ICTF2016
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Wide-Area Deployable Ad Hoc Networks

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Niigata University

Outline

- ICT and ITS evolution
- Ad hoc network and routing protocol
- A concept of wide area ad hoc network (WANET)
- Fixed node networking
- Balloon node networking
- Automobile node networking
- Unmanned Aircraft (UA) node networking
- Perspective
- Conclusions

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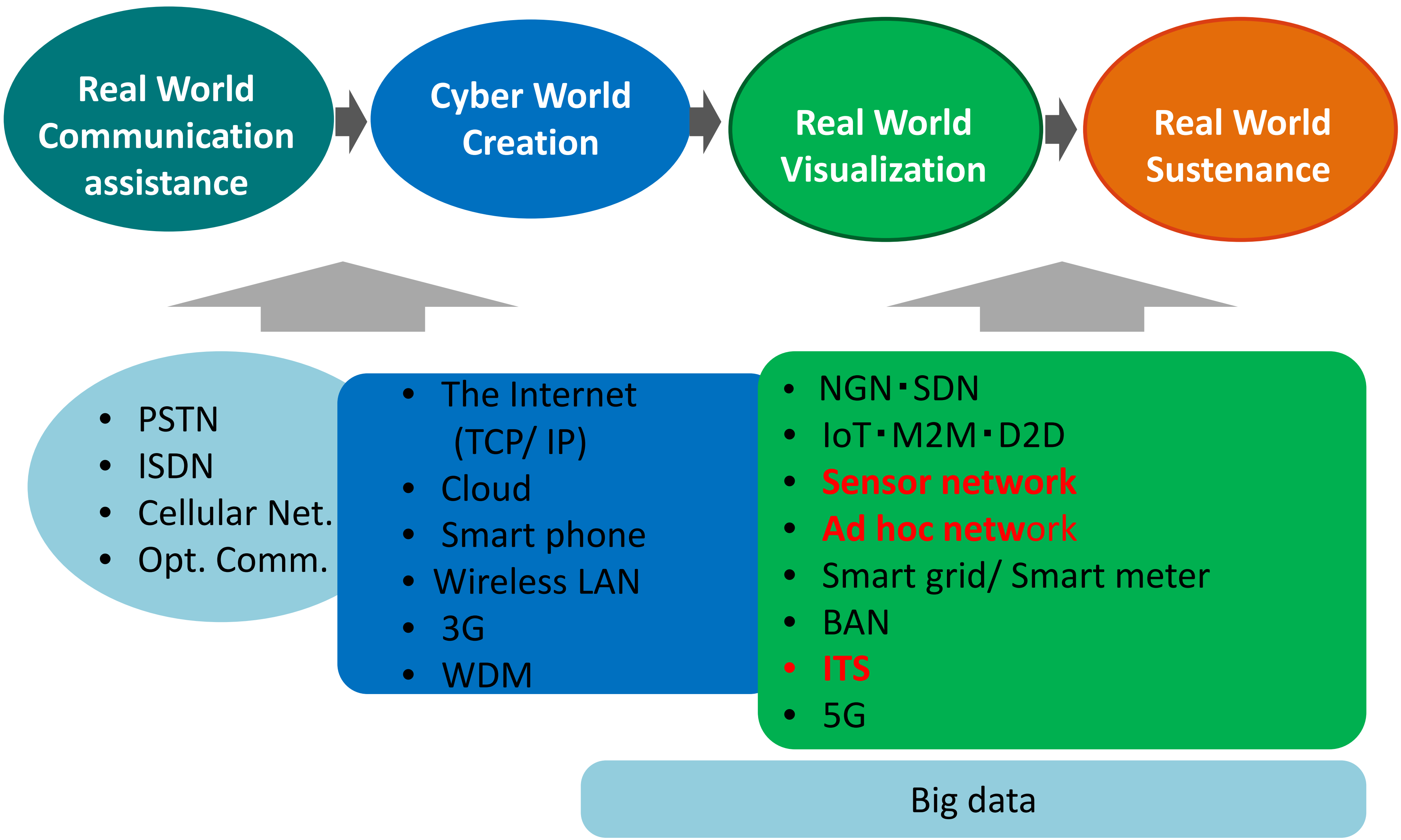
Roles of ICT


Real World Communication assistance
Cyber World Creation
Real World Visualization
Real World Sustenance
PSTN
ISDN
Cellular Net.
Opt. Comm.
The Internet (TCP/ IP)
Cloud
Smart phone
Wireless LAN
3G
WDM
NGN･SDN
IoT･M2M･D2D
Sensor network
Ad hoc network
Smart grid/ Smart meter
BAN
ITS
5G
Big data

