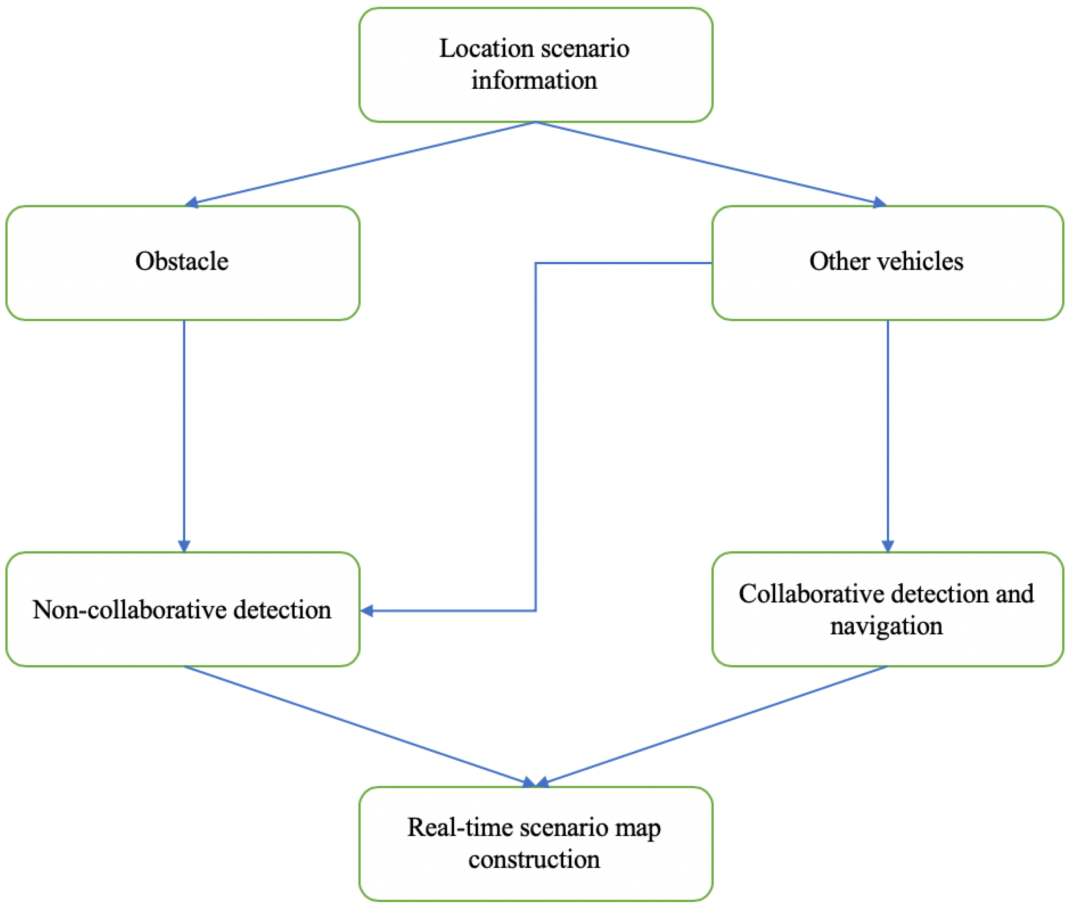

Figure 23. The composition and representation of location situation information

5.3 Cross-layer security mechanism

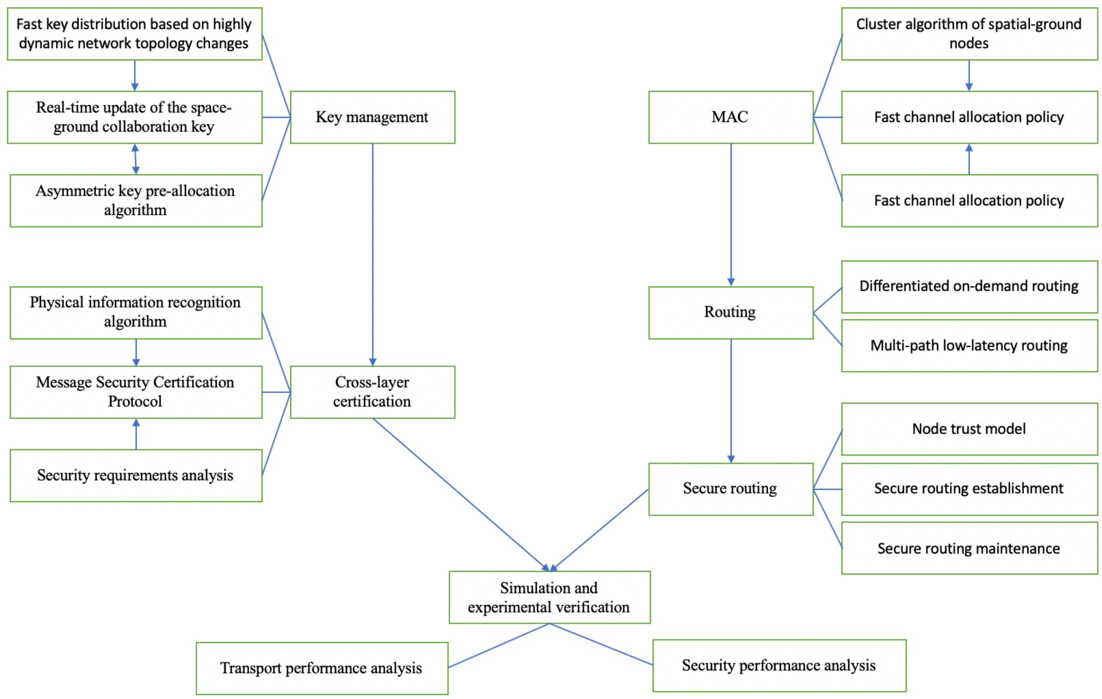

Figure 24. Cross-layer safety technical routes.

The novel SAGIN cluster strategy and MAC fast dynamic wireless channel distribution mechanism will divide the whole network. One is the channel distribution between the air nodes such as UAV and the ground vehicle's cluster head. The second layer is the channel distribution in the cluster of the ground vehicle. Reduce overhead and latency and increase reliability with group switching and resource allocation strategies.

The high and reliable routing mechanism of low latency utilizes the algorithm of ant colony optimization. The backward ant establishes the path from the destination node. The pre-stress ant searches for the route required to reach the destination node. The active forward ant is responsible for maintaining and improving the path, reducing the probability of link failure. Because of MIMO's popularity, the reliability of the link is required to increase, using the distributed intensive learning routing algorithm to choose the right multi-path route. For example, using Q learning to train the ant colony algorithm, let the ants leave pheromones in the path, guide the subsequent ants to choose nodes closer to the track to move, and optimize the algorithm's exploration path.

As you can see from the above information, the biggest problem with UAV is battery life. It makes UAV unsafe when there is no power to cause massive amounts of data loss. Therefore, a new security mechanism is constructed. A pre-allocated tool is adopted. The key distribution path is reconstructed when the drone's node energy reaches the warning value, and the asymmetric key is pre-allocated. When replacing a drone, refactor the nodes on the path, combine the pre-allocated key and the current key in time to form a new key, and revoke the expired drone node and expired key.

It is also essential that the information users received are sent by legitimate users and whether the information is complete. Therefore, a mechanism for the legitimacy and validity of information is required. The existing solution is to use the elliptic curve digital signature algorithm to sign the data. The defect is that it cannot process a large amount of information in a short period. Therefore, in future research, we need to design a new cross-layer authentication mechanism for the characteristics of high dynamic and low latency of the SAGIN network.

To prevent routing attacks from legitimate nodes, further enhance SAGIN vehicle network information transmission's legitimacy and security and introduce the method in machine learning of decision tree into the evaluation and classification of node trust. The dynamic rating of nodes through the historical behavior of nodes can effectively solve the security problems brought about by the network's attack.

5.4 RL based resource management

For reinforcement learning, an agent (i.e., network controller) learns the best policy through interacting with the unknown network/system environment. At each system state (e.g., UAV location), the agent takes action, observes the reward (e.g., path loss or throughput) from the environment to know how good this action is, and adjust its future action based on the reward. Therefore, RL learns the best policy (which should be taken at each system state) for resource management.

