

The logistic capillaries for future cities

# The white paper of 5G robotic delivery network

Jan. 2019



# REPORT SUMMRIES

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## 1 **The 5G robotic delivery network is the solution for the future cities.**

With the rapid development of e-commerce, take-out food business, new retail, the demand of urban delivery services in urban areas has been increasing a lot. Meanwhile the disappearance of the demographic dividend has led to a significant shortage of delivery labors. Fast, safe, zero-emission and human labor-independent robots will become an indispensable infrastructure for urban logistics in the future.

## 2 **ADNET+5G is an efficient form of robotic delivery network.**

The ADNET+5G system integrates in drones, unmanned vehicles, unmanned hub stations and unmanned charging depots, and also through the algorithm enables seamless collaboration between robots, so as to make full use of speed advantage of aerial delivery by the drones and the user-friendly interaction of the unmanned vehicles. At the same time, unmanned hub stations and unmanned charging depots help to realize full automation of the whole network in terms of the material cycle and energy cycle.

In addition, the upper limit of manpower delivery system will be restricted seriously by labor supply during the process of increasing delivery demand. The disappearance of the demographic dividend is driving up labor costs gradually, but the cost of robot delivery will continue to decrease with the expansion of manufacturing scale. At present, the intersection of the two has emerged, and with the upgrading of technology, the advantages of robots will be prominent increasingly in the future.

## 3 **Safety is a core premise of large-scale operation of robotic delivery network.**

From design, development, testing to operation of ADNET, safety is always the first priority, which ensure the safety of flight as the primary focus of the system. The safety of the system is guaranteed by the subsystem redundancy, the complete fail-safe mechanism, the large-scale emergency strategies and the equipment of the certified security personnel. Finally, the security of the system has been verified fully by running tests in a real environment with multiple scenes for a long time..

# 01

## **Delivery requirements and solutions for the future cities**

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# The consensus is that the industry needs to change

“A billion packages a day will take no more than eight years, it could be done in six or seven years.” — *Jack Ma*

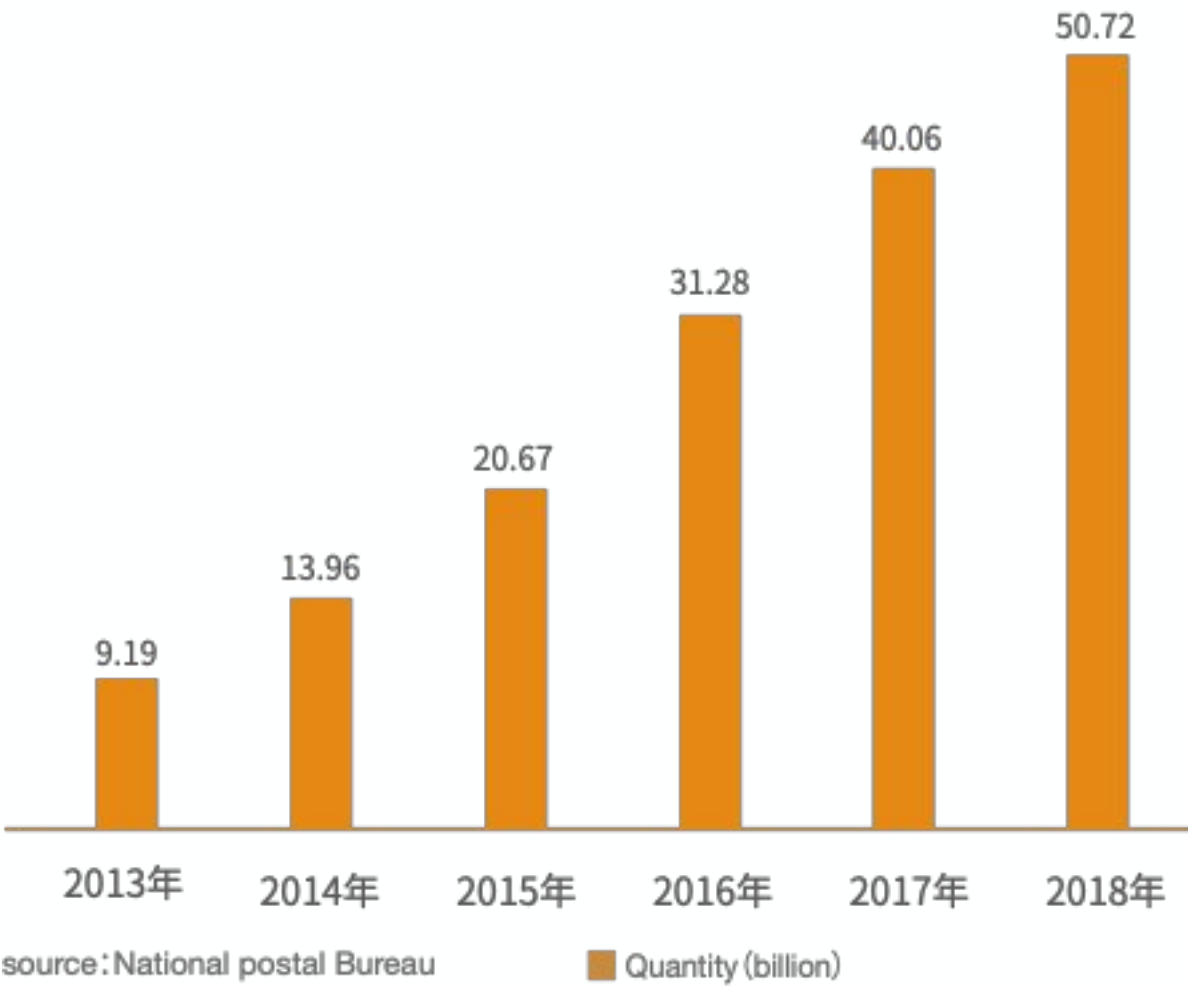
“Finding enough labor for the logistics industry could become extremely difficult or even impossible.” — *DHL*

“Get ready for a world where autonomous vehicles deliver 80 percent of parcels.” — *McKinsey&Co*



# Increasing demands widen the labor supply gap

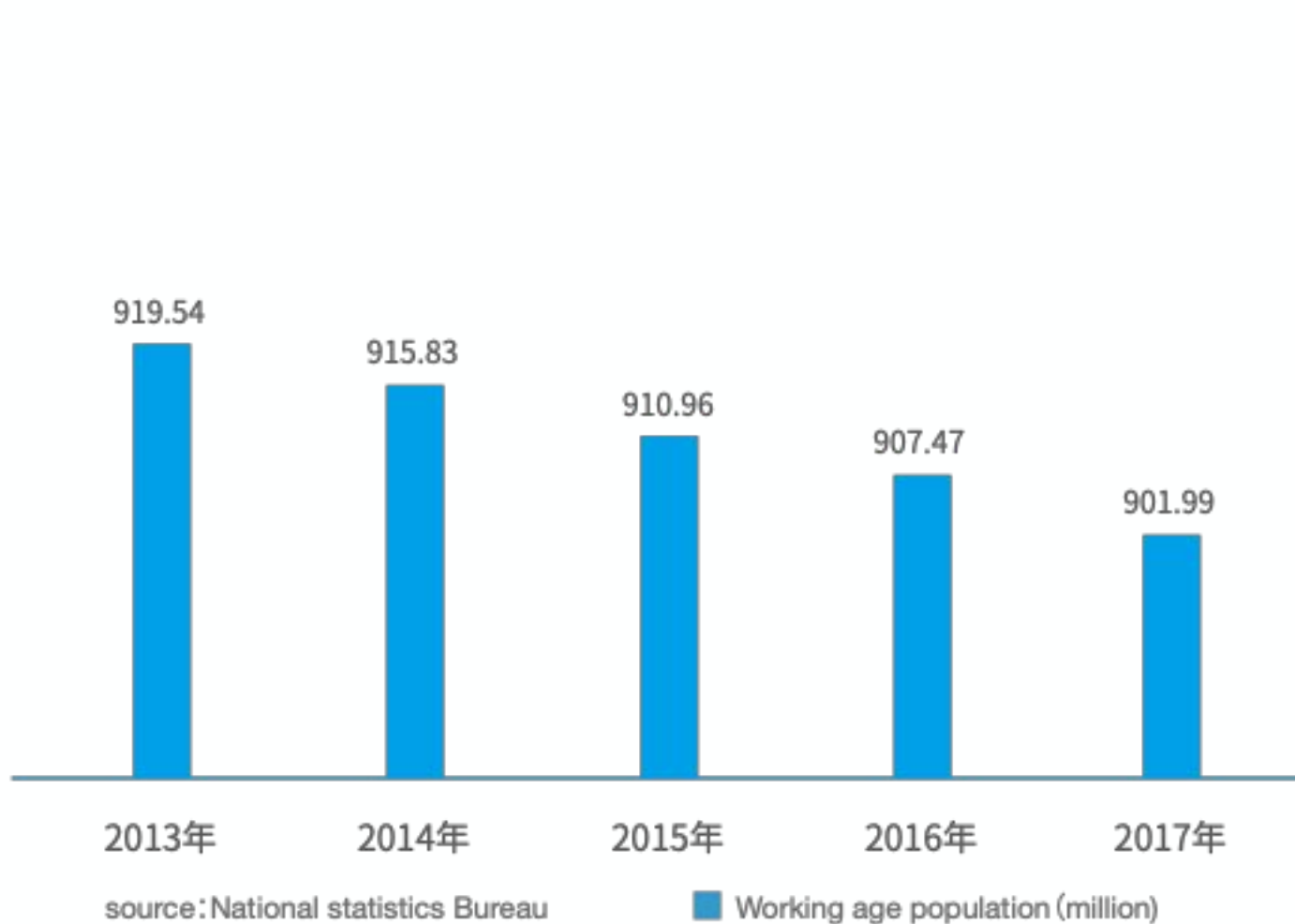
The growth rate of the courier express delivery industry has maintained above 25% annually over the past few years, and the total volume of courier express delivery in 2018 has exceeded 50 billion. Meanwhile, the instant delivery of inner-city delivery has been growing faster. The annual instant delivery volume has exceeded 10 billion in 2018, which is 10 times of the volume in 2013. On the other hand, the working-age population in our country is declining year by year. The contradiction between supply and demand of logistics delivery industry is prominent increasingly. Beurea