Intelligent Transport System (ITS) Evolution

Targets

- Traffic jam clearance
- Traffic accident prevention
- Traffic guidance

Accident・Jam zero society

Contribution to resolving social problems

- Decreasing birth rate and aging population
- Global warming
- Old infrastructures
- Large-scale disaster

Present

Car navi.
VICS
ETC
・・・

Next-generation ITS

Human, Car, Road

- Automatic driving (AV)
- Connected vehicle (CV)
- Electric vehicle (EV)
- Fuel cell vehicle (FCV)

Transportation as a service
（Robot taxi）
Platooning vehicle（Understaffed driver）

ITS everywhere

Human, Vehicle, Road, Space, Environment

- Mini-EV, Robot
- UA (Unmanned Aircraft)
- Innovation on city & road structure
（Compact city, Car-type classified lanes）

Human-friendly and free mobility
Society & nature-friendly mobility

VICS: Vehicle Information and Communication System
ETC: Electronic Toll Collection System

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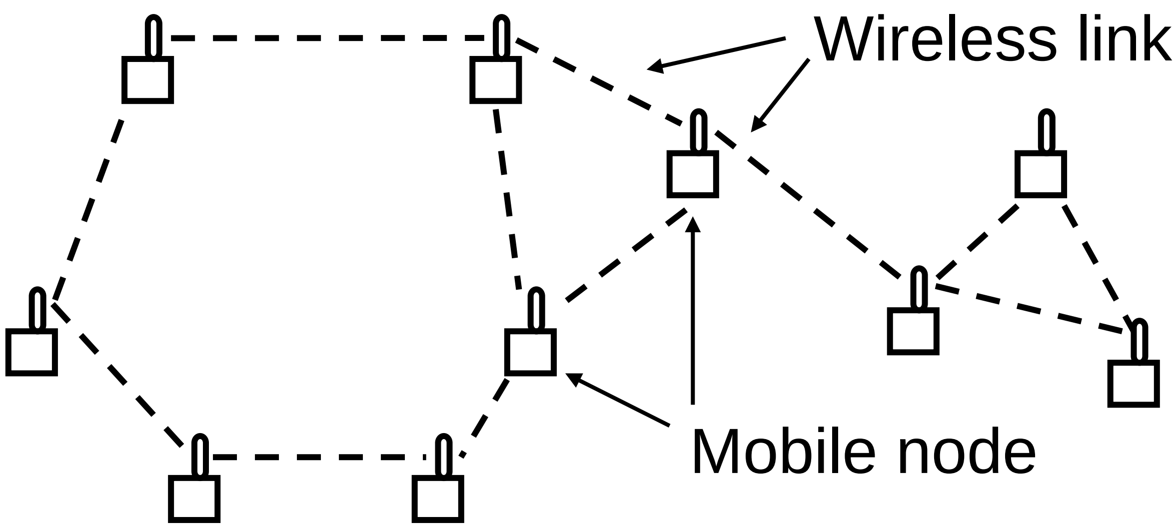
Ad hoc network

- No wired connection, no infrastructure support, and autonomous networking of nodes
- Multihop wireless communication
- Node mobility and frequent topology change
- Bandwidth-constrained
- Energy-constrained operation



Ad hoc network routing

- Topology-based routing

（Detection of a series of relay nodes between source and destination）

  - Path exists between source and destination
  - Node distribution is uniform
  - Node speed is low

- Position-based routing (Geographic routing)

（Selection of next-hop node closer to the destination）

  - A path may not exist between source and destination
  - Node distribution is non-uniform
  - Node speed is high

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WANET is characterized by

- Energy unconstrained operation
- A large number of nodes
- Wide movable range of a node
- Long-range transmission between nodes
- Abundant bandwidth
- A large number of multihop capability
- Carry and forward capability
- Cooperated movement
- Use of relay only nodes

