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Wide-Area Real-Time Surveillance Using Electric Vehicles and Helicopters for Disaster Recovery

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- EV-based ad hoc networks (EVANET)
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Backgrounds

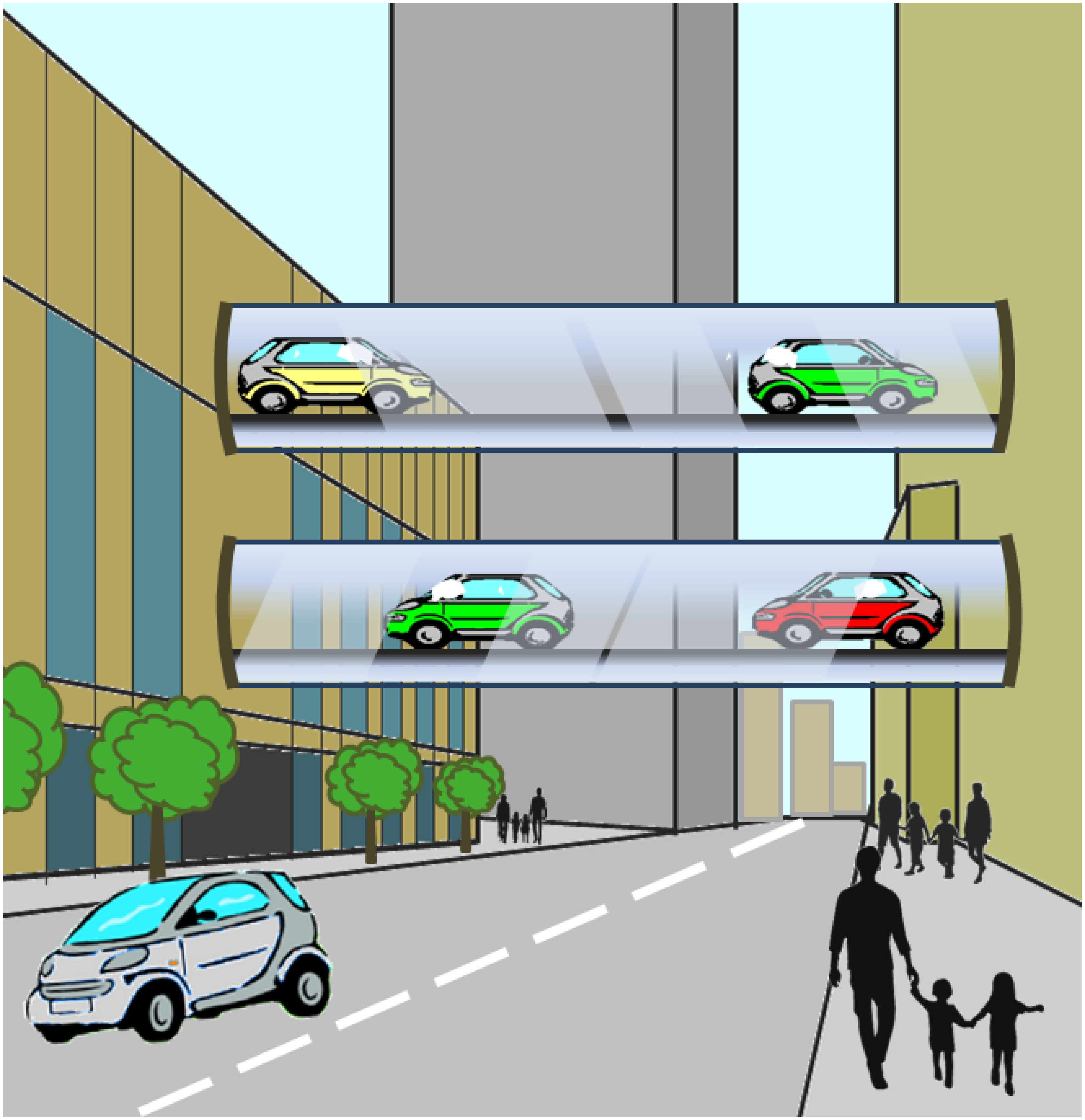
- Recent UN report showed that natural disasters have continuously threatened human life and livelihood worldwide.
- Annually, more than 226 million people are affected by natural disasters. More than 680,000 people died in earthquakes between 2000 and 2010, mainly because of poorly built structures. On average, 102 million people are annually affected by floods; 37 million, people by cyclones, hurricanes, or typhoons; and nearly 366,000 people, by landslides.
- In Asia-Pacific, over the past four decades, the average number of people exposed to annual flooding has increased from 29.5 to 63.8 million, while the population in cyclone-prone areas has grown from 71.8 million to 120.7 million.

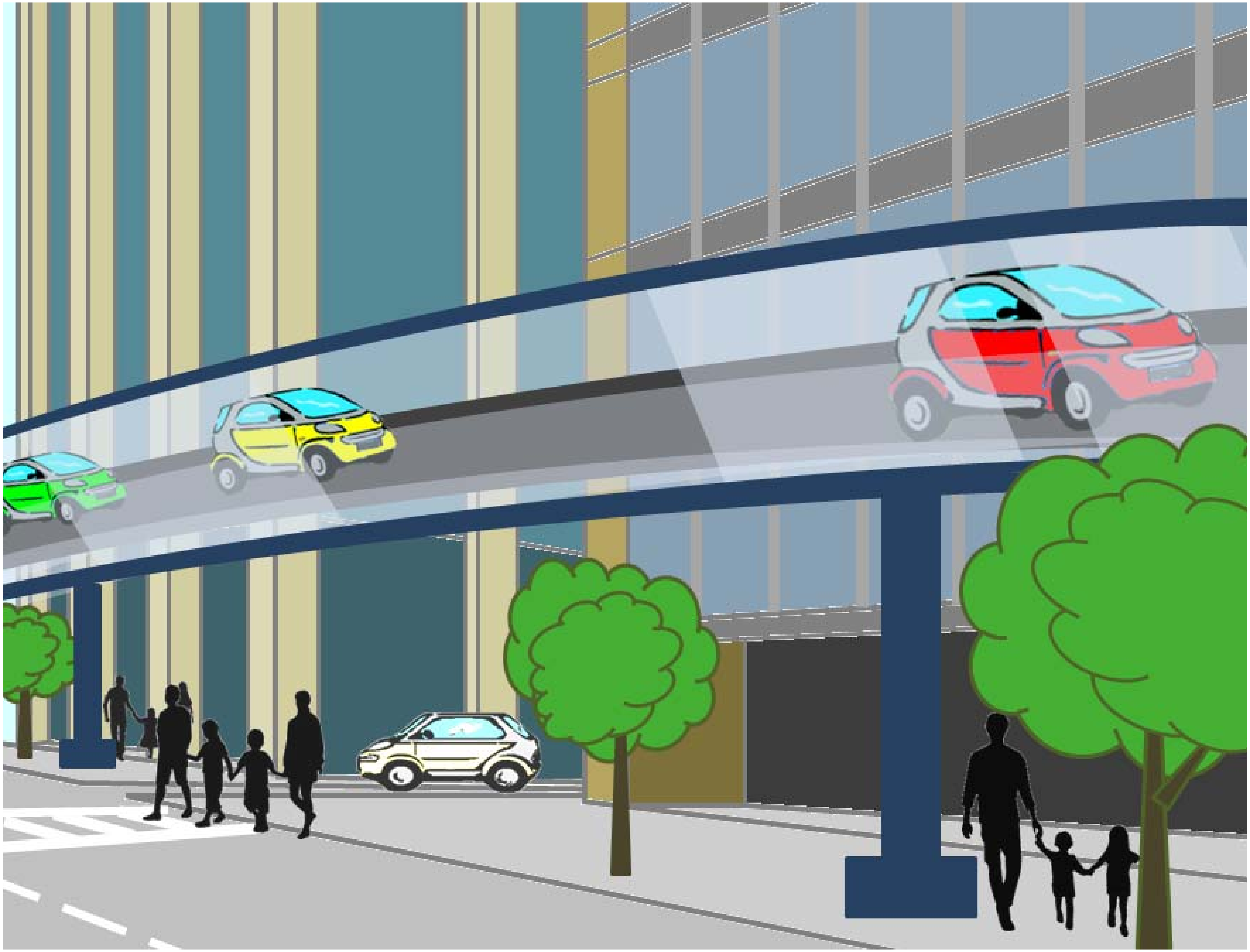
Surveillance network necessities

- Although we cannot avoid the occurrence of natural disasters, we can attempt to minimize the impact of such disasters on human life and livelihood.
- The first priority is to recognize the scope and extent of the disaster damage over the affected area in order to most effectively begin rescue and disaster recovery activities.
- The efficiency of activities such as surveying the damage and discovering survivors is reduced by the lack of information on the disaster area owing to the prolonged confusion in telecommunications services.
- There is an urgent need to establish a more effective way of quickly providing a temporary communications and surveillance network over a large disaster area.