The development of courier express delivery business in China from 2013 to 2018



The instant delivery volume and growth rate of China from 2013-2019



The working-age population in China from 2013 to 2017

# Consumers need higher quality delivery service

1 The requirement for delivery speed is getting higher.

2 Shopping is getting more random.

3 More goods need to be delivered instantly.

4 Goods get closer to consumers.

5 Faster delivery response is expected.

6 Safer, more orderly traffic is needed in urban areas.

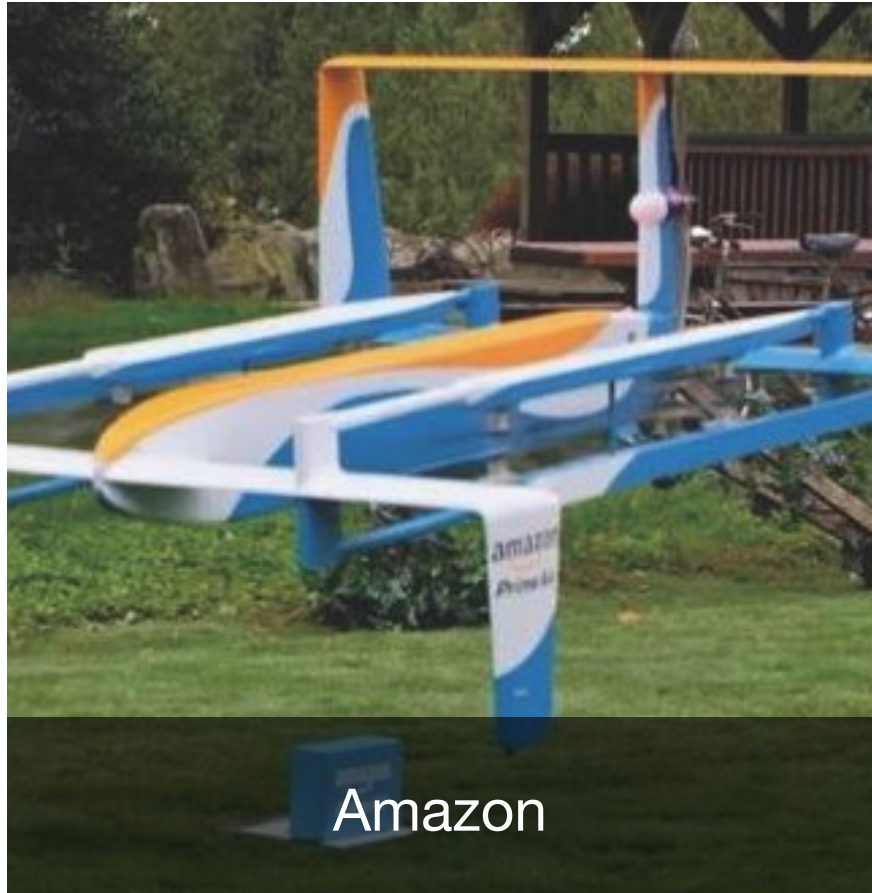


# Problems in traditional delivery service

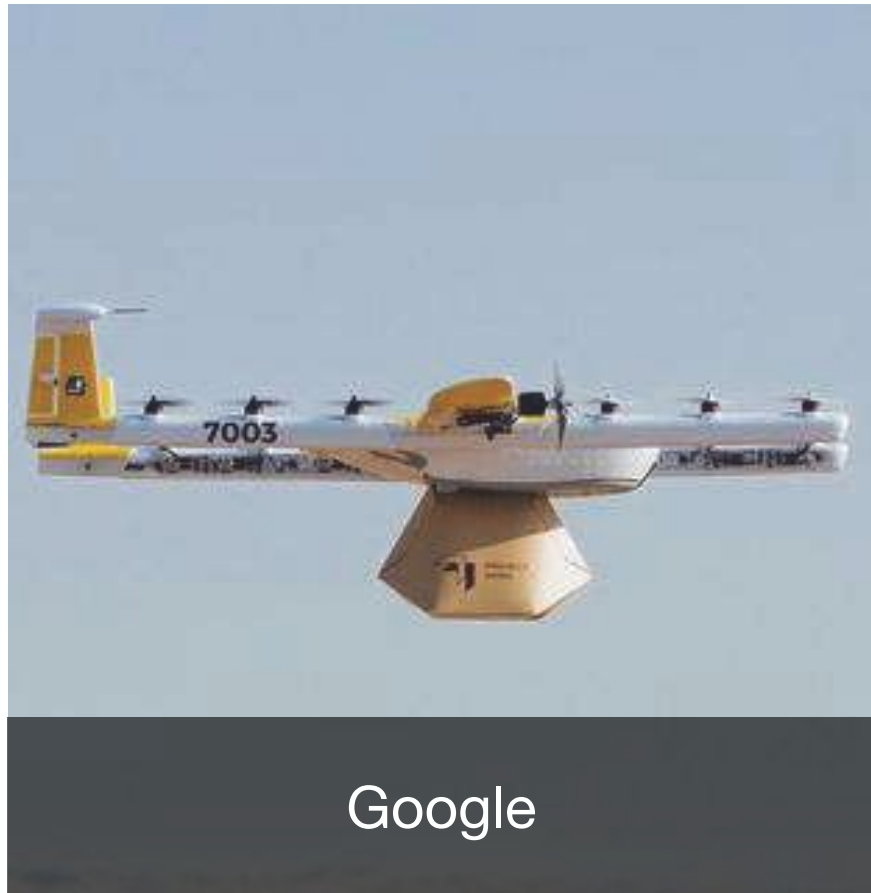
- 1 Unstable quality of service
- 2 Long delivery time
- 3 Affected by weather
- 4 Limited night delivery delivery
- 5 Increased burden of public transportation
- 6 Intense labor and difficult management



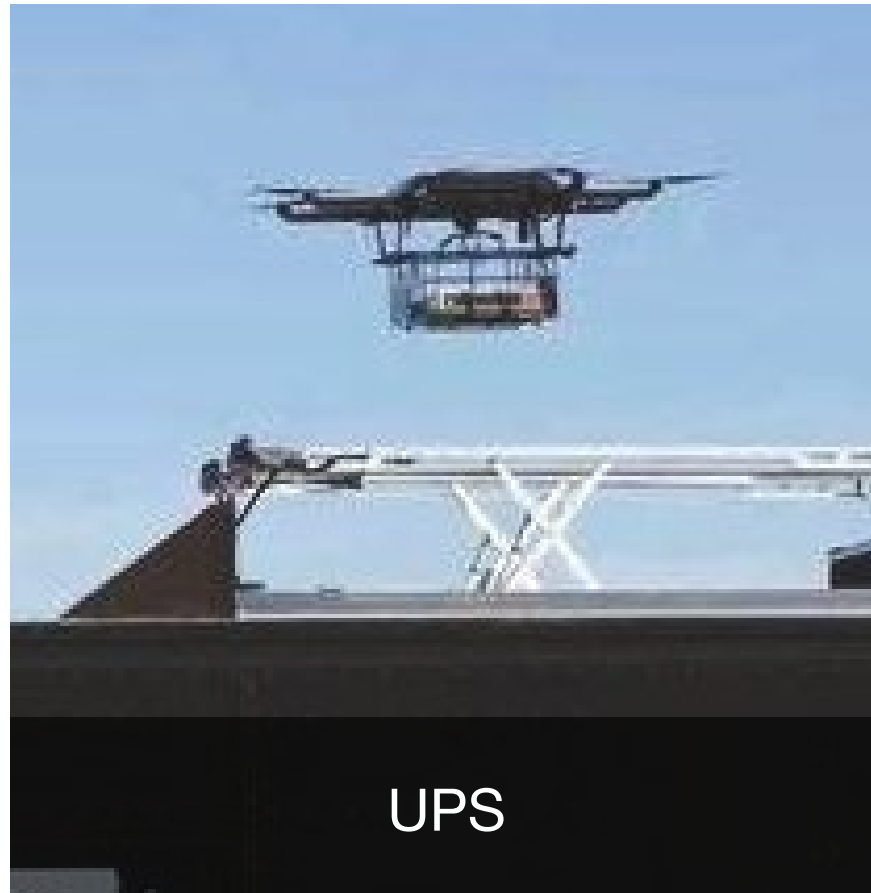
# Industry giants poured into unmanned delivery