Optional

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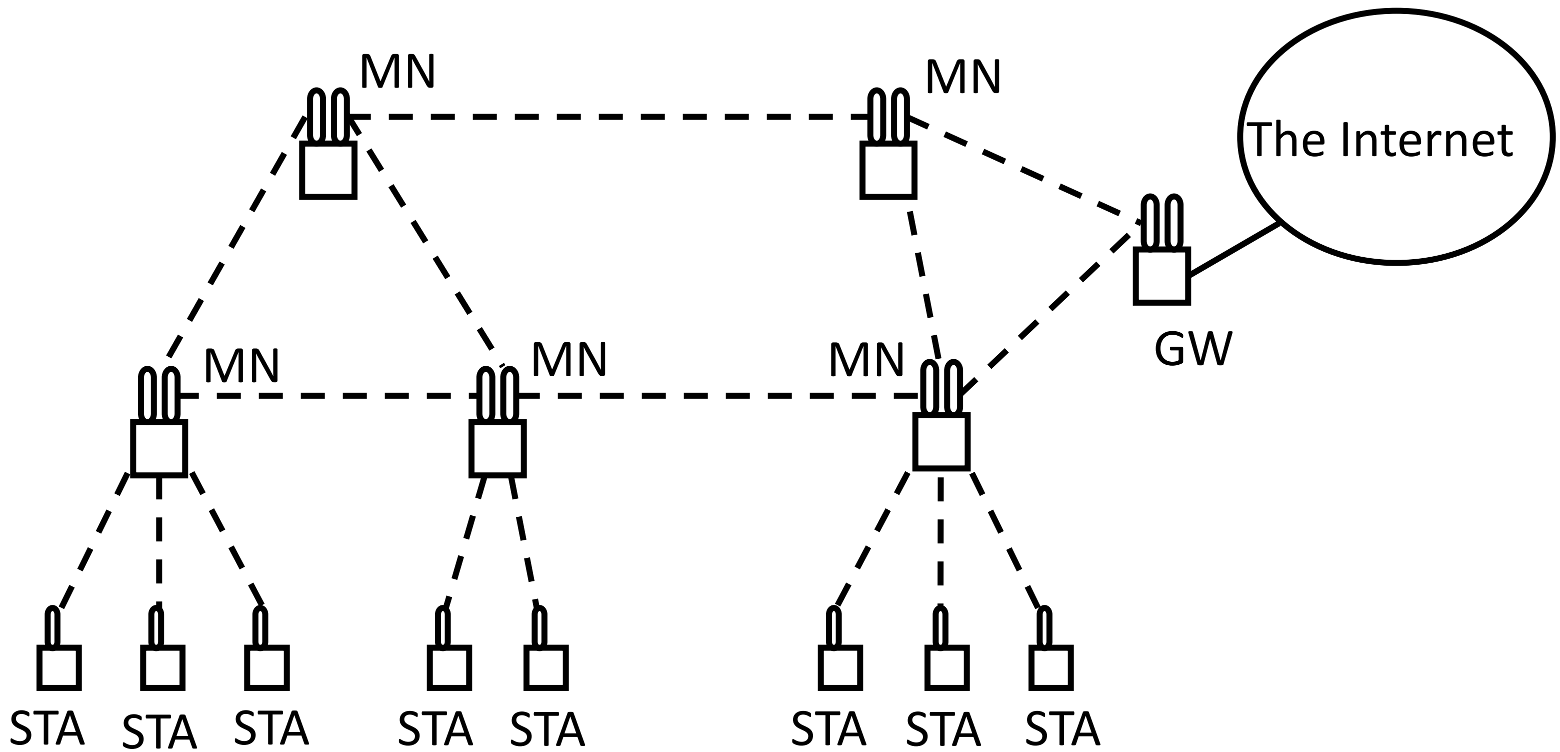
Fixed node networking
(Wireless mesh network)