EV industry and market

- Automobile exhaust has been a major cause of air pollution worldwide. The Electric Vehicle (EV) is free of exhaust and promising to create a low-carbon smart community.
- The EV market has recently witnessed significant growth.
- A small-sized EV with one or two seats (Mini-EV) may widely be used in aging society and contribute to further expand the market.
- Elderly drivers typically have one or two passengers, and their driving distance is generally less than average.
- Mini-EV is easy to drive and charge.
- Mini-EV may support personal daily mobility for the aged who may have difficulty walking.





Use of EVs in the disaster area

- In the near future, a tremendous number of EVs may be in use by a community, leading to the ubiquitous EV society.
- When a disaster occurs, many of these, owned by public offices and volunteered by individuals, may be utilized for disaster recovery.
- The use of EVs in the disaster recovery is promising because they have large-capacity battery and can be recharged using local power generation facilities.

EV–based surveillance network

- For conducting efficient surveillance and rescue activities over a wide disaster area, surveillance team members should be spread out over the area.
- EVs provide a means of travelling that enables them to quickly move around the wide disaster area.
- EVs also provide a means of surveillance and data delivery.
- Each EV is equipped with cameras, sensors, and communication devices. The information obtained by each EV is delivered to the data collection station in the area.

EV-based mobile ad-hoc network

- Vehicular and-hoc network (VANET) have been studied within the framework of ITS.
- In VANET, gasoline-powered vehicles have been assumed.
- A gasoline-powered vehicle has a small-capacity battery and cannot work as a communication node when the engine is switched off.
- The applications of a VANET while driving are of major interest.
- An EV can work as a communication node regardless of driving or parking using its large-capacity battery.
- EV-based MANET (EVANET) applications may not be limited to only driving situations.

Surveillance from the air

- EVANET-based surveillance on the ground can be powered up by adding surveillance capability from the air.
- Unmanned aerial vehicles (UAVs) are attractive in terms of the efficient surveillance, low investment and operational ease.
- Cameras, other sensors, and communication devices are mounted on each UAV for monitoring the disaster-affected area and transmitting acquired data to other UAVs or ground stations.
- A number of UAVs may be required to monitor a wide disaster area. Therefore, communication among the UAVs and ground stations is necessary, and a mobile ad hoc network can be used to meet this requirement.

Surveillance from the air
Alternatives

	Mobility	Hovering	Wind resistance	Flying time and range	On-EV charging	Logistics
Tethered balloon	No	Yes	Limited	Fair	Feasible	Full backup needed
Airship	Low	Yes	Limited	Fair	Difficult	Full backup needed
Helicopter	Low	Yes	Fair	Limited	Feasible	Light support needed (electric helicopter)
Airplane	High	No	Fair	Limited	Difficult	Full backup needed

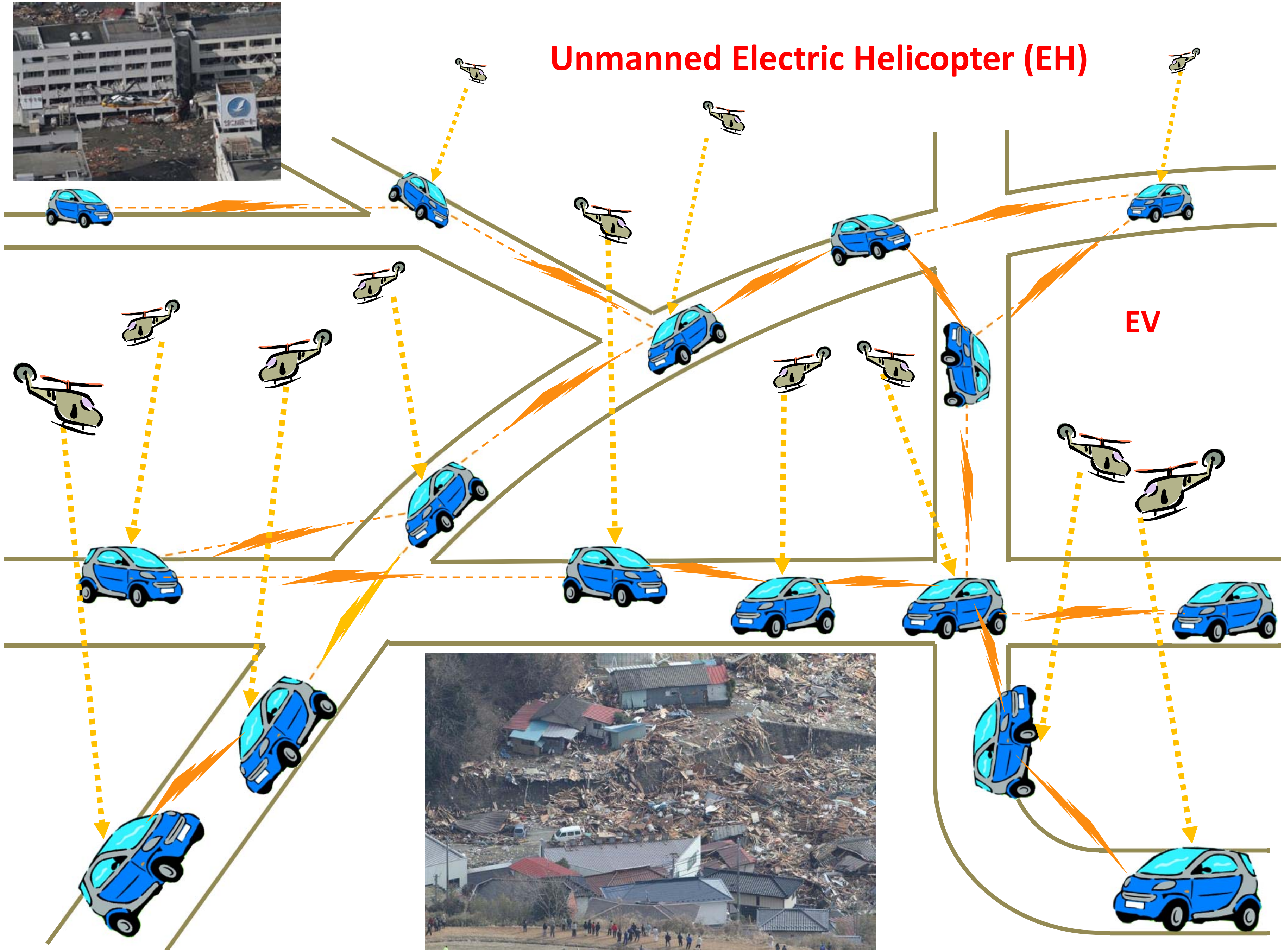
- Tiny unmanned electric helicopters (EHs) is adopted.
- The flying time and range of an EH are limited owing to its battery capacity.
- EV battery can be used to re-charge EH battery (on-EV charging).