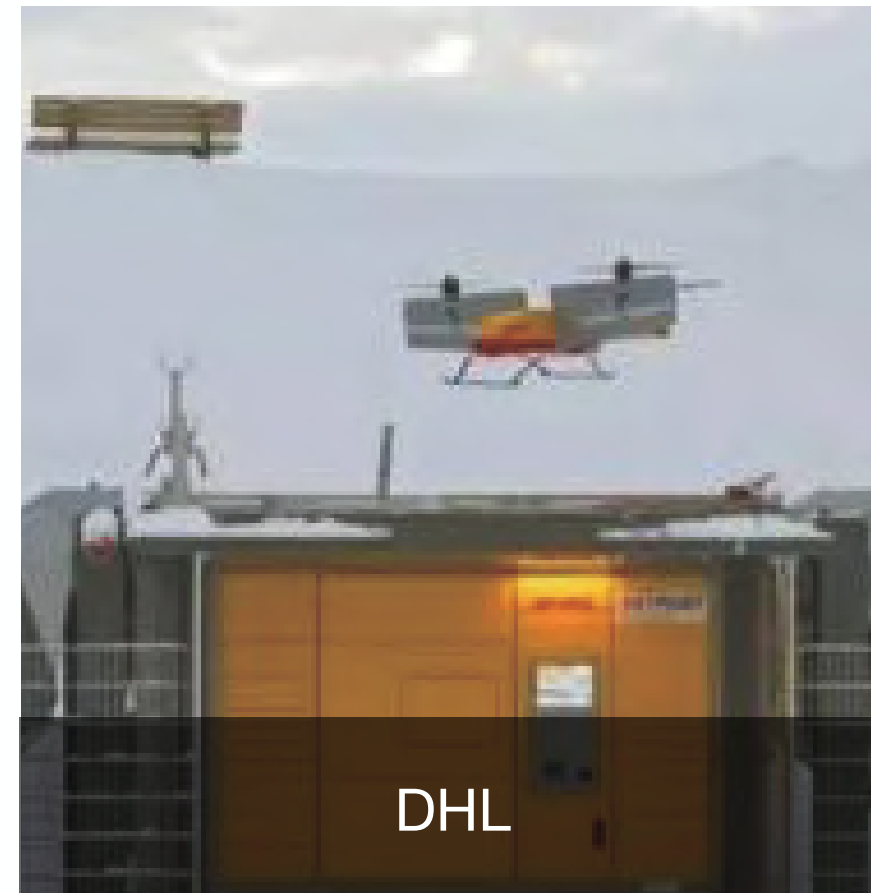
Amazon



Google



UPS



DHL



Swiss post



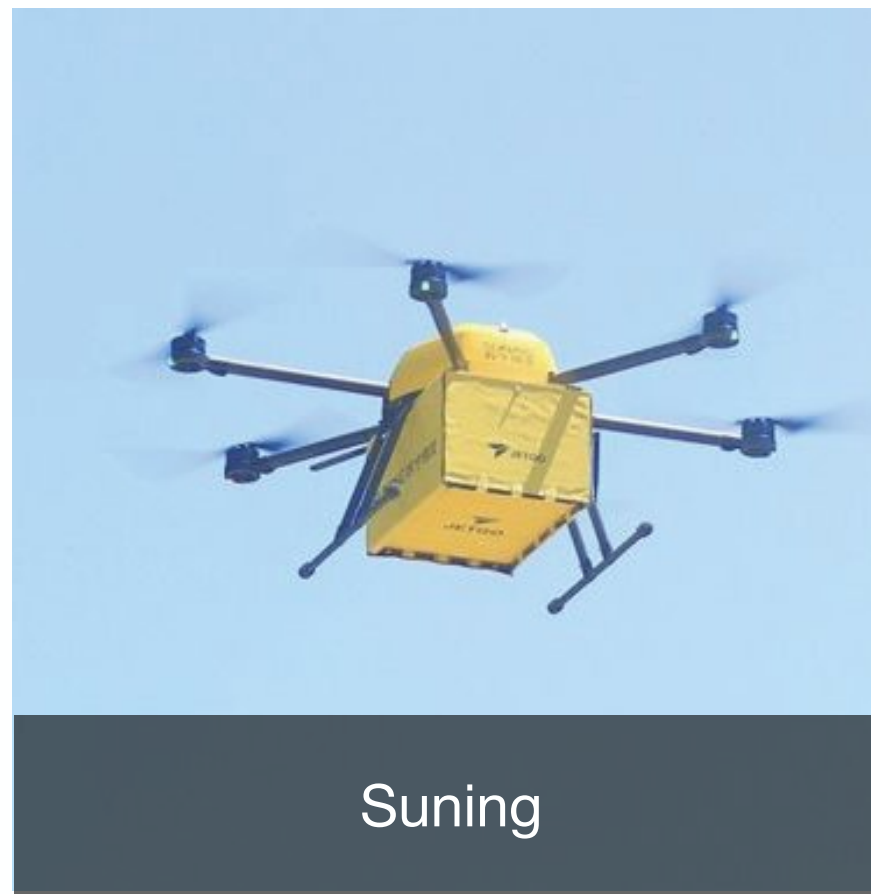
JD.COM



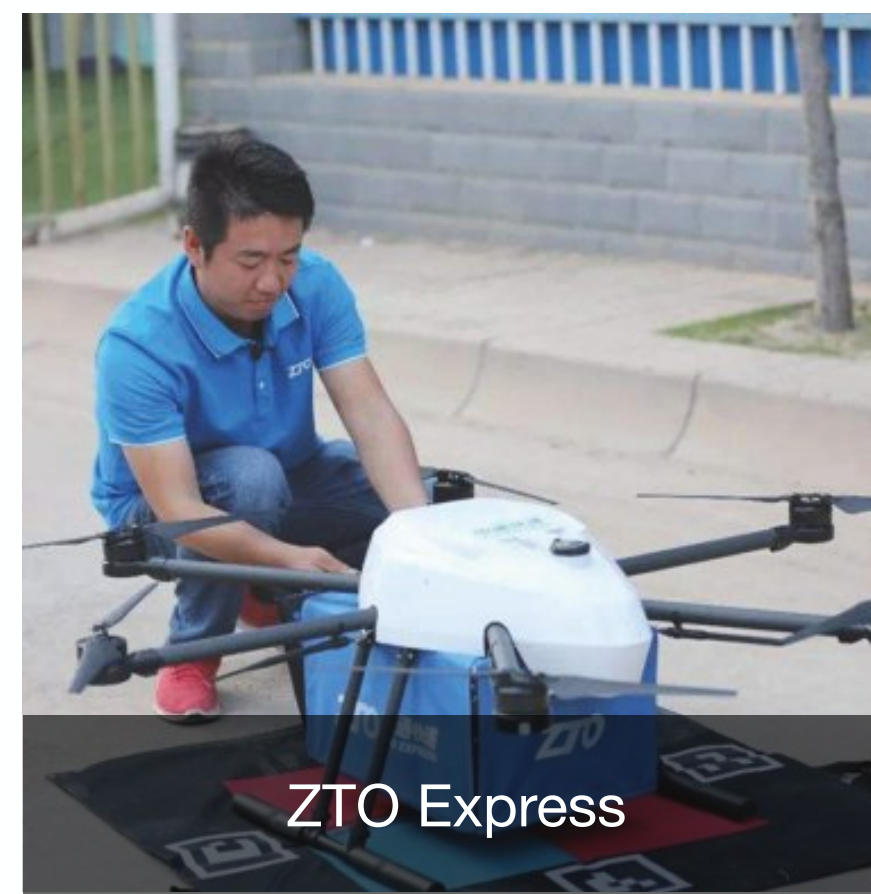
China Post



Cainiao



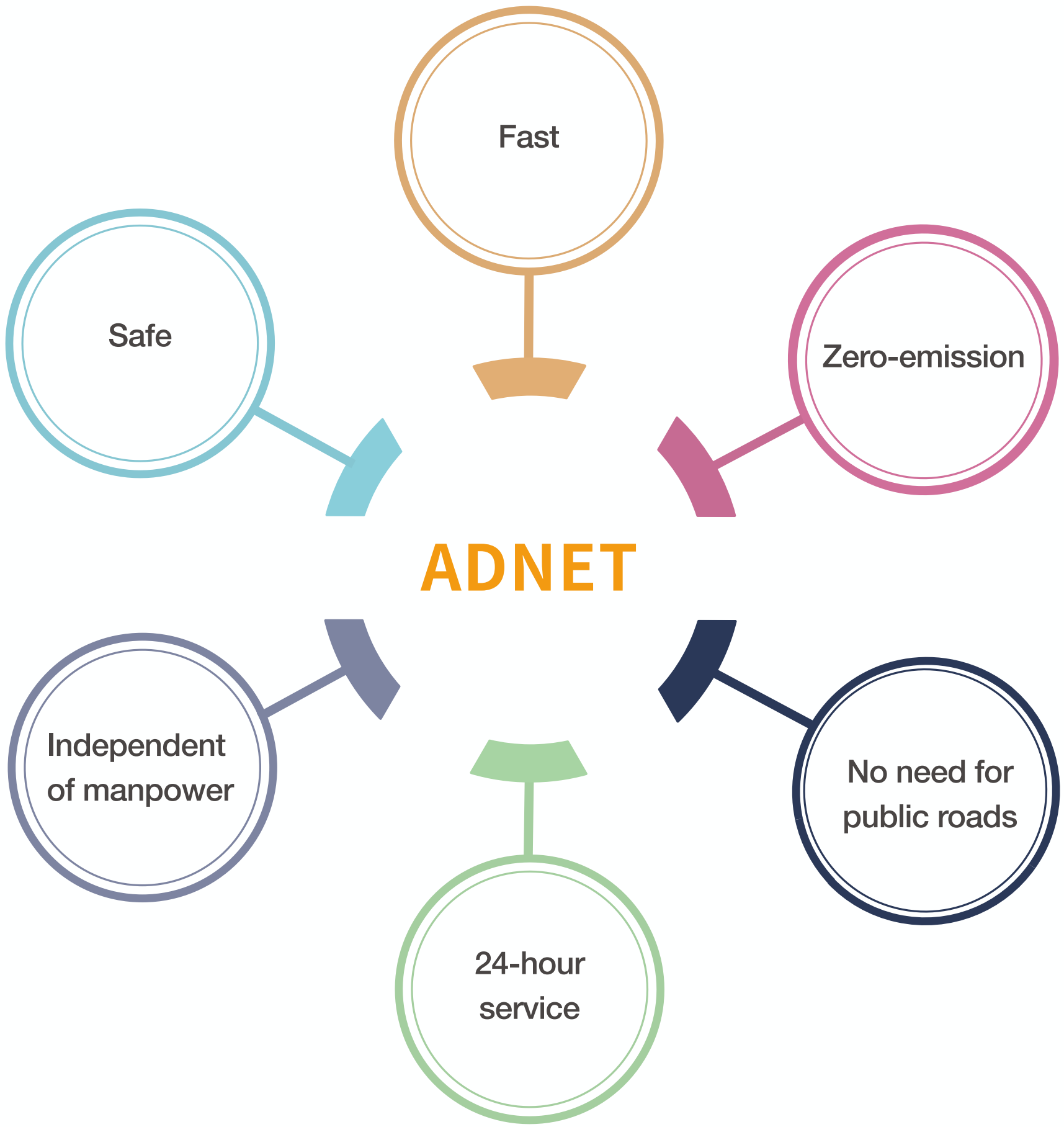
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ZTO Express



# The robotic delivery network is the optimal choice



# 02

## **ADNET turns robotic network concept into reality**

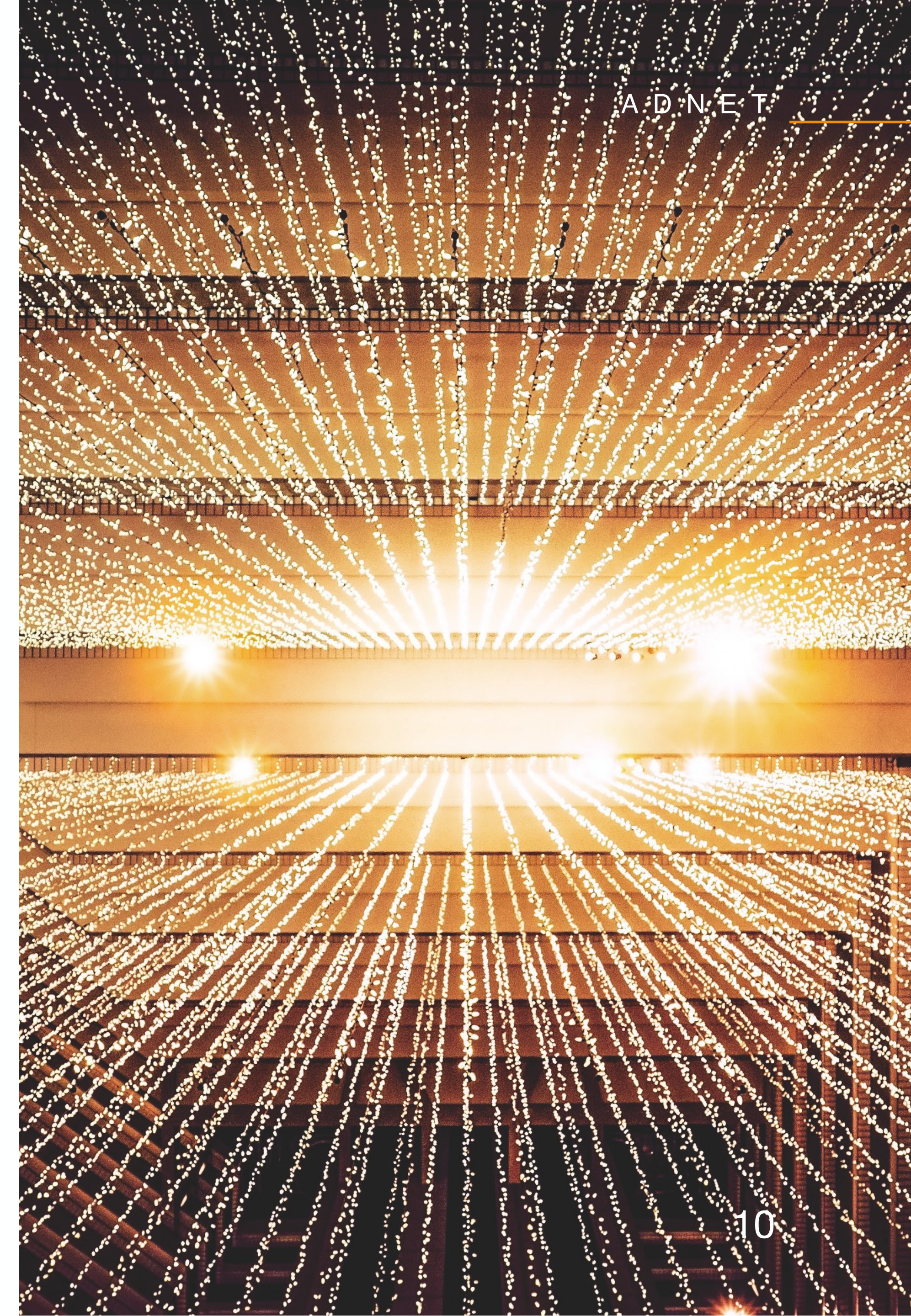
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# ADNET Introduction

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ADNET= Autonomous Delivery Network

By building a robotic delivery network covering the whole city, ADNET can meet the instant delivery needs of small and medium-sized items in the same city with the highest efficiency. With integration of high moving efficiency drones, user-friendly unmanned vehicles, large-scale automatic scheduling algorithm, hub stations, and charging depots, the purely electric driven ADNET can realize fully autonomous operation. Thus ADNET meets the future cities' logistic requirements of high speed, low cost, environmental-friendliness and all-time service response.