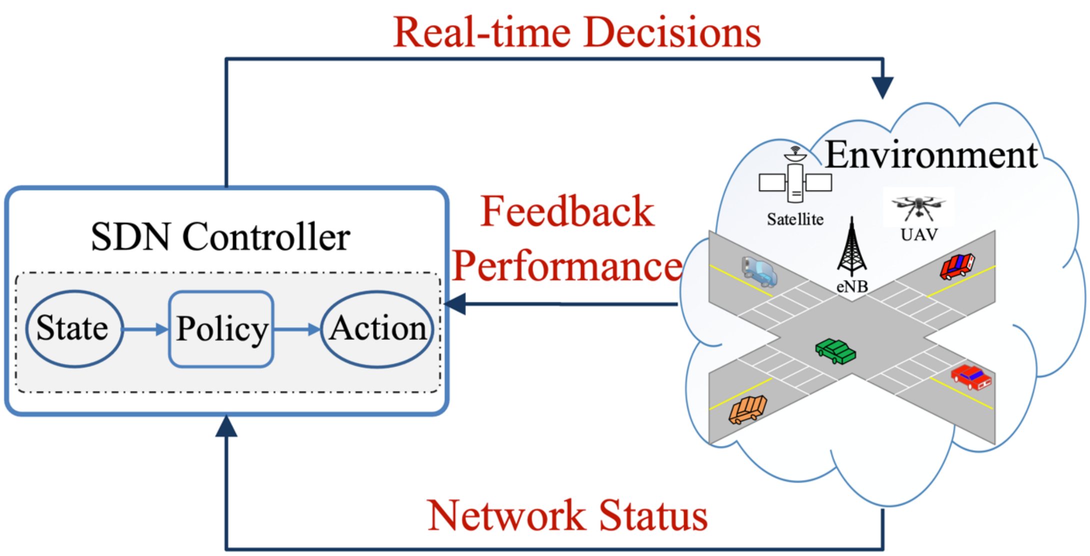

Figure 25. RL-based SDN controller

We can apply the RL architecture to SAGVN's resource management well. As shown in the Figure 25, the SDN controller can collect real-time network status information, make online decisions, make performance changes based on environmental feedback after making decisions, and further adjust the next stage of decision-making until convergence to a stable optimal state. The RL-based control framework has three main advantages in SAG resource management: 1) it does not rely on a large number of labeling data (e.g., these data reflect the known information about the network, such as in historical observation, the vehicle density is $100/km^2$, the label is a light-duty network, but if vehicle density is $1000/km^2$, the label is a heavy-duty network, although these markings can help decision-making, but require a large number of labors, and only for known environments), you can explore and find the best decision in any new environment. 2) Online, we can do a lot of pre-learning so that it is the real environment, the fastest convergence to an optimal state. 3) Based on the latest network status information, it can make decisions quickly, just a matching process, do not need to do a lot of optimization calculations, very suitable for the real-time demanding onboard environment.

The RL-based control algorithm implemented in the SAGVN platform has a workflow, as shown in the Figure 26. First of all, offline, based on the simulation platform, we will do a lot of pre-learning. Based on the pre-learning model, enter real-time environment status information, including Network connectivity, Available resources, Vehicle mobility, Request density, QoS requirements, and quick online decisions.