Surveillance architecture

３ Dimensional Mobile Surveillance（3DMS）

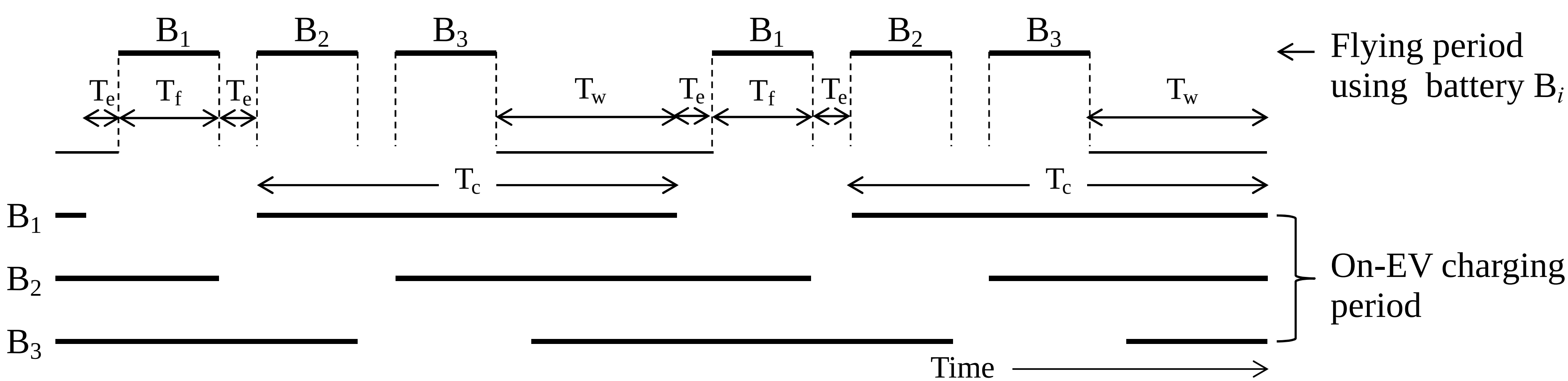
- The proposed surveillance system is composed of multiple EVs and unmanned EHs, each equipped with cameras, sensors, and communication devices.
- EVs function as the carrier of EHs and supplier of energy by means of recharging and replacing EH batteries.
- EV drivers cannot manually pilot the EHs. Autonomous piloting of the EH should thus be supported.
- EVs and EHs form a mobile ad hoc network and share the information collected by each EV and EH, delivering the information to a data collection station.
- When two EVs are out of transmission range with each other, an EH in the air can be used as their relay node or message carrier (carry and forward).

3 Dimensional Mobile Surveillance (3DMS)



On-EV charging may take time

- A carrier EV is equipped with spare EH batteries.
- By substituting a spare EH battery for the spent battery, the EH can immediately resumes surveillance.
- The spent battery is recharged on the EV for later use.



T_f : Flying time

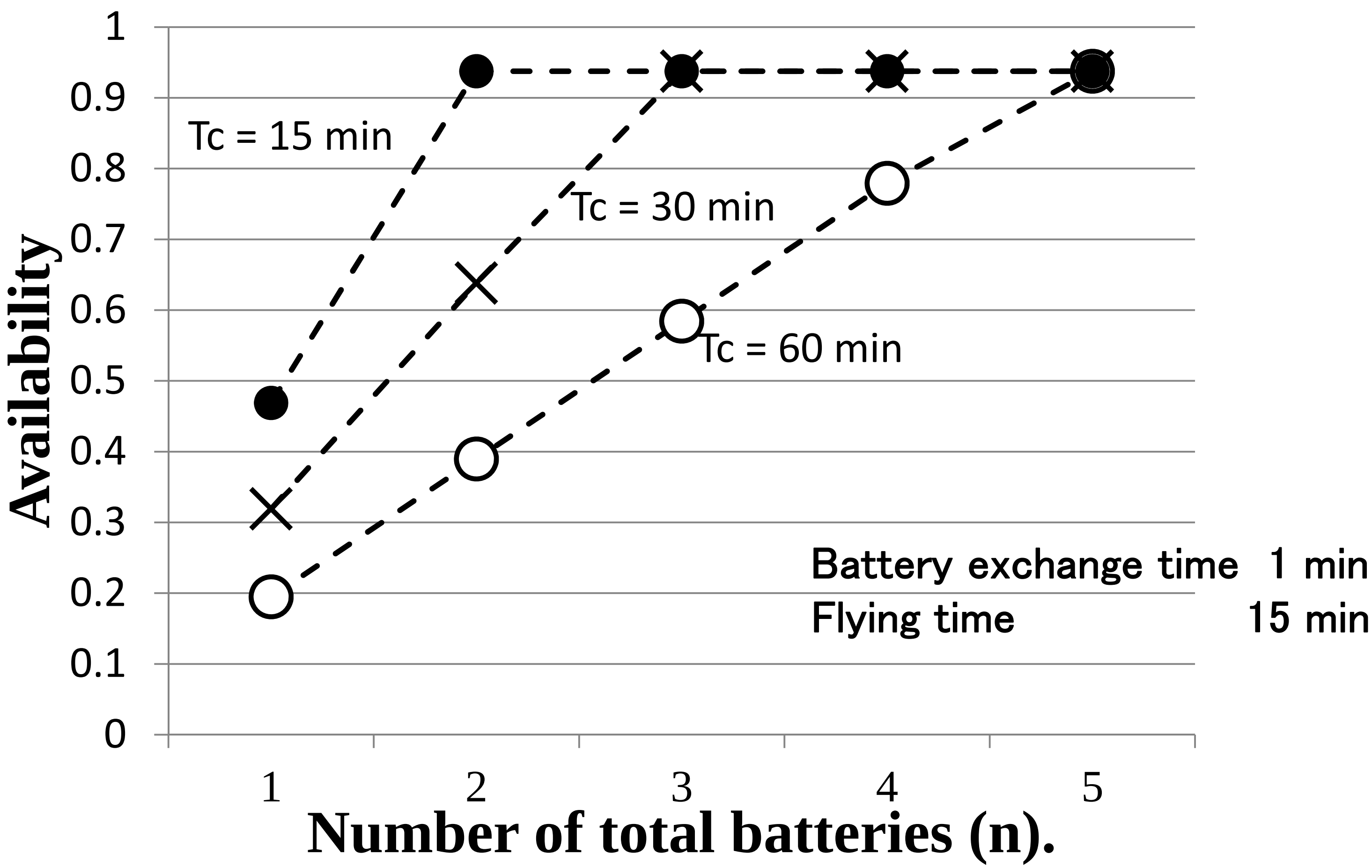
T_e : Battery exchange time

T_w: Waiting time

T_c : Charging time

B_i: Battery i (i=1,2,3)

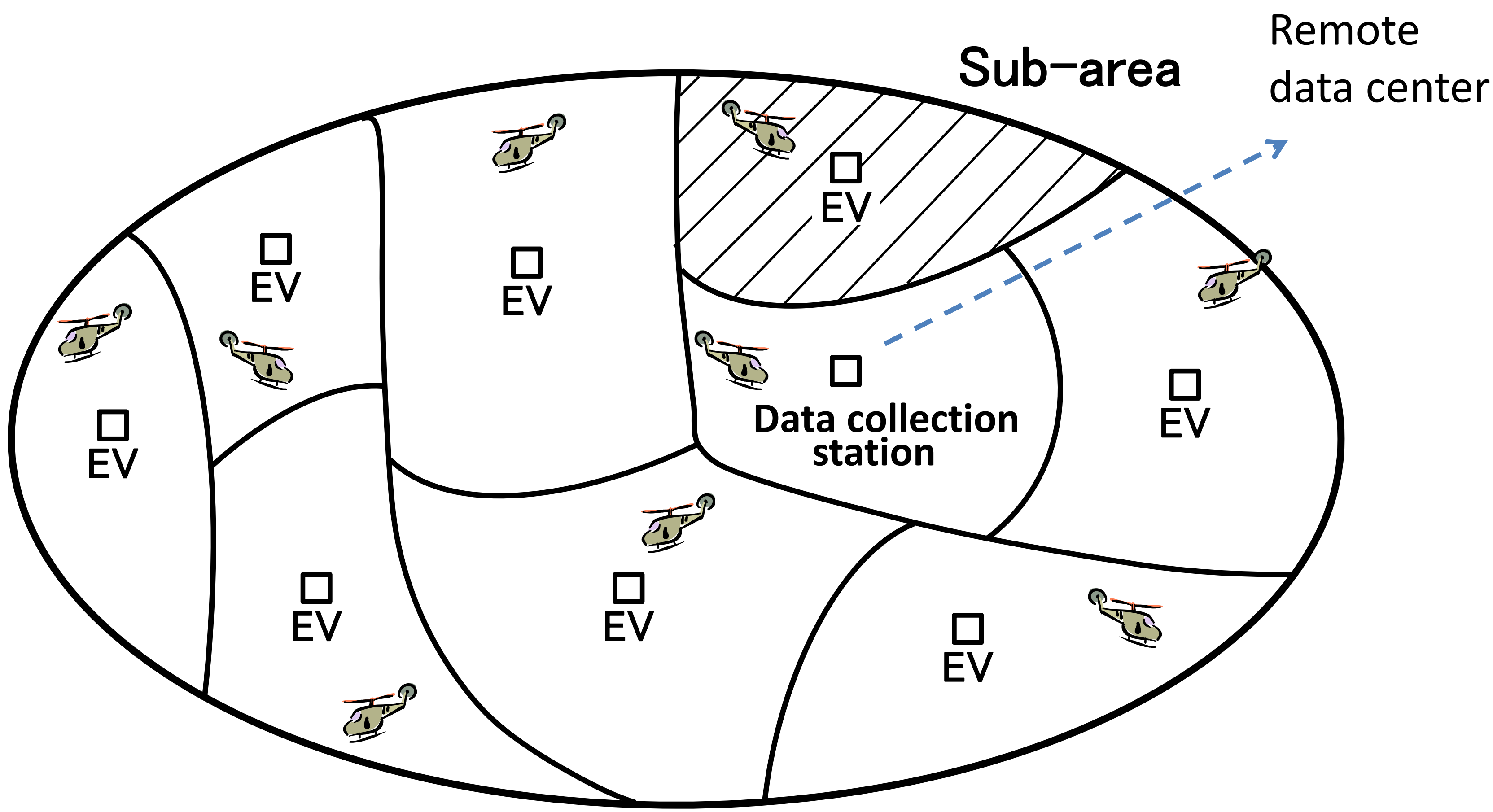
Availability of EH for airborne surveillance