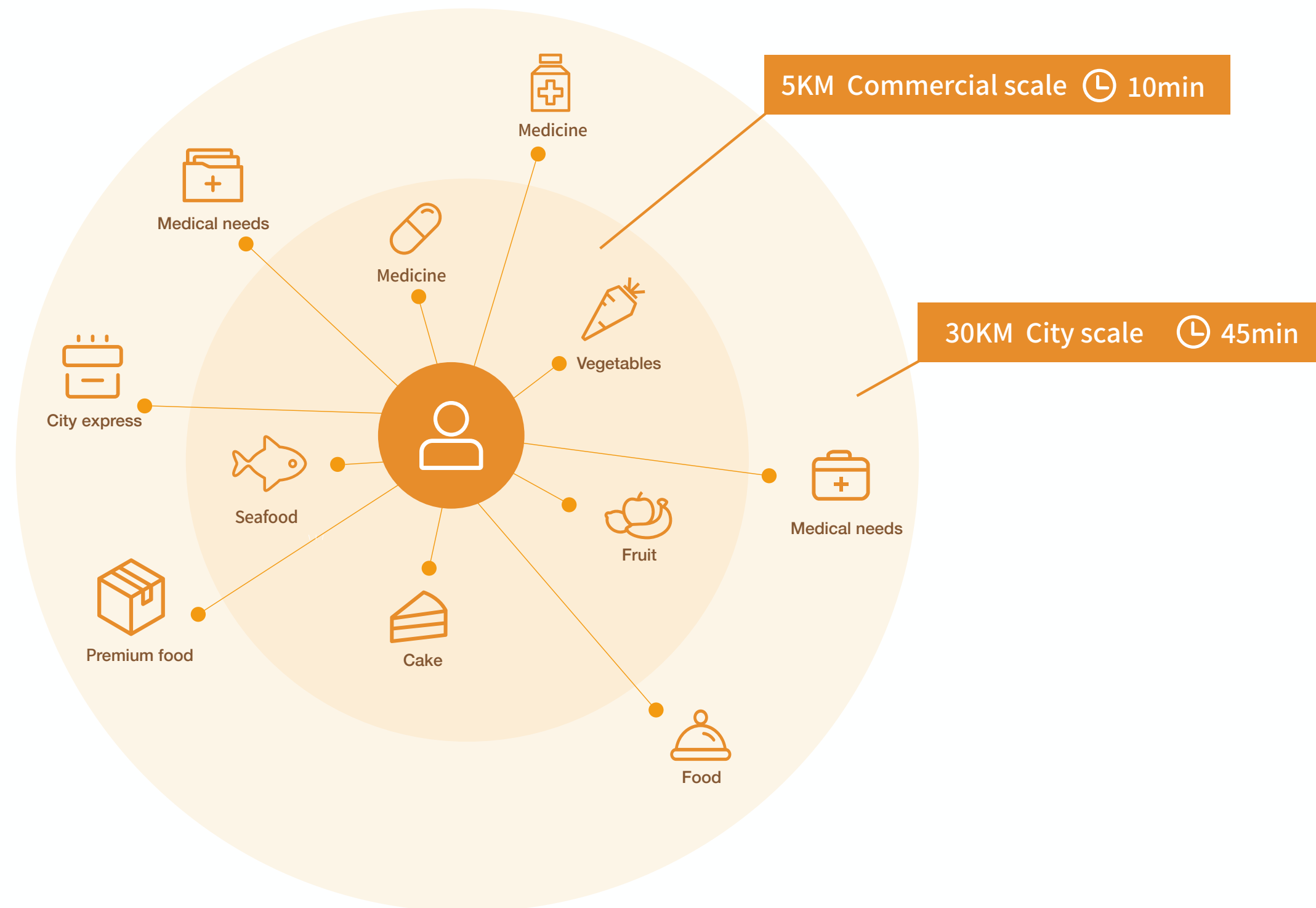


# Maximized values of connecting

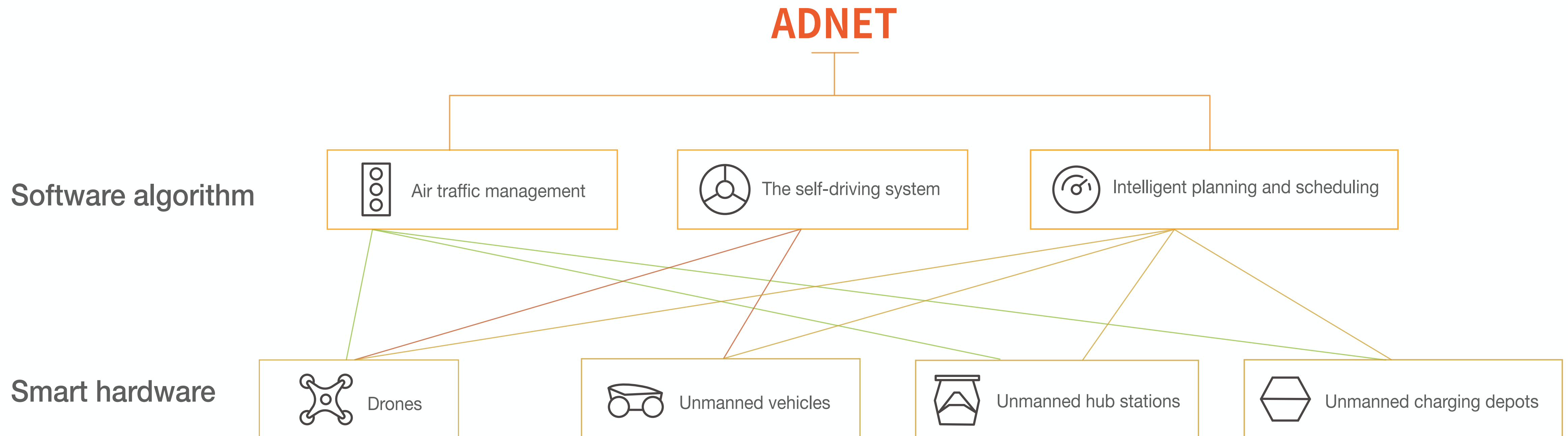
According to different types of urban delivery needs, ADNET can build a robots delivery network at commercial district scale or city scale.

Moreover, the robotic delivery networks of multiple commercial districts in the same city can be connected to each other, and form a network eventually covering the whole city, connecting every consumer, every business and every public service provider in the city. City scale ADNET can provide complete inner-city instant delivery service, which can cover all kinds of demands such as medical emergency, high-timeliness delivery and C2C delivery, and shorten the time span of connection between any two points in the city to less than 45 minutes.

The delivery network of the commercial district scale can cover a range of about 5km in diameter, and also can connect the surrounding restaurants, supermarkets and pharmacies for the consumers within the service range to deliver the goods in an average time of 10 minutes for take-out and daily life.



# Algorithms highly integrated with SW and HW



# Intelligent delivery robots



## Drone RA3

- ✓ Maximum loading 6kg
- ✓ Maximum miles 25km
- ✓ Wind resistance Level 6
- ✓ Flying speed 60KM/h
- ✓ Rain and snow proof



## Unmanned Vehicle RG1

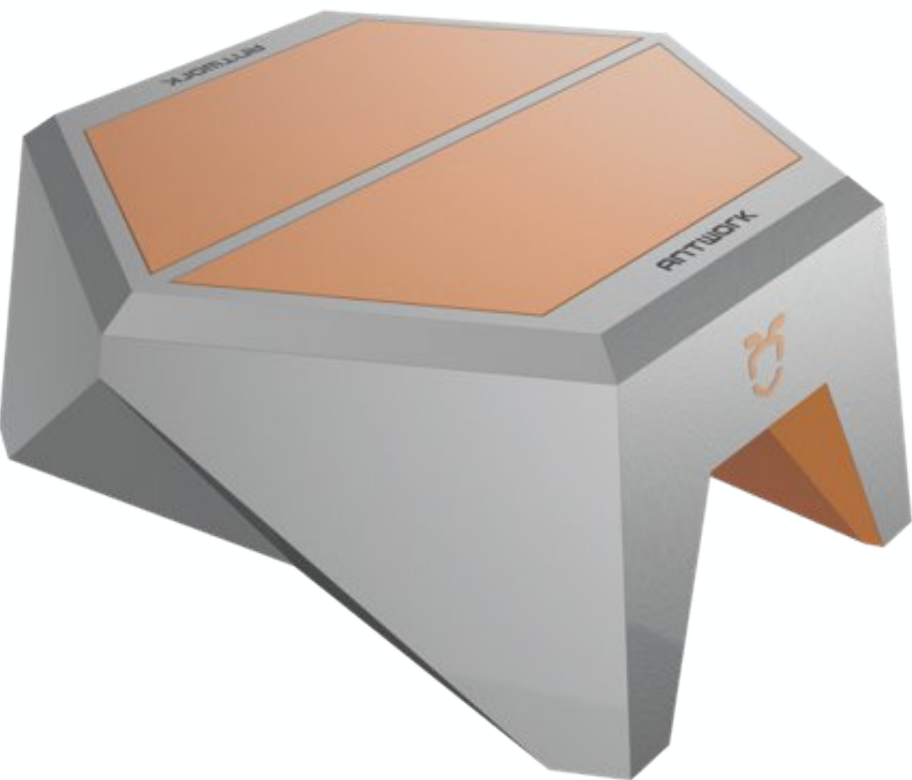
- ✓ Maximum loading 10kg
- ✓ Maximum miles 20km
- ✓ Driving speed 10KM/h
- ✓ Indoor / outdoor operation

# Automatic infrastructure



## Unmanned Hub Station RH1

- ✓ Charging ports for drones and unmanned vehicles
- ✓ Goods transit temporary storage
- ✓ Unmanned car garage
- ✓ The drone lifts the platform
- ✓ Support for human-computer interaction



## Unmanned charging depot RE1

- ✓ Drone apron
- ✓ 1C high power charging
- ✓ Communication positioning aid
- ✓ Contact charging

# The self-driving function of the delivery robots

The drones and unmanned vehicles in ADNET are all delivery robots with L4 self-driving ability.