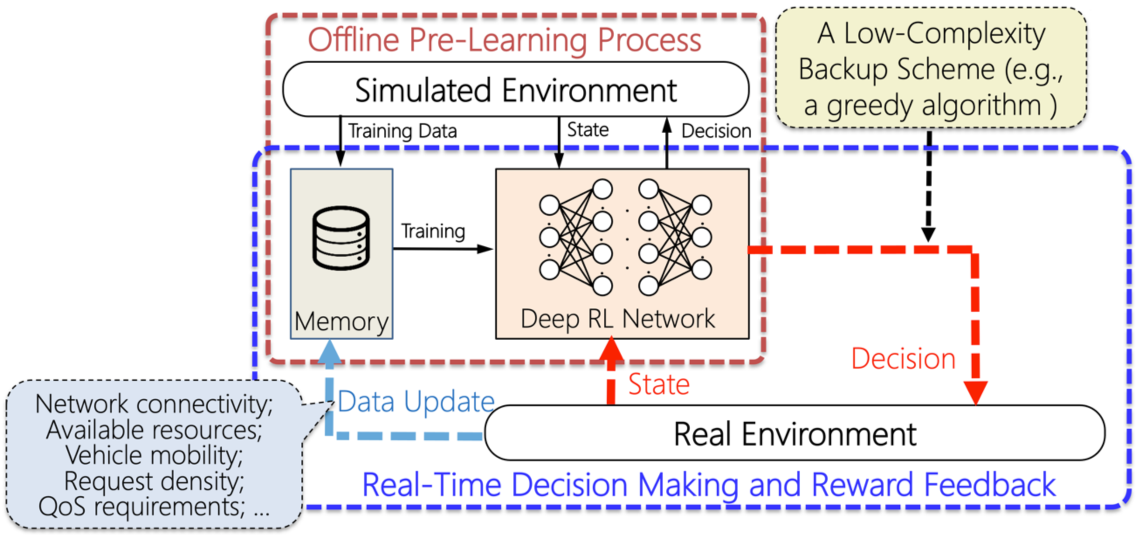

Figure 26. The structure of RL-based resource management

After the decision is made, feedback from the real environment (including performance and environmental status information) is collected, and the model is further updated online. Besides, while we do a lot of offline pre-learning for the environment, we often encounter situations that we haven't learned online when making decisions with the RL model is often not ideal. Therefore, we need a backup mechanism (e.g., low complexity of the green algorithm, that is, each user connected to the signal of the most robust access network). Although the mechanism cannot guarantee optimal results, it can ensure a certain degree of performance in the new environment. When RL decision-making is not ideal, the backup mechanism can be used to help the system make decisions to ensure a specific performance. So, the RL model once again learns the optimal decision, re-enables the RL model to make decisions.

The Backup mechanism is that because the RL algorithm takes time to explore and learn in a new environment and then converge to an optimal state, performance can be abysmal (very random) during the initial learning phase. So we need to design a simple standby mechanism that, during the initial learning phase, assists the RL algorithm (RL algorithm can learn better decisions faster based on the decision-making and performance response of the standby mechanism). The tool can be a simple greedy algorithm. For example, in access control, each user can simply connect to the most vital signal strength network.

6. Conclusion

This paper introduces the structure of the SAGIN system and the existing research in four parts. The first part briefly presents the framework of the SAGIN system and the current system and puts forward the limitations of the SAGIN system. In the second part, through automated driving and V2X communication, VANET added to the integrated system to form the SAGVN. The third part is to add civil airlines to the integrated system, more effectively increase air communications tools. The fourth part summarizes the research of the existing integrated system.

7. References

[1] Liu, J., Shi, Y., Fadlullah, Z. M., & Kato, N. (2018). Space-air-ground integrated network: A survey. IEEE Communications Surveys & Tutorials, 20(4), 2714-2741.

[2] N. Lu, N. Cheng, N. Zhang, X. Shen and J. W. Mark, "Connected Vehicles: Solutions and Challenges," in ***IEEE Internet of Things Journal***, vol. 1, no. 4, pp. 289-299, Aug. 2014

[3] STK https://www.agi.com/products/stk

[4] MATLAB https://www.mathworks.com/products/matlab.html

[5] VISSIM https://www.ptvgroup.com/en/solutions/products/ptv-vissim/

[6] Shi, Y., Cao, Y., Liu, J., & Kato, N. (2019). A cross-domain SDN architecture for multi-layered space-terrestrial integrated networks. IEEE Network, 33(1), 29-35

[7] Flightradar24: Live Flight Tracker - Real-Time Flight Tracker Map [Online] Available: https://www.flightradar24.com/

[8] Wang, X., Zhang, H., Tian, Y., & Leung, V. C. (2018). Modeling and analysis of aerial base station-assisted cellular networks in finite areas under LoS and NLoS propagation. IEEE Transactions on Wireless Communications, 17(10), 6985-7000.

[9] Zhou, Y., Cheng, N., Lu, N., & Shen, X. S. (2015). Multi-UAV-aided networks: Aerial-ground cooperative vehicular networking architecture. IEEE vehicular technology magazine, 10(4), 36-44.

[10] Garzón, M., Valente, J., Zapata, D., & Barrientos, A. (2013). An aerial-ground robotic system for navigation and obstacle mapping in large outdoor areas. Sensors, 13(1), 1247-1267.

[11] Pace, P., Aloi, G., De Rango, F., Natalizio, E., Molinaro, A., & Marano, S. (2004, May). An integrated Satellite-HAP-Terrestrial system architecture: resources allocation and traffic management issues. In 2004 IEEE 59th Vehicular Technology Conference. VTC 2004-Spring (IEEE Cat. No. 04CH37514) (Vol. 5, pp. 2872-2875). IEEE.

[12] Evans, B., Werner, M., Lutz, E., Bousquet, M., Corazza, G. E., Maral, G., & Rumeau, R. (2005). Integration of satellite and terrestrial systems in future multimedia communications. IEEE Wireless Communications, 12(5), 72-80.