Cooperative surveillance

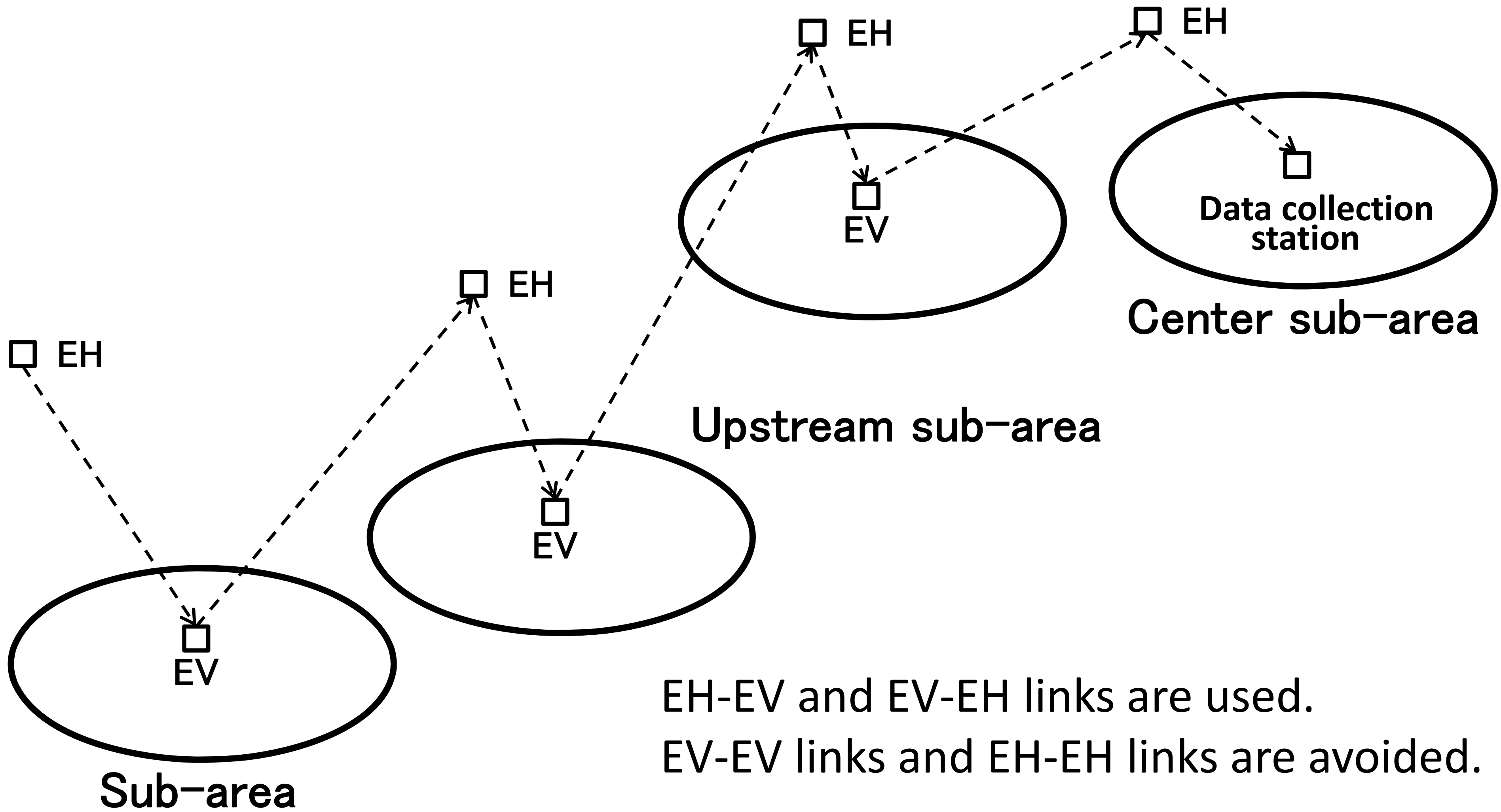
- Each EV has a partner EH and vice versa.
- An entire surveillance area is divided into sub-areas and an EV and EH pair is assigned to each sub-area.
- One of the EVs works as the data collection station for the area and is in charge of delivering the collected data to the remote data center.
- Each EV remains at its initial position in the sub-area, while its partner EH flies over the assigned sub-area for surveillance and transfers the gathered surveillance data to its partner EV.
- The data obtained by each EH is delivered to the data collection station via wireless multi-hop communication through EVs and EHs.

Area division example



Disaster-affected area

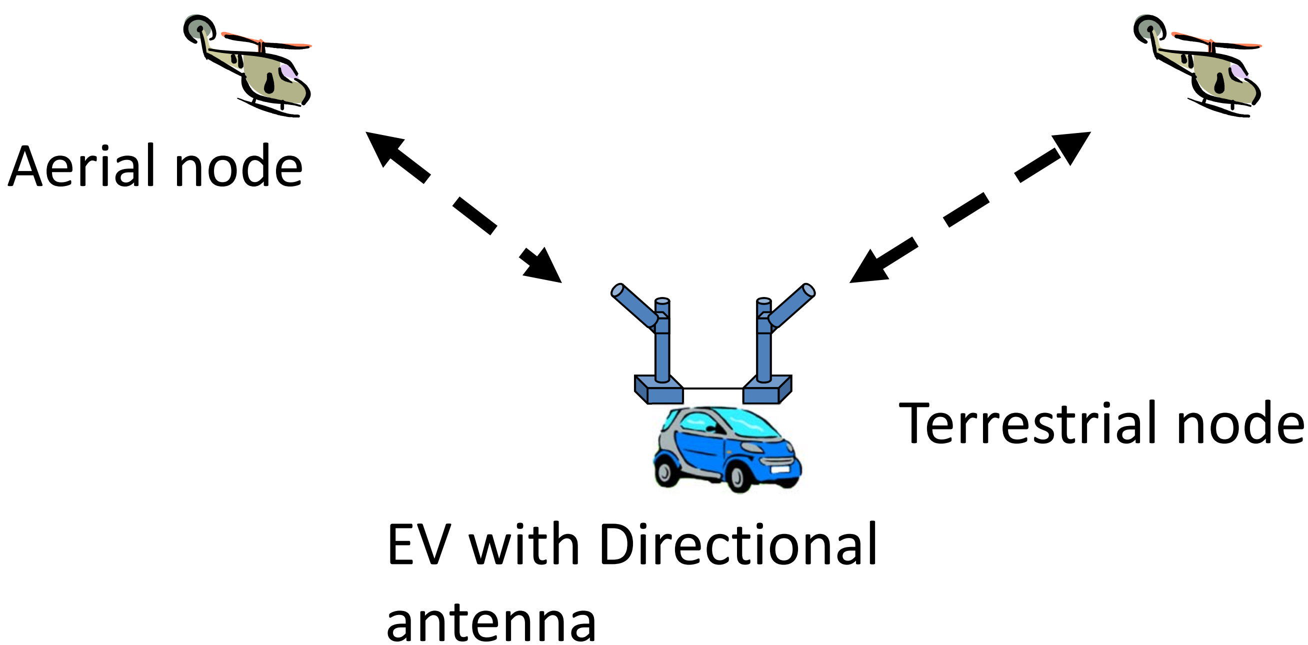
Data delivery over wireless multi-hop communication



EH-EV and EV-EH links are used.
EV-EV links and EH-EH links are avoided.