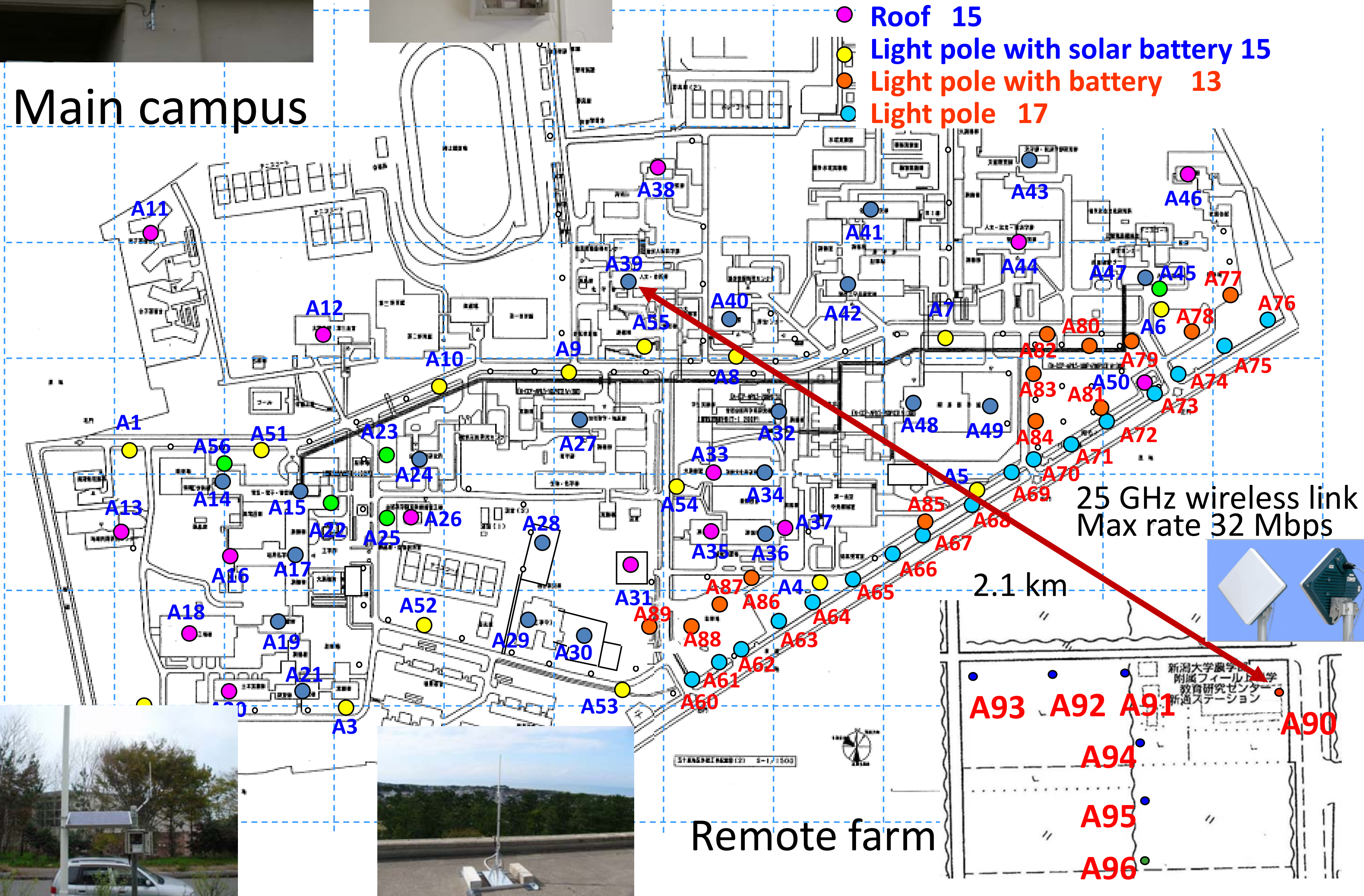
- A backbone is composed of mesh nodes (MNs).
- No wiring between MNs to save cost and time to deploy.
- An MN may have multiple interfaces with different channels and accommodate stations (STAs).



Practice 1

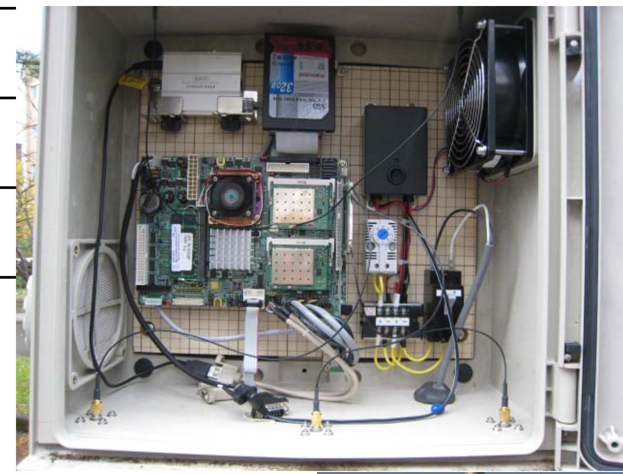
First testbed Axx (2004)
Second testbed Axx (2008)

- Roof entrance 22
- Building side 4
- Roof 15
- Light pole with solar battery 15
- Light pole with battery 13
- Light pole 17



Node specification

Mother board	LS-571 miniPCI x2, PCI x1, Wired LAN IF x2 COM Port x5, USB x8, etc. SSD/Linux
CPU	Intel Core2Duo T7500 2.2GHz FSB800MHz
Memory	1GB
CF	8GB
SSD	32GB
Wireless LAN	Silex SX-10WG x2 IEEE 802.11 b/g miniPCI Silex SX-10WAN x1 IEEE 802.11 b/g/n miniPCI Atheros AR9160B, AR9106A ath9k Antenna diversity
Antenna	5dBi Collinear x5
Others	Fan, Temperature sensor, Breaker