## Perception

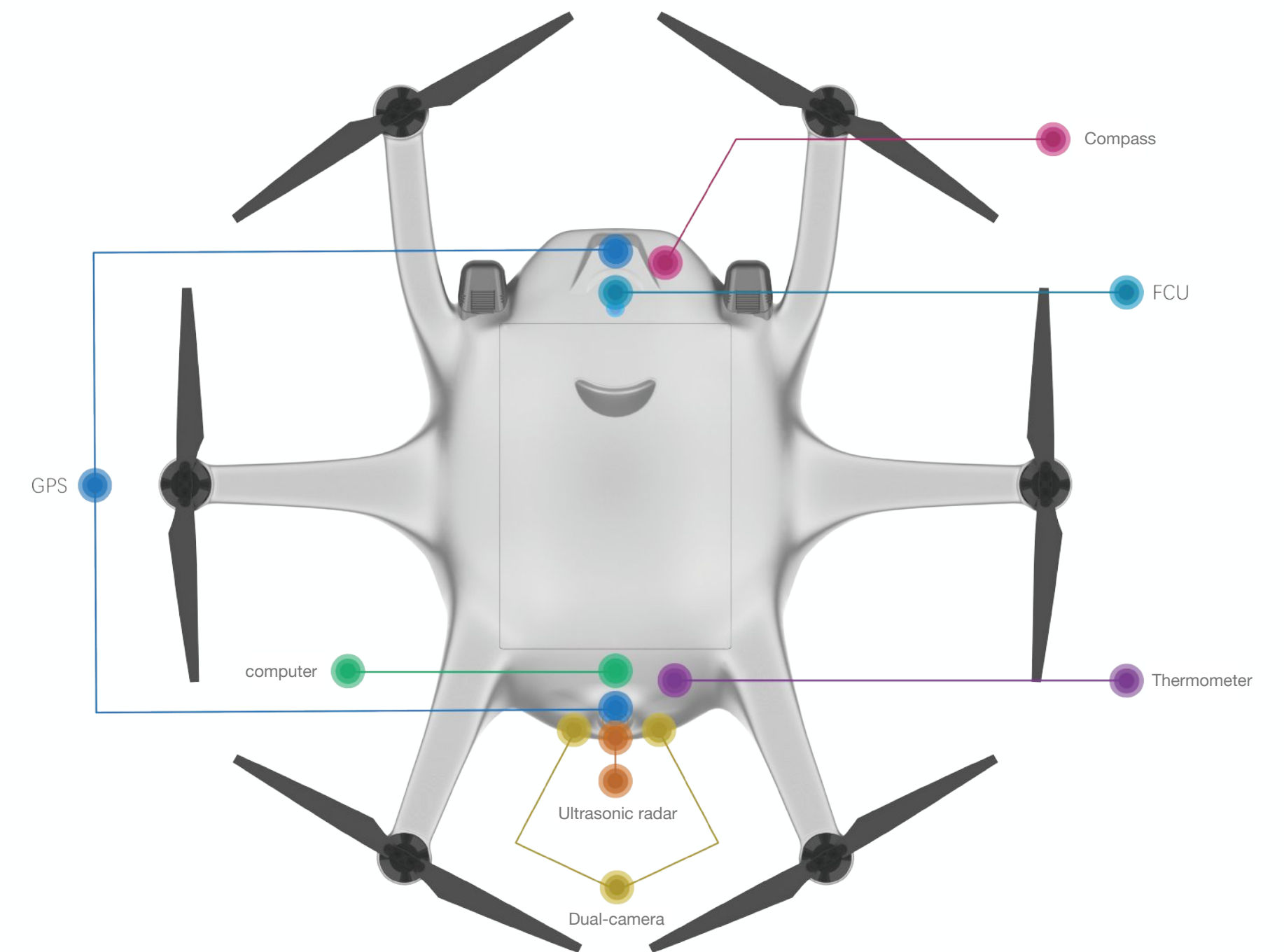
The robots are equipped with a camera set, ultrasonic radar, lidar, TOF, IMU, GPS and other sensors. Together with the ability of cloud communication, robots can realize the perception of the external environment and information collection.

## Decision-making

The robots' on-board computing system forms a complete set of understanding and corresponding algorithms for the external world based on the basic physical laws, experiences and data of the outside world. The algorithm will make a series of reasonable interpretations and decisions on the external information and changes provided by the sensors to realize the function of self-driving.

## Learning

The data accumulated in the actual operation of the robots will be fed back into the training model, and the decision-making algorithm of the system will be improved constantly to adapt the complex and abnormal situations. Any useful experiences that a robot learns will be shared with all other robots in the delivery network system.



## 5G Application

The delivery robot in ADNET can connect to the cloud server through 5G mobile communication network, of which speed is 10 to 100 times higher than 4G network. The peak transmission rate can reach 10Gbps, and the end-to-end delay can be shortened 5 times. The application can realize the smoothness of the drones's remote beyond-line-of-sight real-time control, and can guarantee responsive manual intervention to correct the outputs of the self-driving algorithm whenever necessary.



# Sophisticated algorithms realize large-scale collaboration

## Intelligent planning and scheduling

The intelligent planning and scheduling system solves the following problems mainly: delivery order for pickup and delivery, automatic aerial route design, real-time route planning of unmanned aerial vehicles, ground route planning of unmanned vehicles, and stock management of unmanned hub stations.

The locations of take-off and landing points will be selected according to the delivery requirements of the city and the geographical environment characteristics before the deployment of ADNET. The planning algorithm can design reasonable routes automatically between airports based on the input of the location of all airports in the network, the distribution of geographical features within the region, the distribution of population density and the existing flight restrictions. The real-time flight route will also be adjusted dynamically according to the real-time flight restriction notice, crowd gathering or other abnormal conditions along the aerial route.

In the process of ADNET operation, the scheduling algorithm will carry out automatic order dispatching and delivery path planning according to real-time order flow, current drones, unmanned vehicle capacity delivery and occupancy, flow rate and saturation of unmanned station and other data. The response of each delivery robot to the cloud scheduling instruction is real-time, so ADNET has obvious efficiency advantages in processing large-scale and highly concurrent orders.

# Digital air traffic regulations manage busy flights

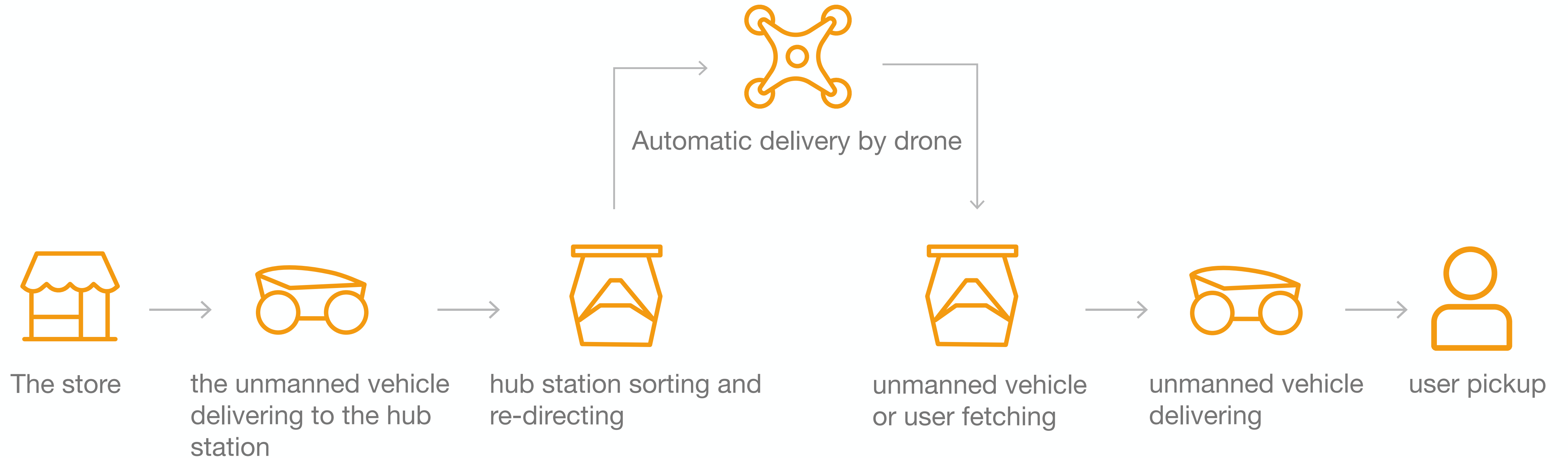
## Air traffic management

In order to meet the requirements of high-density delivery flight, ADNET adopts air traffic management system, which is designed according to the highest level C4 standard in FAA/NASA UTM technology roadmap, and can realize beyond-line-of-sight flight, urban high-density environment operation, automatic V2V communication, real-time online, and large-scale emergency response mechanism.

By using the on-board communication module, every drone in ADNET can maintain communication connection with the cloud, adjacent airports and other drone nearby through the 4G/5G WAN communication network and ad-hoc local communication network. The airspace management algorithm and airport approaching algorithm in the cloud play the roles of airspace regulator and airport approaching regulator in the civil aviation system respectively. The algorithms can issue the approaching and takeoff and landing instructions to the drone to ensure the safe and orderly takeoff and landing, departure and airway flight of multiple drones automatically according to the scheduling requirements. At the same time, the self-driving algorithm in the drones' on-board computers, as the "pilot", can not only receive instructions from the cloud, but also get the location and status of the adjacent drone and airport in real time through local communication.

ADNET can conduct real-time communication and collision avoidance with other drones in the same airspace through the unified data interface of the monitoring platform.

# Collaborative delivery process by robots

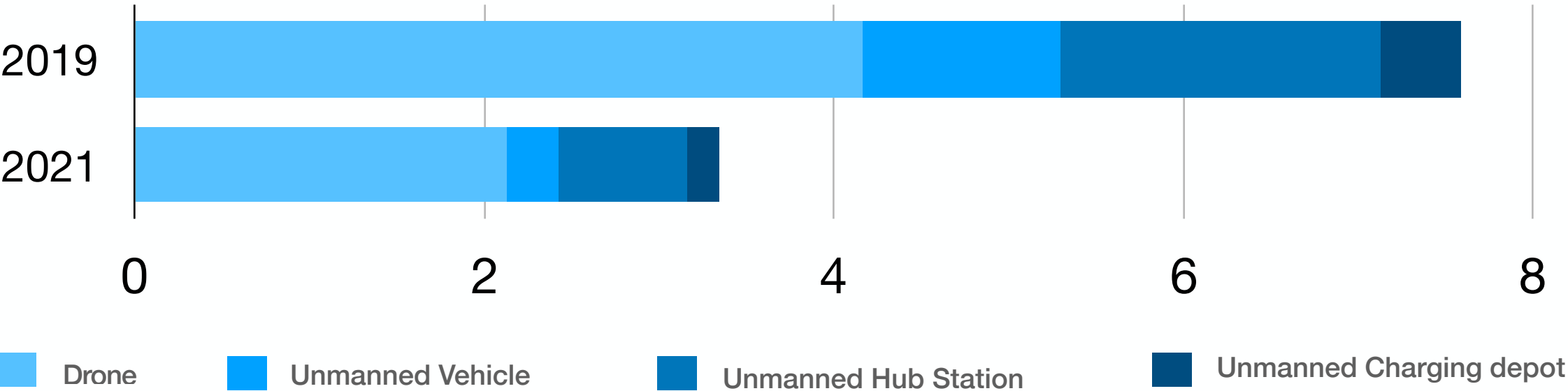


# ADNET cost structure

The standard delivery process of ADNET is completed by the cooperation of unmanned vehicles (terminal pickup and delivery), drones (intermediate transport) and unmanned hub stations (sorting and re-directing) (supported by unmanned charging depots).