EH–EV and EV–EH links

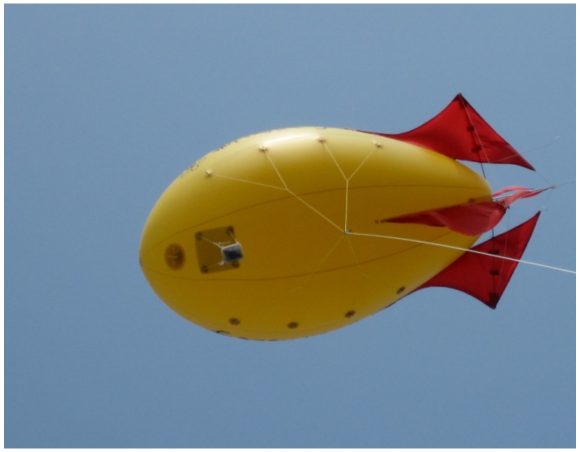
- Line-of-sight can be easily assured.
- The transmission range can be extended by using directional antennas for the EV side.



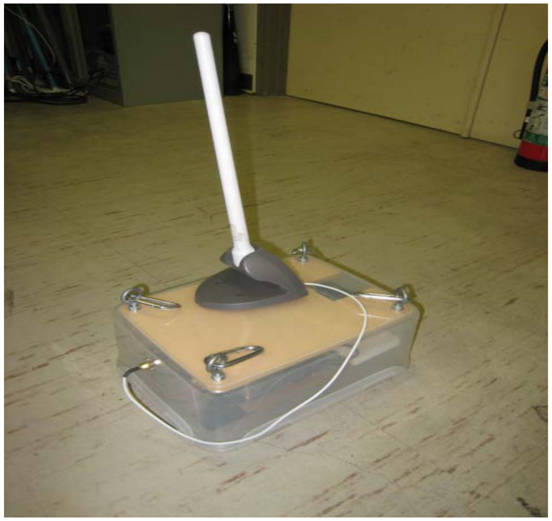
Experimental setup

- Aerial node

Balloon



Communication Equipment



Material	Body:0.12 mm vinyl chloride
	Fin : nylon taffeta
	Pipe : duralumin
size	Length: 6398 mm Width 3130 mm
Weight	9.62 kg
capacity	20 m^3

Mini computer	ARM926J-S CPU clock 200 MHz, BUS clock 100MHz SDRAM 64 MB, FLASH 8 MB
Wireless LAN interface	Mini PCI type 802.11a/b/g module
Wireless LAN antenna	Sleeve antenna Gain: 5.5 dBi Half value angle: 45°

Experimental setup

- Terrestrial node with directional antenna

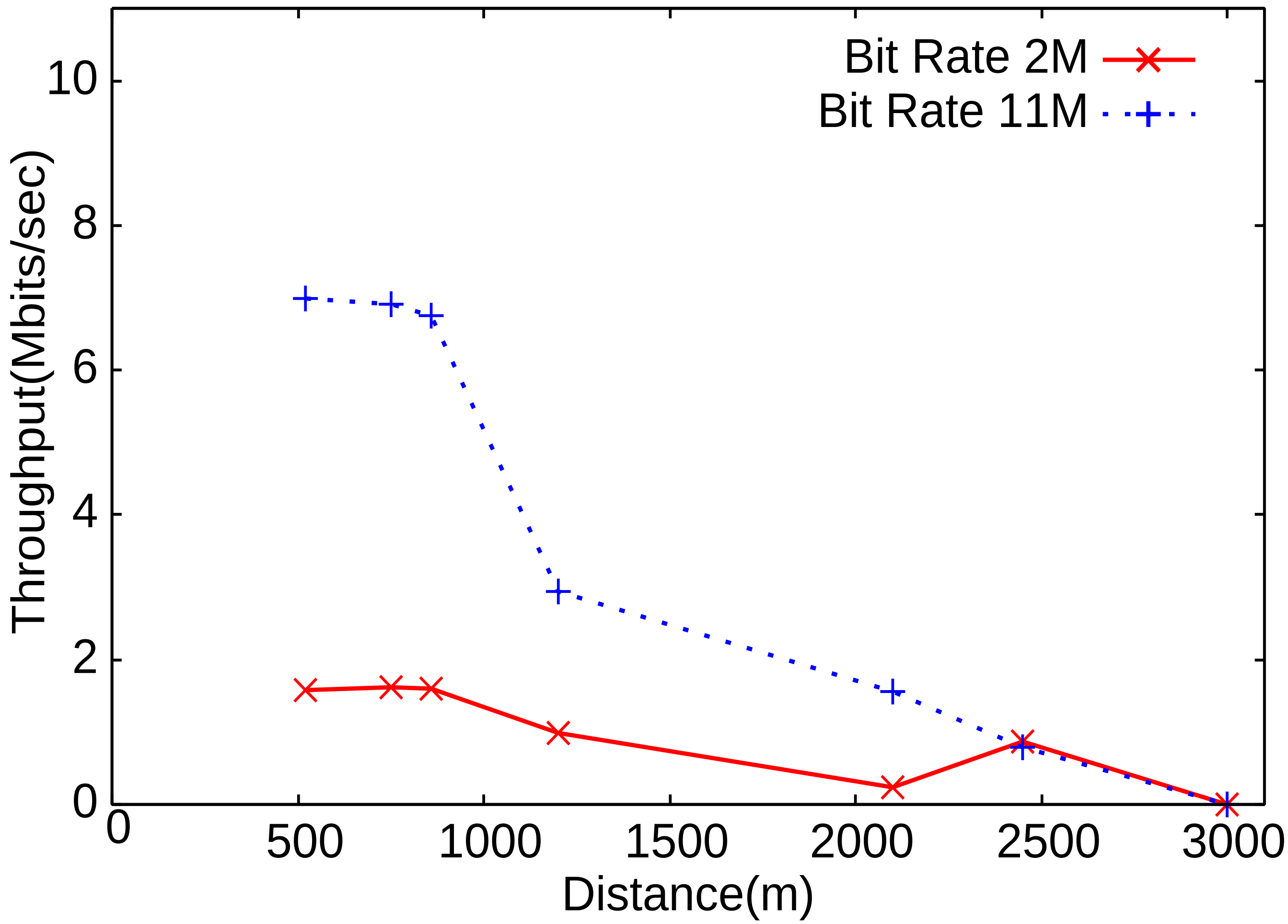
Wireless LAN antenna	Yagi antenna Gain: 14 dBi Half value angle: vertical 32 ± 5° horizontal 32 ± 5°

Mini computer and wireless LAN interface are the same as the balloon node

- Measurement methods

Measurement tool	iperf, tcpdump, iwspy
Measurement time	60 seconds
Number of experiments	10
Transmission bit rate	2 Mbps, 11Mbps
Protocol	UDP

Result – Average UDP throughput



- The longest transmission range between the aerial and terrestrial nodes is about 2500 m.
- It is possible to communicate with high quality up to 1000 m.

Requirements for EH in 3DMS

Items	Values
Size (Length and width)	Less than 1 m
Weight	1–3 kg
Maximum altitude	100–200 m
Maximum speed	50–60 km/h
Payload	500–1000 g
Continuous flying time	No less than 15 min
Wind resistance	6 m/s
Rain resistance	10 mm/h
Remote-control range	200–1000 m

EH prototype development

- Small and light
- Enough flight range and payload
- Autonomous flight controlled by on-board and ground computers.