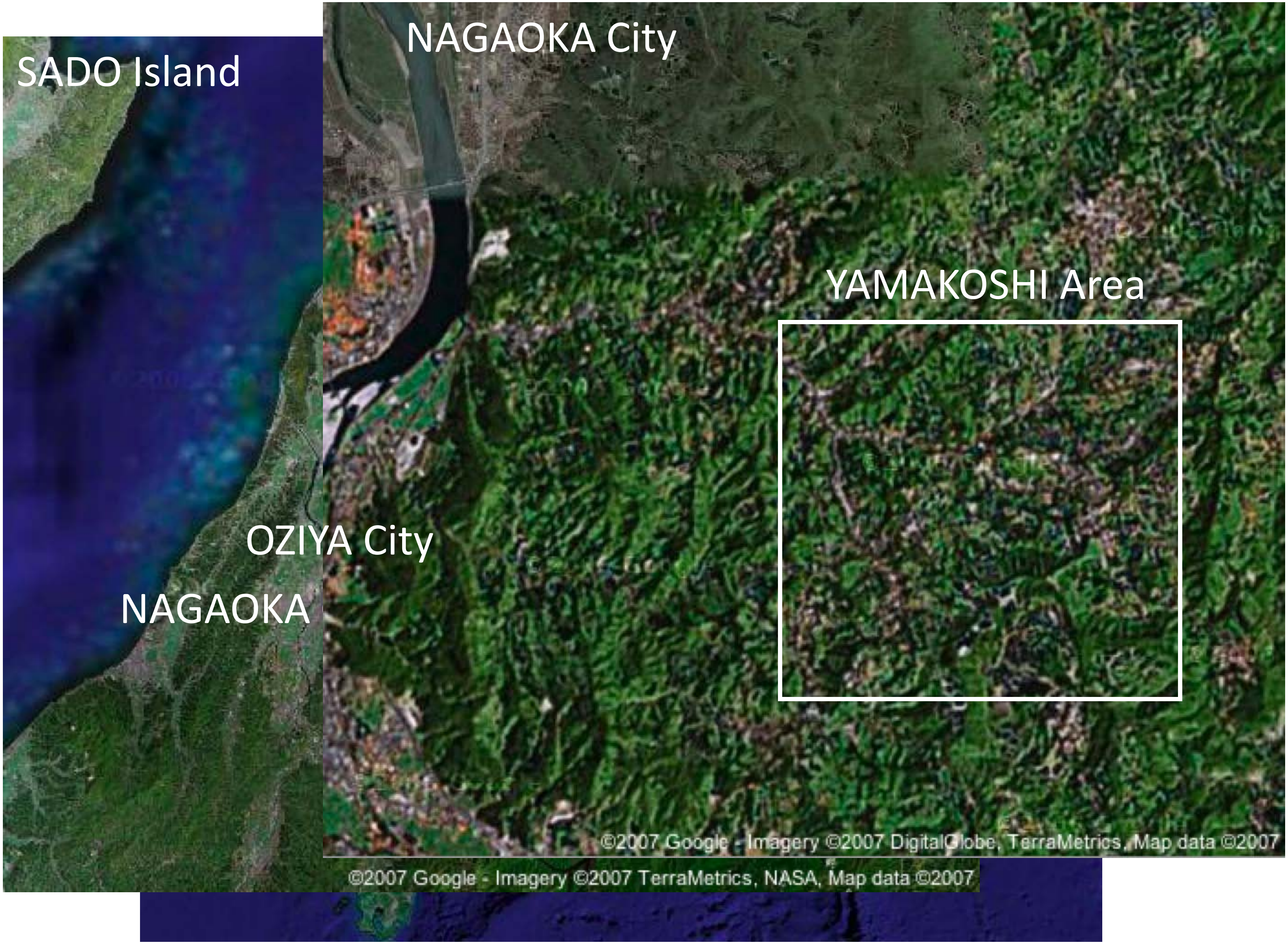


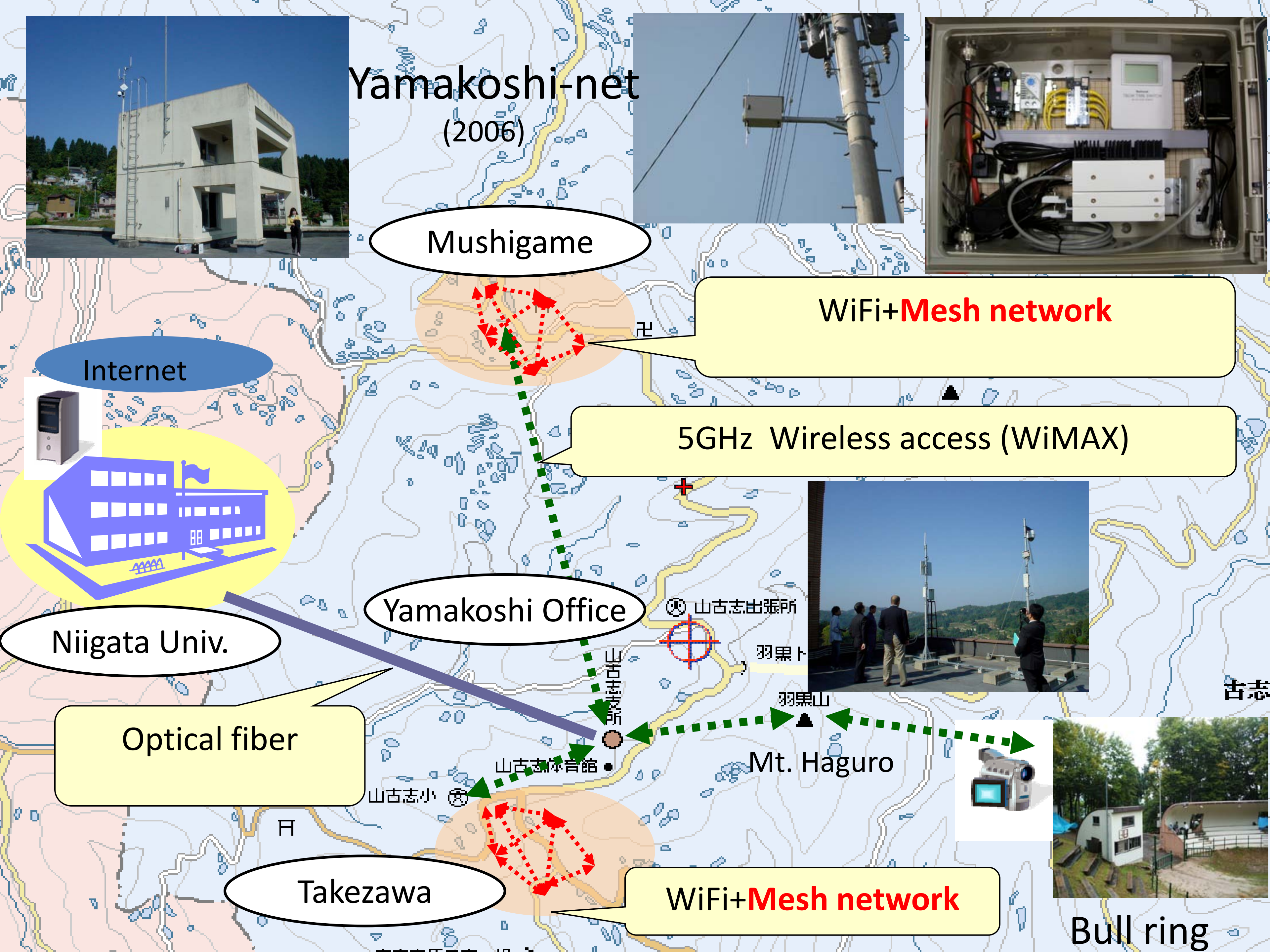
Results and considerations

- OLSRv2 was implemented. Longer control message interval can be allowed, while keeping packet delivery performance.
- The optimum rate can be pre-determined and configured fixedly for each link to significantly improve the throughput.
- Inadequate route selection may occur due to link quality fluctuation. Excluding low quality and unnecessary links (link filtering) can improve throughput.
- Semi-fixed rate control (SFRC) was developed and implemented. Throughput improvement is confirmed.
- Initial network formation protocol is useful to minimize manual setting.
- Solar battery operated nodes were workable even during winter owing to power saving equipment and appropriate battery power design.