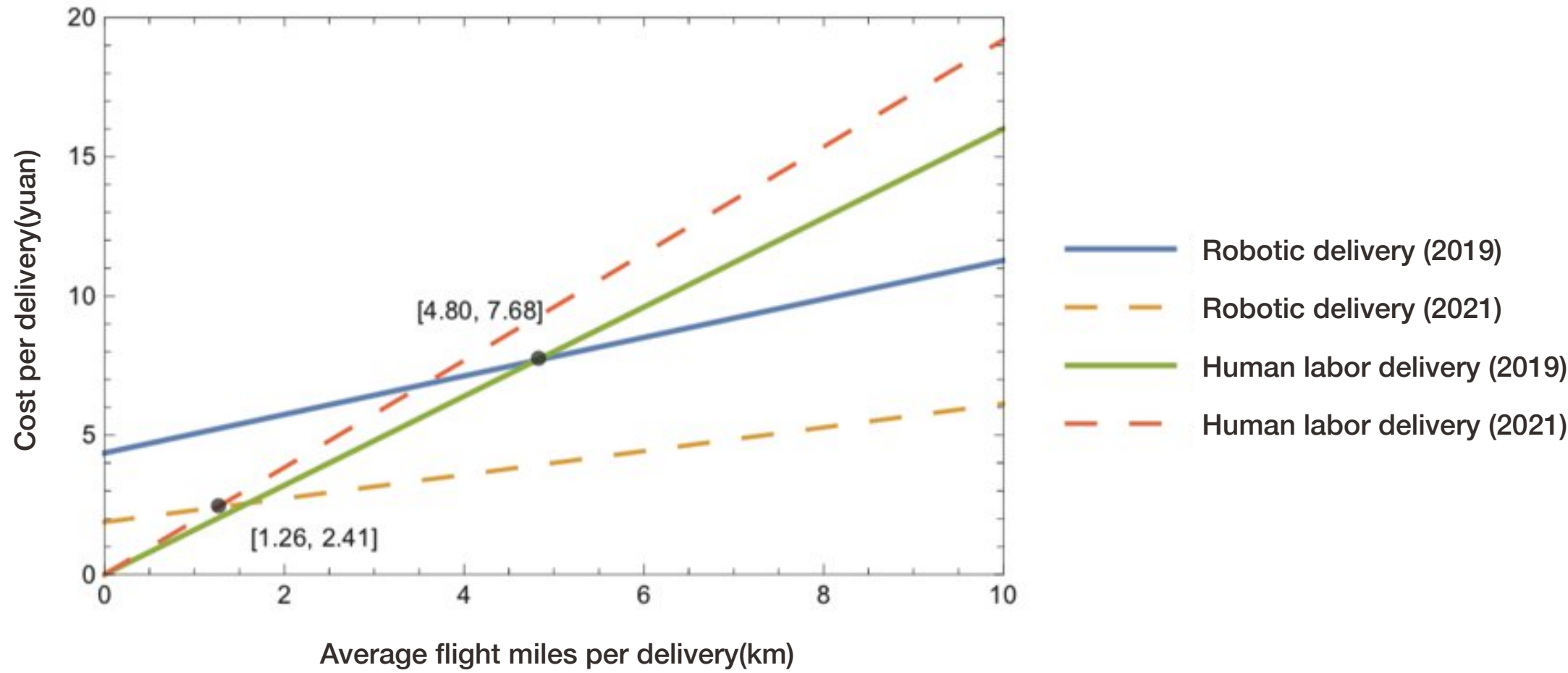
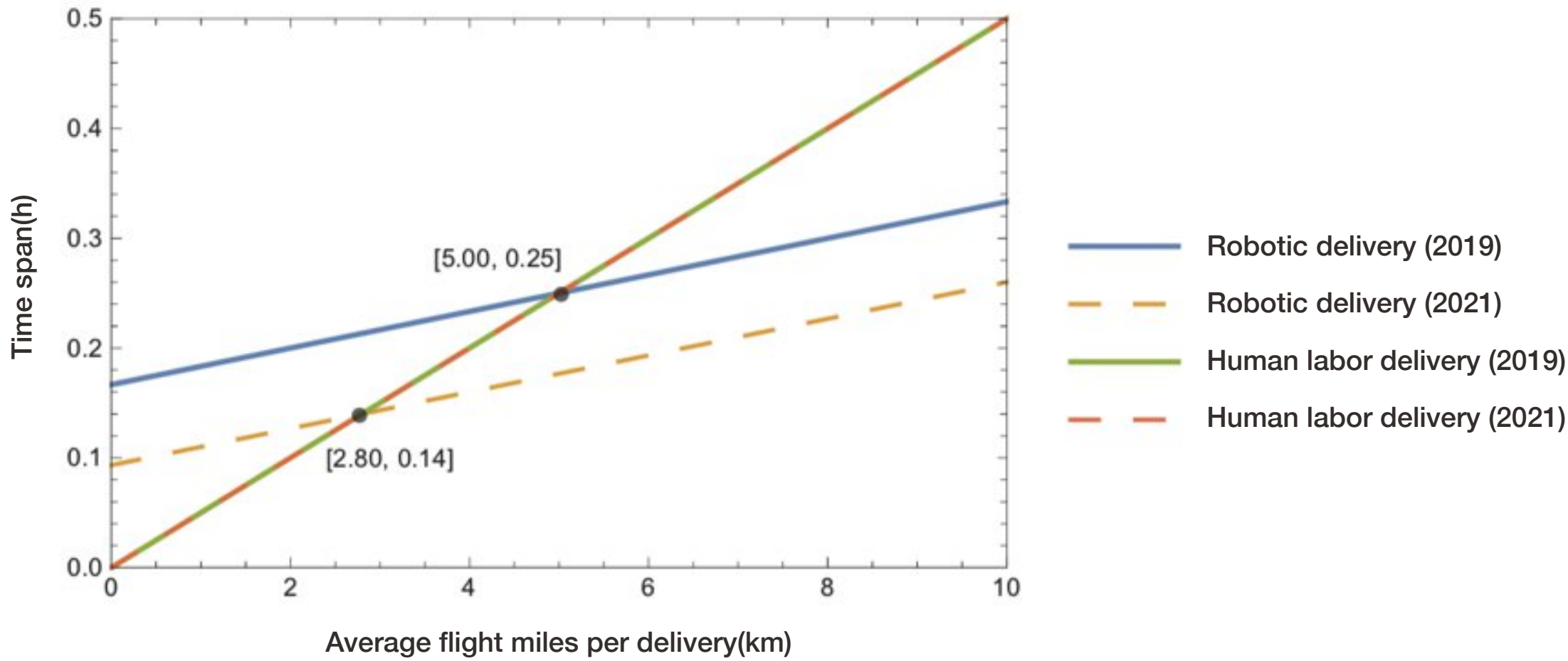
The operation of the robot will generate corresponding depreciation, energy, communication, operation and maintenance, supervision, insurance, land and other costs. The comprehensive cost of a single delivery of 5KM is 7.59 yuan based on the cost level in 2019.

With the upgrading of technology and large-scale production, it is estimated that the cost of a single 5KM delivery of ADNET can be reduced to 3.33 yuan in 2021.



# ADNET cost comparing to human labor

In the process of ADNET delivery, the operation and relay among unmanned vehicles, unmanned hub stations and drones are required. In addition, the takeoff and landing of drones also take some time, and the manual delivery can be completed by a single person without handover. Therefore, the human delivery is faster and less cost in short distance deliveries. The time span and cost advantages of ADNET start to emerge, when the delivery distance exceeds 5KM by calculation. With the reduction of equipment cost and the increase of labor cost in the future, the ADNET will become more efficient than human labor even at 2km in the future.



# ADNET user experiences

## ■ High speed

The drones flies in a straight line, which is not affected by road congestion, and the time span is guaranteed.

## ■ Low cost

There is no need for delivery personnel, and the labor cost saved allows users to enjoy lower delivery cost.

## ■ Safety

The two sides of the mobile phone are connected by a robot without human involvement, the goods are more safe and sanitary.

## ■ Responsiveness

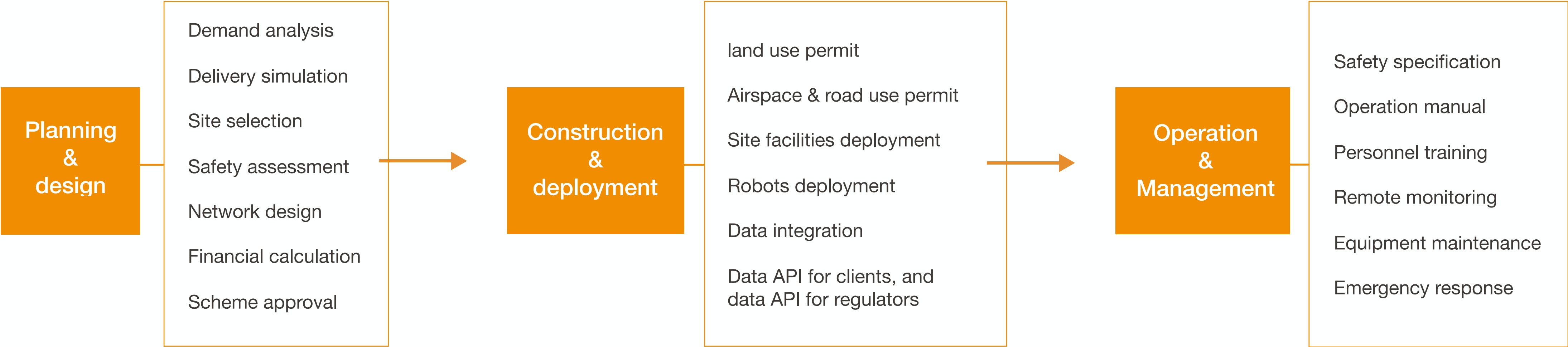
Robots can be on call 24 hours a day with zero latency.