Our own combo

Six wings multi-rotor framewheel F550 (DJI)
Multi-Rotor stabilization controller WooKong (DJI)
Radio controller (JR Propo)
G3 3S/11.1V 6500mAh (Hyperion)
Carbon propeller

AR.Drone 2.0(Parrot)

Comparison of AR.Drone and our own combo

	AR.Drone 2.0	Our own combo
Size (cm)	45.0×45.5×11.5	60×80×37
Weight (g)	42.5	2000
Maximum velocity (km/h)	20	50
Maximum altitude (m)	65	800
Payload (g)	140	1000
Flight range（Min.）	10	16

AR.Drone

- Remote-controlled quad-rotor helicopter
- Controlled over wireless networks
- Used in many applications
  - AR video games
  - Disaster area monitoring system

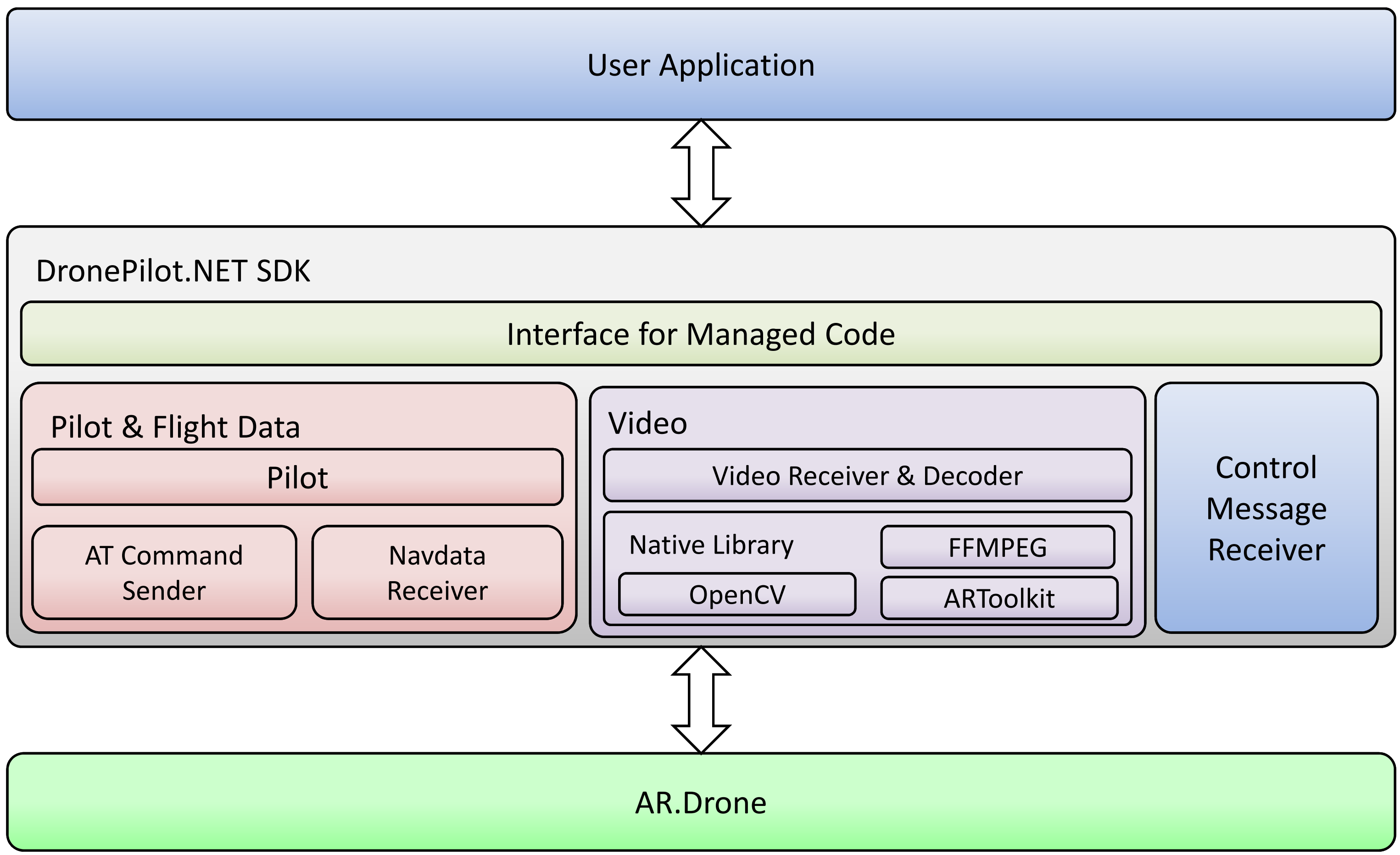
SDK for programming AR.Drone applications

- Several SDKs for programming the AR.Drone.
  - Parrot's AR.Drone SDK
  - ARDroneForP5
  - JavaDrone

DronePilot.NET SDK

- Support languages
  - C#, Visual Basic
  - C++/CLI
- C#, Visual Basic
  - Access only standard functionality
- C++/CLI
  - Access native libraries directly

The Structure of DronePilot.NET



Qualitative Comparison of the DronePilot.NET and other SDKs

	DronePilot.NET	Parrot SDK	AR.DroneForP5	JavaDrone
User Programming Language	C#, VB, C++/CLI	C, (C++)	Processing	Java
Native Library	Yes	Yes	No	No
AR.Drone2.0	Yes	Yes	No	No
HD Video	Yes	Yes	No	No
Image Analysis	Yes	No	No	No
Marker Recognition	Yes	No	No	No
GPS data capturing	Yes	No	No	No
Cross-Platform	No	Yes	Yes	Yes

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Cross-Platform	No	Yes	Yes	Yes

Image processing time measurements

	SD Resolution, MPEG4 (ms)	SD Resolution, H.264 (ms)	HD Resolution, H.264 (ms)
Decoding	1.87	2.62	5.9
Face detection by OpenCV	16.8	16.52	14.49
Marker recognition by ARToolkit	5.97	5.69	12.41
Drawing 3D object by OpenGL	21.01	20.11	28.02
All	45.69	44.99	60.87

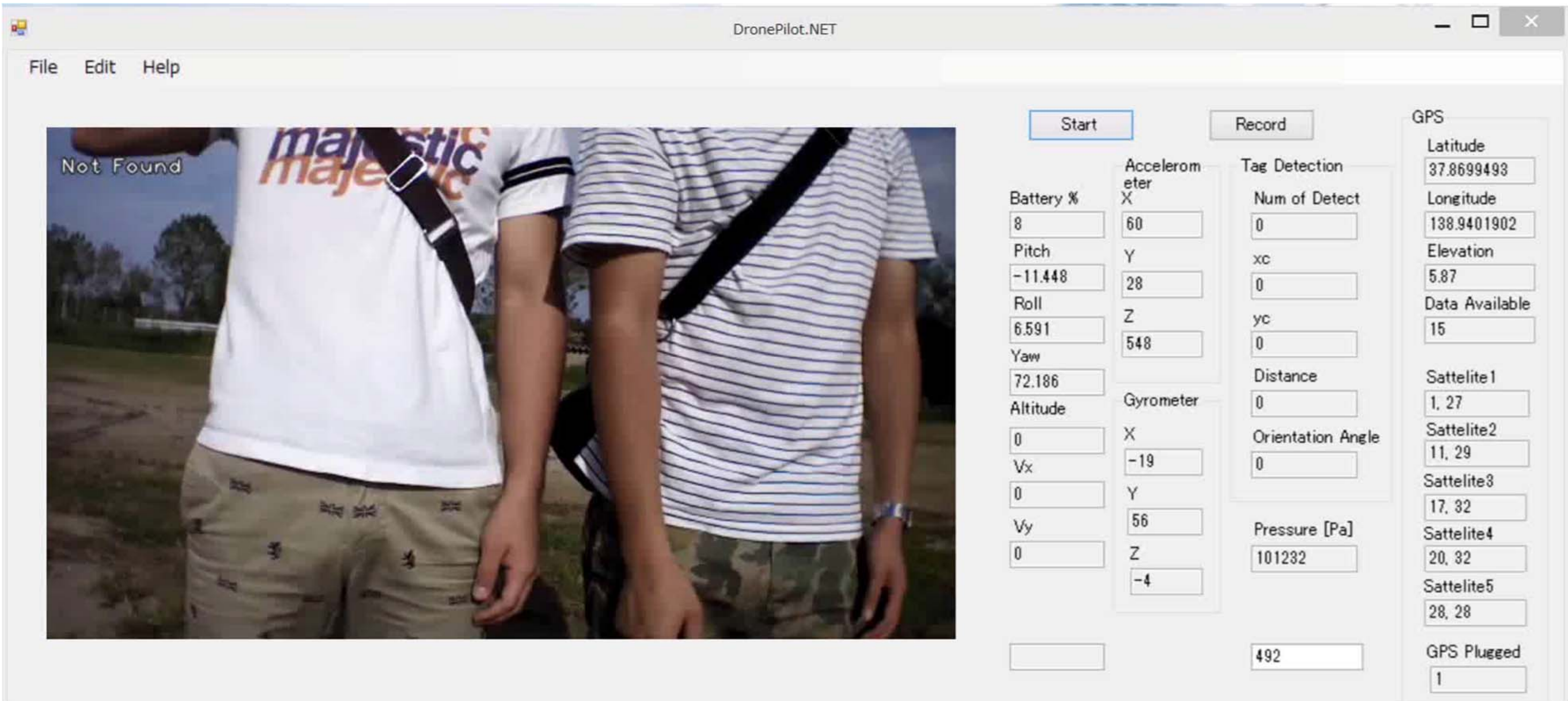
DronePilot.NET SDK can process image data at approximately 15 frames per second.