Practice 2: A rural-hill area network Yamakoshi-Net

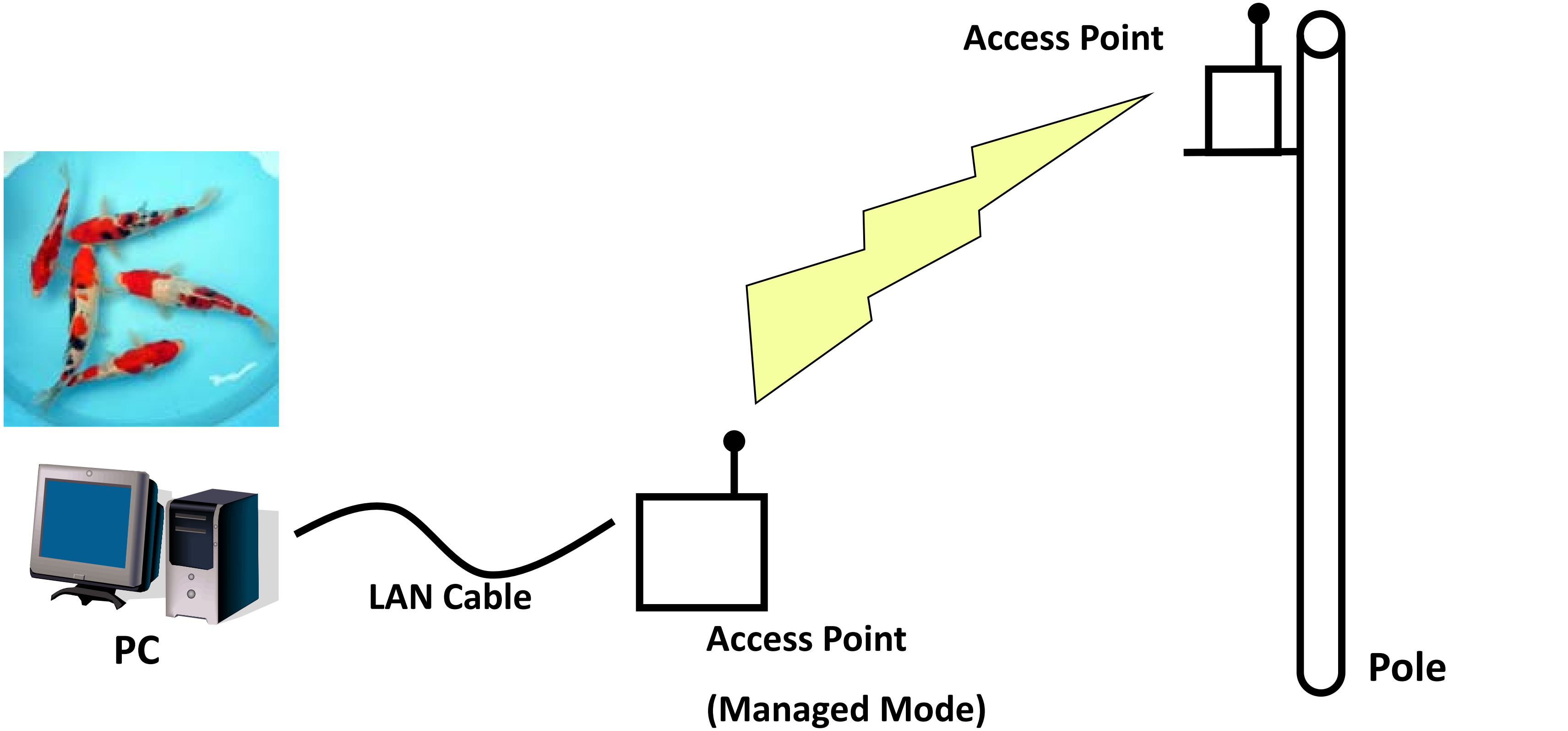
- The Mid Niigata Prefecture Earthquake, Oct 23, 2004.
- Research Center for Natural Hazards and Disaster Recovery was established in Niigata Univ. in April 2006.
- Yamakoshi is a small mountain village in Nagaoka-city, Japan. No commercial broadband service was available for a long time because of its geographical conditions. It was severely damaged by the earthquake.
- Yamakoshi-net joint experimental project, started in May 2006, is a five year project and led by Niigata University in collaboration with NTT-East group, KDDI, Shinetsu Bureau of Telecommunication, Niigata Prefecture, and Nagaoka City.
- The aims of this project is to build a WMN testbed, called Yamakoshi-net and to perform experiments using this testbed to develop networking technologies for deploying economical and disaster-tolerant communication networks in rural-hill areas.


SADO Island
NAGAOKA City
YAMAKOSHI Area
OZIYA City
NAGAOKA
©2007 Google - Imagery ©2007 DigitalGlobe, TerraMetrics, Map data ©2007
©2007 Google - Imagery ©2007 TerraMetrics, NASA, Map data ©2007



Yamakoshi-net
(2006)
Mushigame
WiFi+Mesh network
Internet
5GHz Wireless access (WiMAX)
Yamakoshi Office
山古志出張所
Niigata Univ.
山古志支所
羽黒山
Optical fiber
山古志体育館
Mt. Haguro
山古志小
Takezawa
WiFi+Mesh network
Bull ring