## ■ Privacy protection

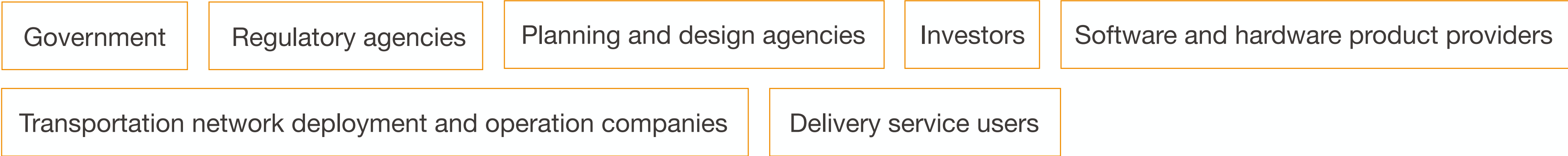
No phone calls and knocking on the door, which protect the privacy and personal safety.



# ADNET's deployment and operation



## ADNET operation stakeholders



# ADNET's challenges and potential solutions

## Laws and regulations

At present, the government is still in the process of establishing and improving the regulatory system and regulations for the regular flight of drones. Therefore, the deployment and operation of ADNET must be in deep cooperation with the regulatory authorities, starting with typical scenarios test operations. ADNET needs to fulfill the most adequate reliability verification, and cooperate closely with the authorities to carry out the research and development of relevant laws and regulations. On the other hand, the unmanned vehicle in ADNET is designed as small and low-speed vehicle, and only operating inside industrial or residential parks. So it is of low risks by design.

## Public acceptance

The operation of ADNET requires the public to get used to and accept the new service experience of robotic delivery. Although the service flexibility and humanization of robots are not good enough, they work better in terms of speed, cost, reliability and privacy protection, comparing to traditional human delivery. The public acceptance will continue to improve with the popularity of the robot service.

The drone in the ADNET is flying at a noise level of about 60-80 decibels, equivalent to the volume of a normal car driving on the road. This has the effect of noise on nearby residents or passers-by. In response, ADNET will replace the propellers of drones with low-noise version to reduce aerodynamic noise by 50% in the future. In addition, it will isolate noise sources from consumers by deploying more charging depots and unmanned hub stations on the roof of building.

## Battery technologies

At present, the lithium polymer battery commonly used in multi-rotor drones has low energy density, limited life cycles and high material cost, resulting in unsatisfying endurance and high battery cost, which accounts for about half of the total cost of each delivery flight. To overcome the disadvantages, on one hand, ADNET uses unmanned hub stations as delivery relay nodes to extend the distance range covered by drone delivery. On the other hand, the battery with capacity attenuation after long-term use of drones can be used consequently by unmanned vehicles, which has lower requirements on the battery reliability. Thus the battery life can be significantly extended and the operating cost of the system can be reduced.



# 03

**Safety is the prerequisite of ADNET large-scale application**

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# ADNET's safety by design

## A design process focusing on flight safety

- 1 Establish a complete quantitative risk model
- 2 Identify risk items one by one and carry out detailed analysis
- 3 Multiple components redundancy design reduces the probability of failure
- 4 Complete fail-safe strategies to further reduce the possibility of injury



# Multi-dimensional safety system

## Aerial safety

DAA (detect and avoidance) system integrates wide-area communication, ad-hoc local area communication, machine vision, shared airway, and automatic adjustment of safe distance and waiting time span at the airport

Anti-electromagnetic interference capability of drones (VIO visual navigation algorithm, safe flight at non-GPS condition)

Redundancy of key components (on-board computer, GPS, propeller, motor and battery)

Comprehensive emergency route and airport deployment

## Ground protection

Route planning automatically avoids crowd areas and critical facilities

Drones emergency parachute (failure protection capability in extreme cases)

## Unmanned vehicle Driving safety

Obstacle avoidance algorithm with fusion of multi-sensor signals

Redundancies of critical systems (sensors, computing systems)

Low speed (less than 20KM/h)

## Operation safety

Complete operation management manual, strict operation and maintenance personnel training and qualification assessment measures

The monitoring center monitors the whole process of the operation process of the remote safety staff

Emergency plan, commercial insurance, standby safety team on-site

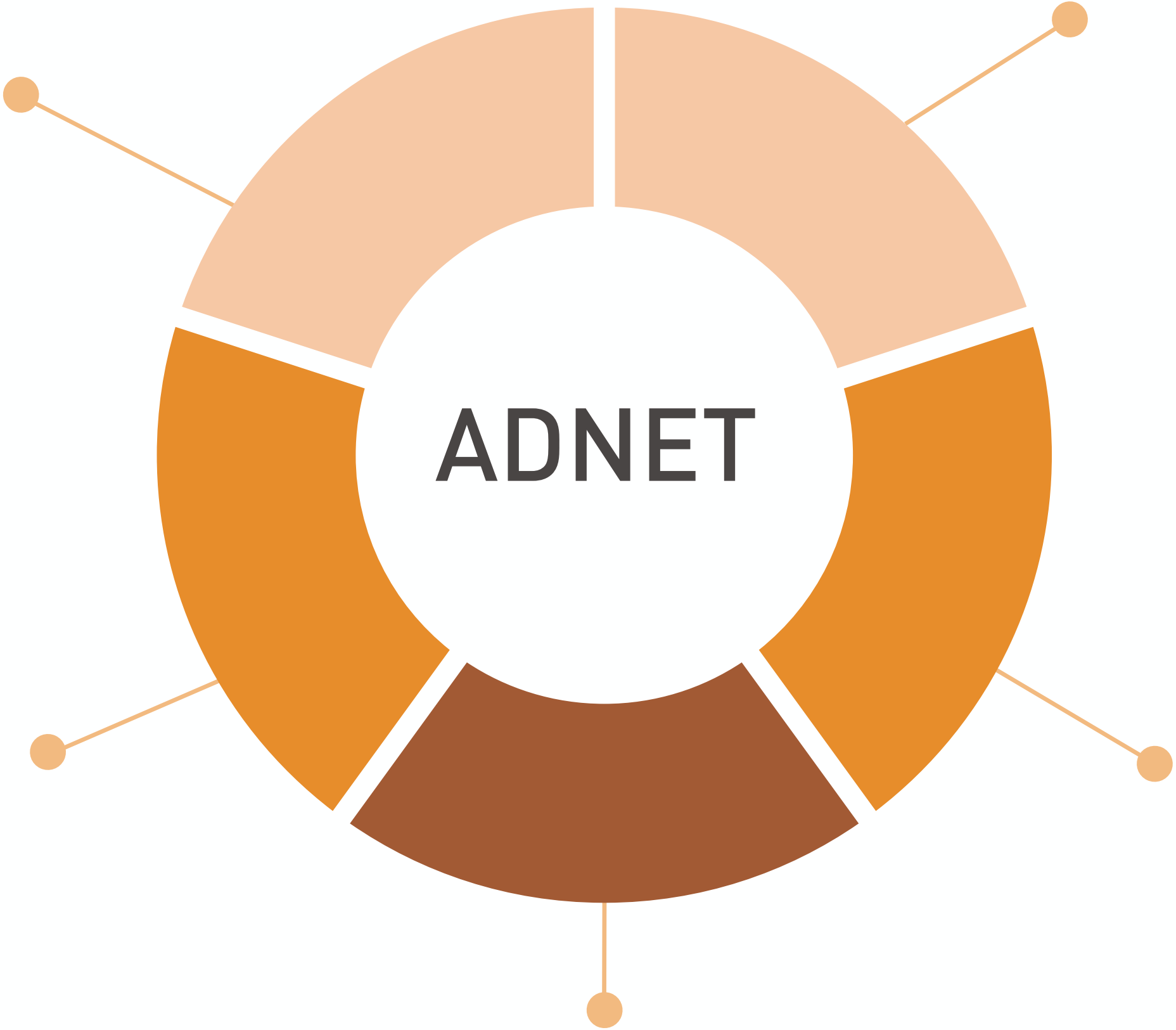
# Multi-step safety verification process

The MBD (model based design) method for complicated systems adopted to design the ADNET system.



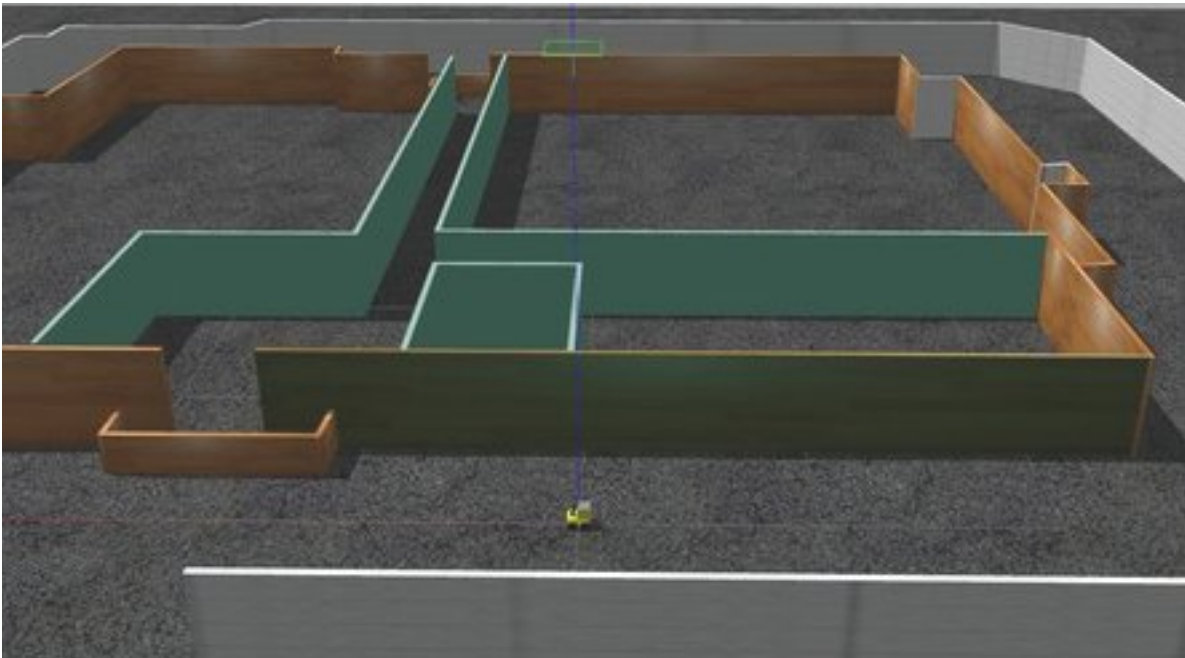
The traffic management algorithm test of dispatcher carried out in the indoor flight laboratory

Complete failure and accident analysis, repairing problems and upgrading system in time



Complete failure and accident analysis, repairing problems and upgrading system in time