This performance is fast enough to control the flight of the AR.Drone
using image analysis because 15 fps is the shortest control cycle of AR.Drone.

Flight demonstration using DronePilot.NET

This student first operates AR.Drone.
He can manage the flight well owing to the attitude controlled by the computer.

Demonstration of face detection by DronePilot.NET



When a face is detected, a red circle is drawn around the face.
You can see that DronePilot.NET can detect faces in real-time.

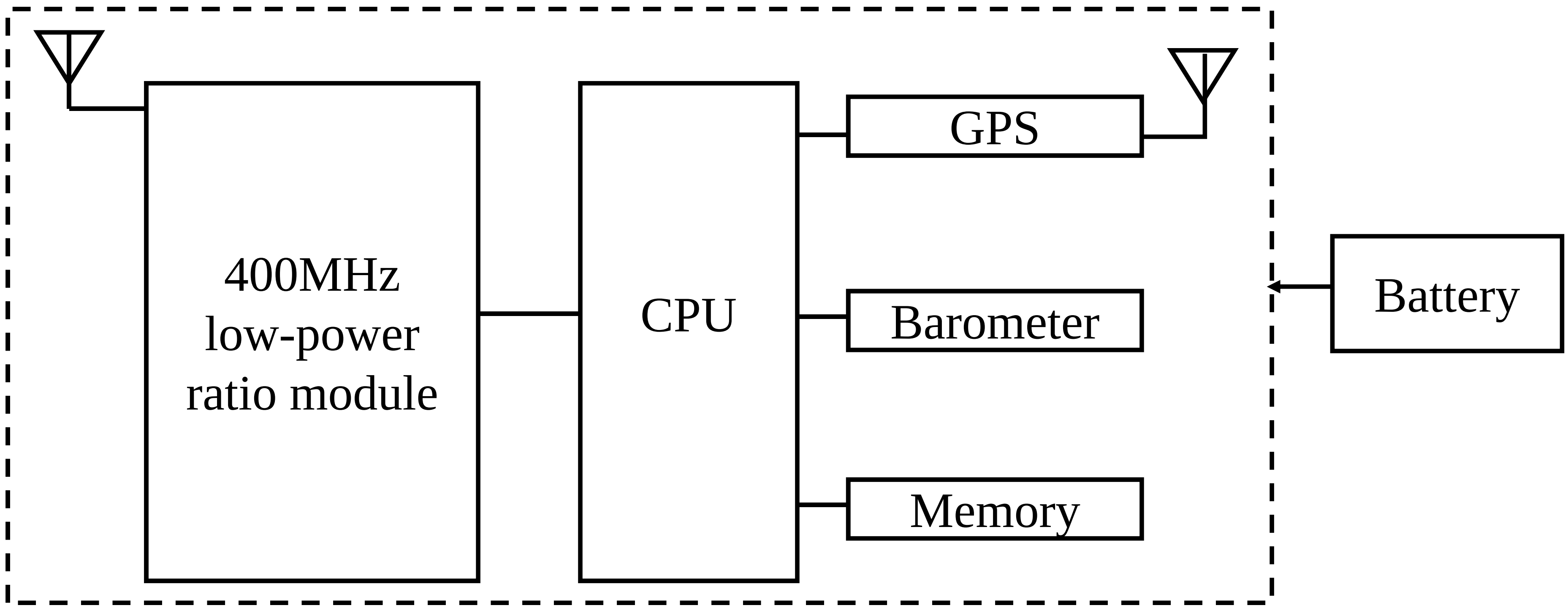
Summary of the experiments

- DronePilot.NET SDK
  - It is easy to understand and use
  - C# and Visual Basic are supported.
  - Direct access to native libraries is supported.
  - Many functions are supported such as
    - Image Analysis
    - Marker Recognition
    - GPS data capturing
  - Satisfactory performance is obtained.

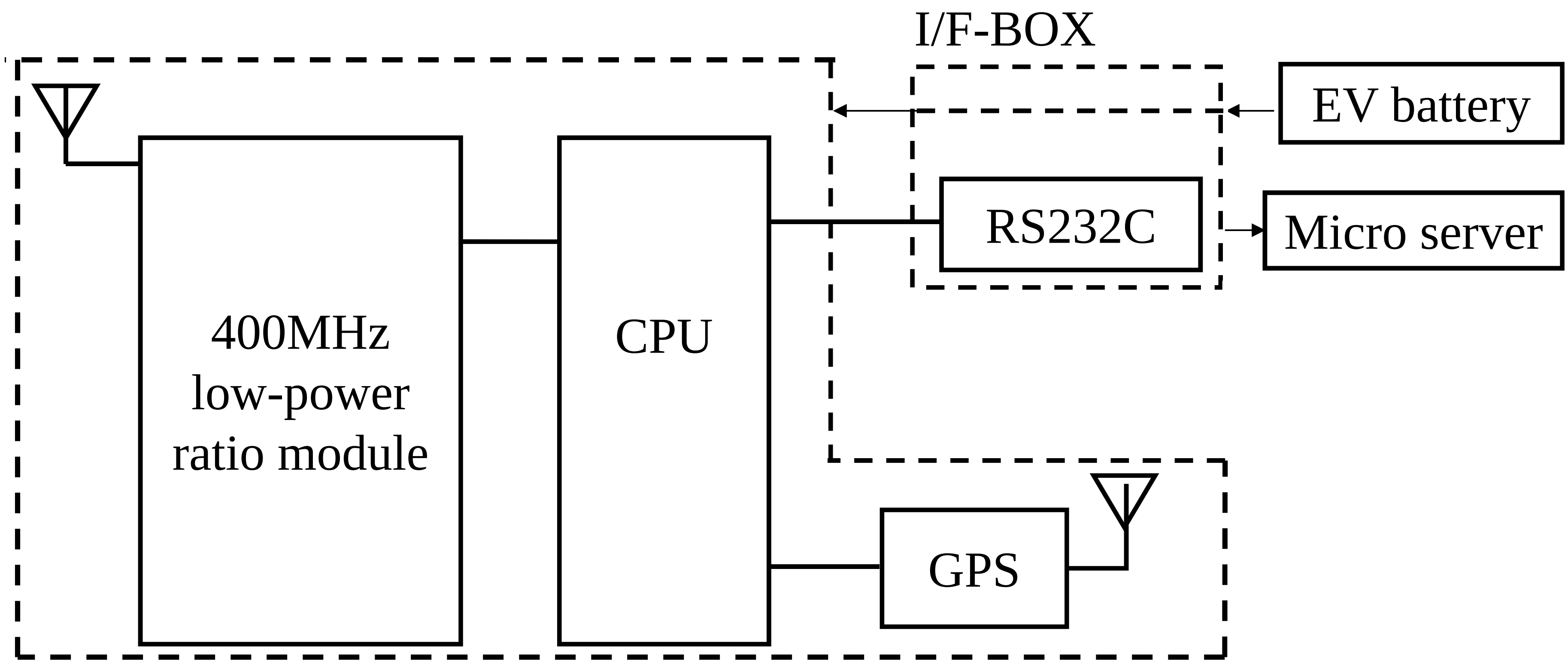
EH positioning system to support autonomous piloting

- The basis of the autonomous piloting is to recognize the current positions of the EH and the partner EV.
- To this end, both the EH and the EV are equipped with GPS receivers and barometers. The measurement data are periodically transmitted from the EH to the partner EV.
- The EH controller on the EV compares the position data history of the EH with that of the EV and sends appropriate commands to guide the EH toward the desired position.

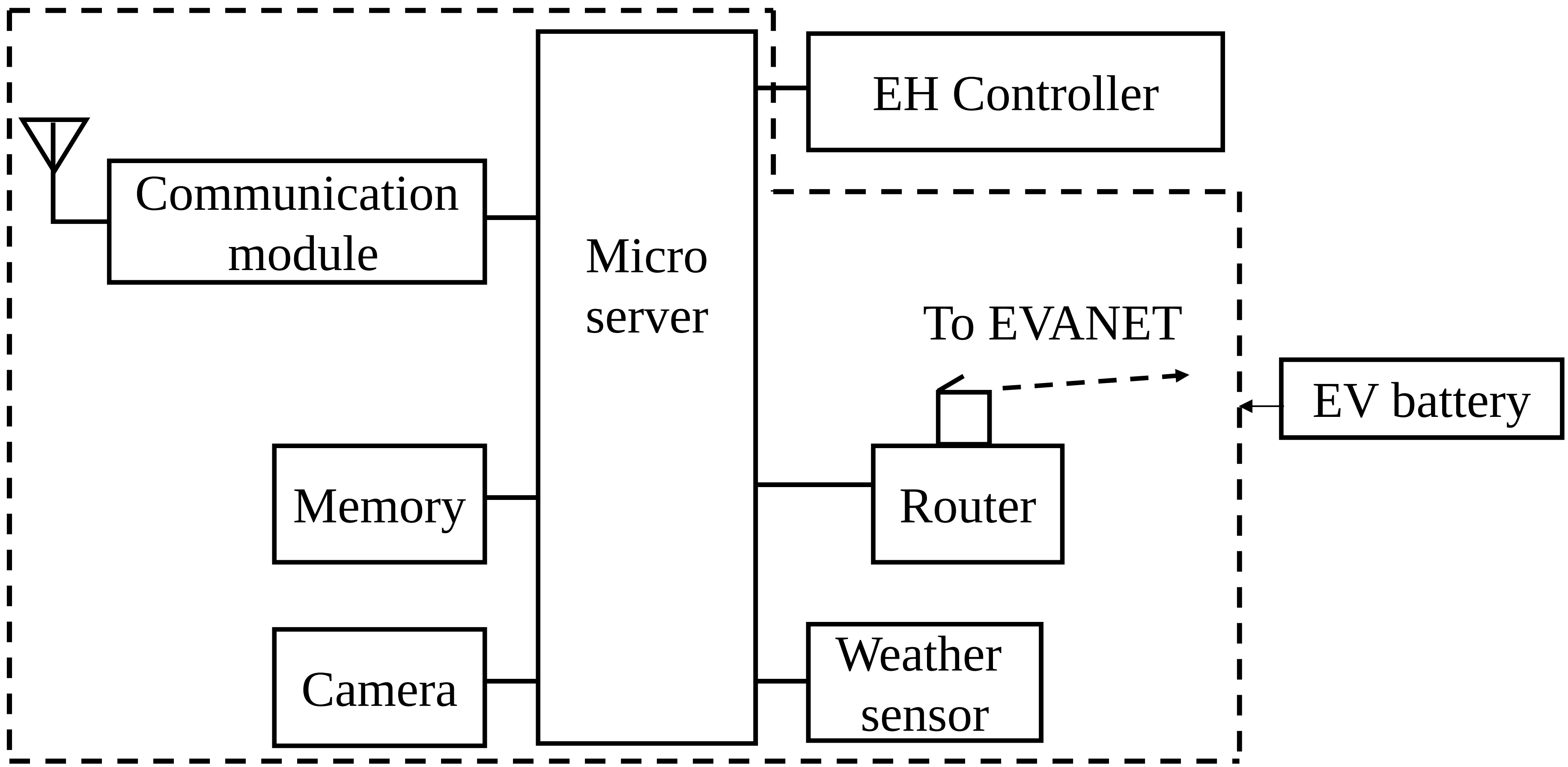
Functional blocks of an EH-tag



Functional blocks of communication module of a base station on EV



Functional blocks of a base station on EV



The case and IC mother board developed for an EH-tag

Specifications of components for EH-tag

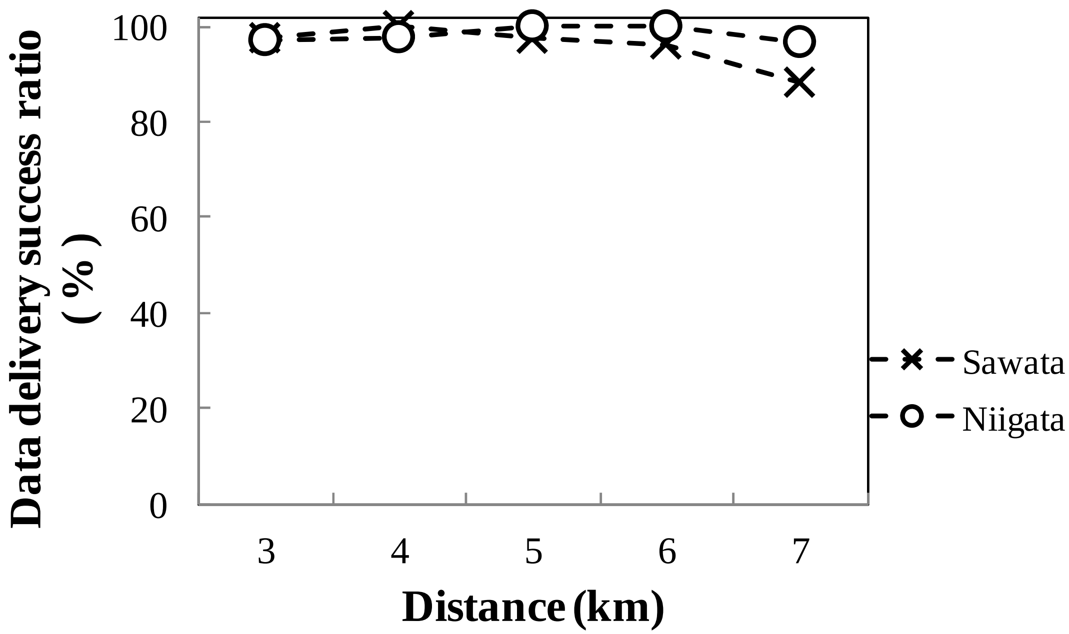
Components	Size (mm)	Weight (g)
IC motherboard	96 × 50 × 0.8	10.5
Case	110 × 53 × 49	33
Lithium-thionyl chloride battery	*Φ14.5 × 24.5*	9
GPS antenna	3.2 × 1.6	0.9
Radio antenna	*Φ5.5*	0.9
GPS module	15 × 12.5	1.1
Microcomputer	17×17	0.5
Resistor, condenser	1.0×0.5	Not measurable

Total weight: 55.9 g

Experimental results

Niigata University

Sawata on Sado Island



Conclusions

- In this study, we considered the problem of surveillance over a wide disaster area and presented the concept of three-dimensional mobile surveillance (3DMS).
- Our approach is characterized by the extensive use of EVs and unmanned EHs.
- We gave an effective method of solving the problem of the limited continuous flying time of EH.
- Prototypes of EH, its SDK, and EH positioning system are presented.
- Experimental results are shown.
- Further studies:

  - A general approach for cooperative surveillance

  - Area division and EV and EH pairs positioning considering geographical conditions and restrictions.

  - EV and data collection station discovery schemes

  - Communication issues for surveillance data delivery.

  - Development of a prototype of the autonomous piloting system