Airsim, Gazebo and other software environments used to perform simulation

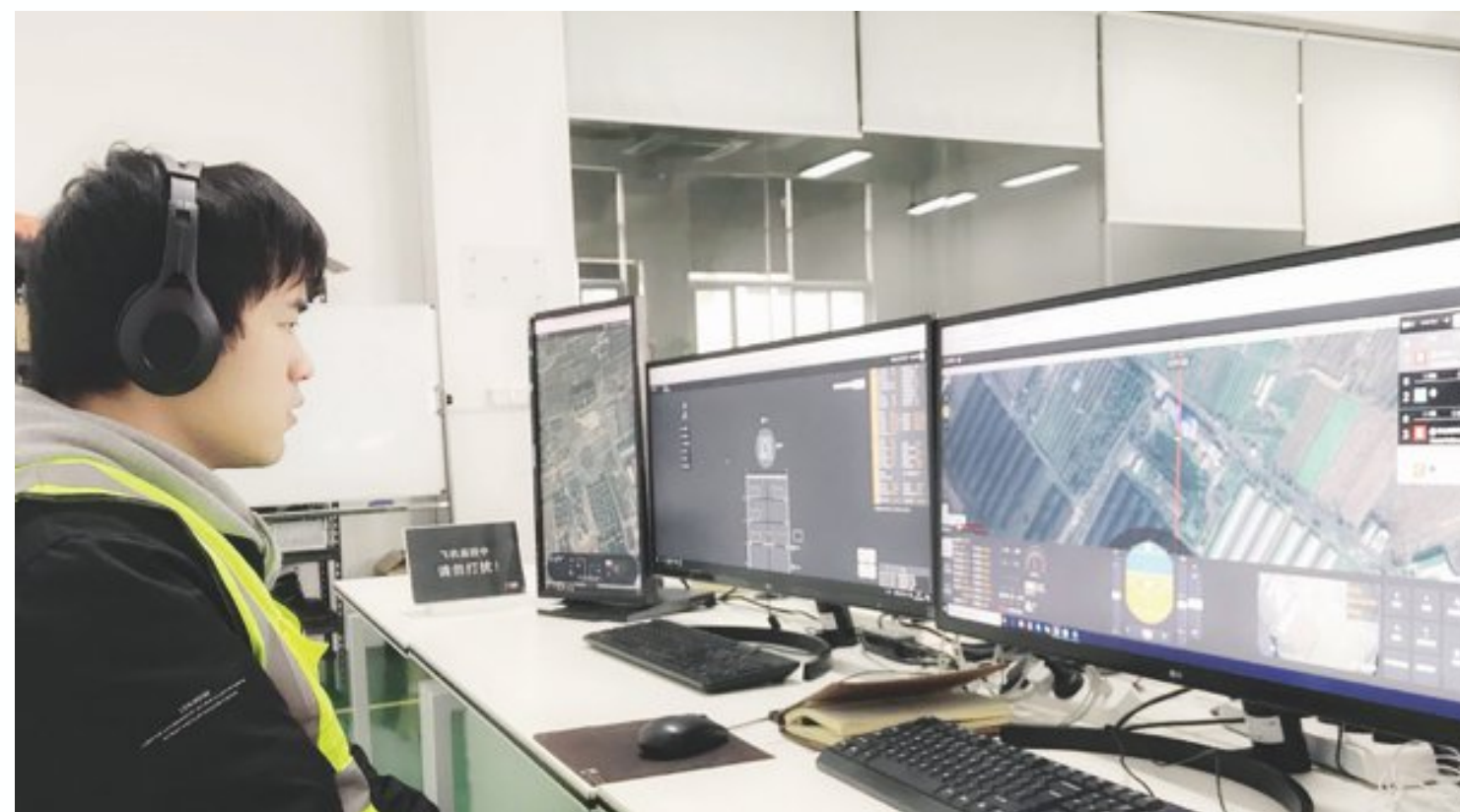


Massive operation tests in real world scenarios

# Multi-approach safety assurance mechanism

Each operating drone and unmanned vehicle in ADNET is monitored by a remote safety staff through the cloud monitoring platform of the system. Every safety staff has been trained and certified to make manual intervention during the operation of ADNET in case of special circumstances, and take over the control of drone or unmanned vehicle remotely to ensure the safety of operation. Data from the remote control is automatically recorded in the system and used to train the robot's autonomous driving algorithm so that the robot can handle similar situations on its own in the future. With the help of automatic warning system, each remote safety staff can monitor 10-20 robots in operation at the same time. With the update of algorithm, the number of human intervention in operation has been decreasing. Meanwhile, the deep integration of 5G makes communication faster and more reliable.

In addition, during the initial phase of system testing and operation, ADNET will also provide a certain number of on-site safety staff to further ensure the safety of the system and quickly deal with emergency situations in operation.



# 04

## **A case study of ADNET application**

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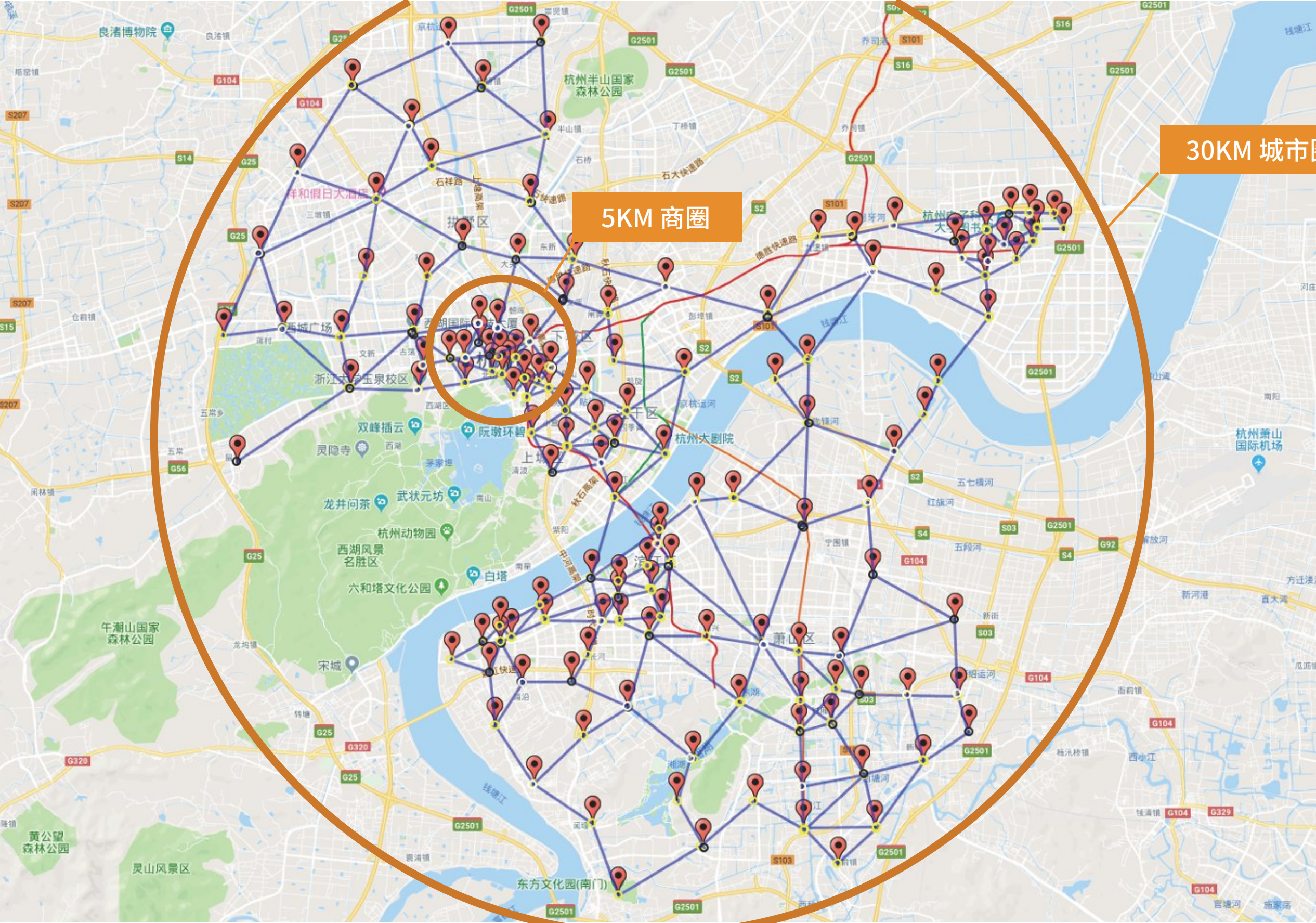
# The blue print of ADNET deployment in Hangzhou city



Taking Hangzhou as an example, we designed an ADNET deployment plan covering the whole city (with the ring expressway as the boundary). After the completion of the first phase of the delivery network, it can meet the instant delivery demand of 60,000 orders per day, accounting for 5% of the total demand of Hangzhou's instant delivery market.

When planning the geographical distribution of drones and routes, we avoided the restricted flight areas of local civil and military airports, scenic spots, squares and other crowd gathering locations, and kept the flight safety risk to the minimum.

# A robotic delivery network serving 5 million consumers



The ADNET project includes 142 airports and 265 air routes with a total length of 927KM, covering an area of 325 square kilometers and serving a population of over 5 million.



# More efficient and safer delivery services

After the ADNET in this scheme is put into use, it is expected to replace 3,000 deliverymen and 3,000 electric/motorcycle vehicles. Hundreds of traffic accidents can be reduced every year, and 200 million yuan of labor cost can be saved. The improvement of delivery speed will save a total of 6.57 million hours of waiting time for consumers.

Hardware allocation	Quantity (set)	Delivery service	Single delivery (h)	Single day (h)	Whole year (h)
Drone	856	Time saving	0.3	18,000	6,570,000
Unmanned Vehicle	424	Delivery service	Single delivery (RMB)	Single day (10k RMB)	Whole year (10k RMB)
Unmanned Hub Station	284	Delivery cost	7.59	45.54	16,622
Unmanned Charging depot	620	Delivery revenue	10	60	21,900

# ADNET enhances smart city

ADNET provides not only efficient delivery services for cities, but also information services by virtue of its large number of intelligent hardware terminals widely distributed and integrated with 5G network. That makes ADNET a significant part of smart city infrastructure.



## Smart city management

ADNET delivery drones densely distributed over the city can observe the city from a height of 80 to 100 meters and transmit 4K high-definition video real-time back through 5G high-speed network, providing rich image data for city management. That gives regulators a useful bird's eye perspective which conventional cameras do not have.



## Smart traffic management

The air traffic management system of ADNET can be provided to regulatory authorities for public use. All drones in the low height airspace of the city can be managed by a unified data interface. The intelligent air traffic management system with automated algorithms can use 5G network to send highly concurrency scheduling instructions to the drones in real time.



## 5G micro base station

The unmanned hub stations of ADNET are usually deployed in the center of each industrial park with a relatively open environment, which is very suitable for the installation of 5G micro base station serving the park. That makes the hub stations a perfect solution for deploying ultra-dense networking scheme required by the 5G technology in the future.



## 5G edge-computing

The AI chip embedded in the unmanned hub station of ADNET can deploy localized deep learning network. By taking advantage of the high-speed communication capacity of 5G micro base station, it can provide high efficiency and low-latency edge computing services for surrounding intelligent equipments such as unmanned delivery vehicles.

## Contact us

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Please feel free to contact us, if you have any questions about the report or any ideas you would like to discuss with us.

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