Access to Yamakoshi-net from a monitor's home

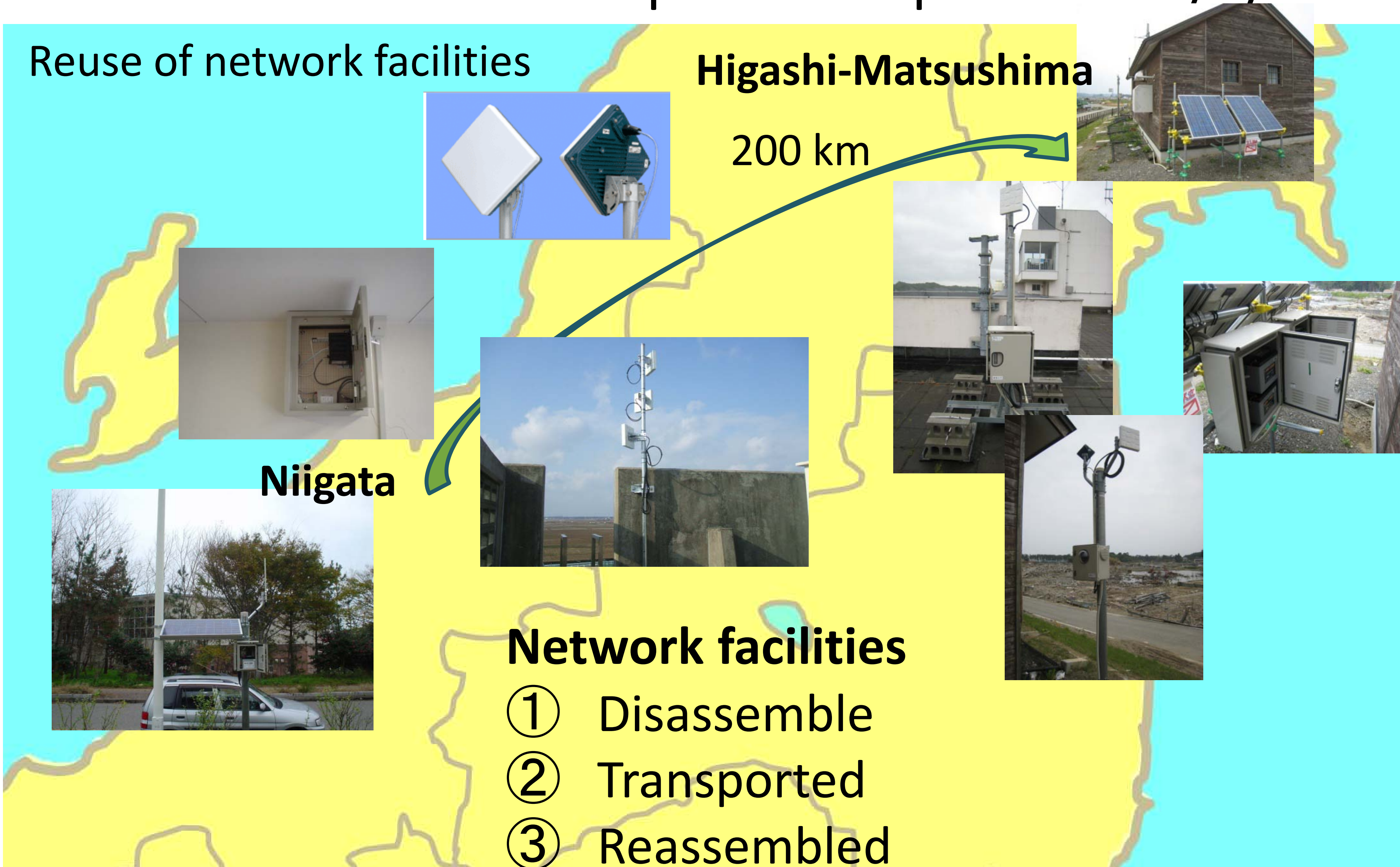


- Internet access service had been provided to monitors using Yamakoshi-net since 2007.
- Yamakoshi is famous for its production of colored carps. One monitor, a breeder of carps, used Yamakoshi-net to send the video of colored carps to oversea customers.

Results and considerations

- Temperature sensor for automatically activating a fan was effective to protect node equipment against hot temperature during summer.
- Snow was attached and frozen on antenna during winter. Straight pole antenna is better than spiral pole antenna.
- Resetting of the power of nodes twice a week was useful to avoid the loss of control by operation mistake. Remote monitoring is useful for minimizing monitoring actions on the site.
- Broadband deployment for mountain village areas is economically possible by making best use of wireless mesh network technologies, contributing to resolve the geographical digital-divide issue.
- Experiences in Yamakoshi Project was recognized as a promising broadband deployment model for mountain village areas.

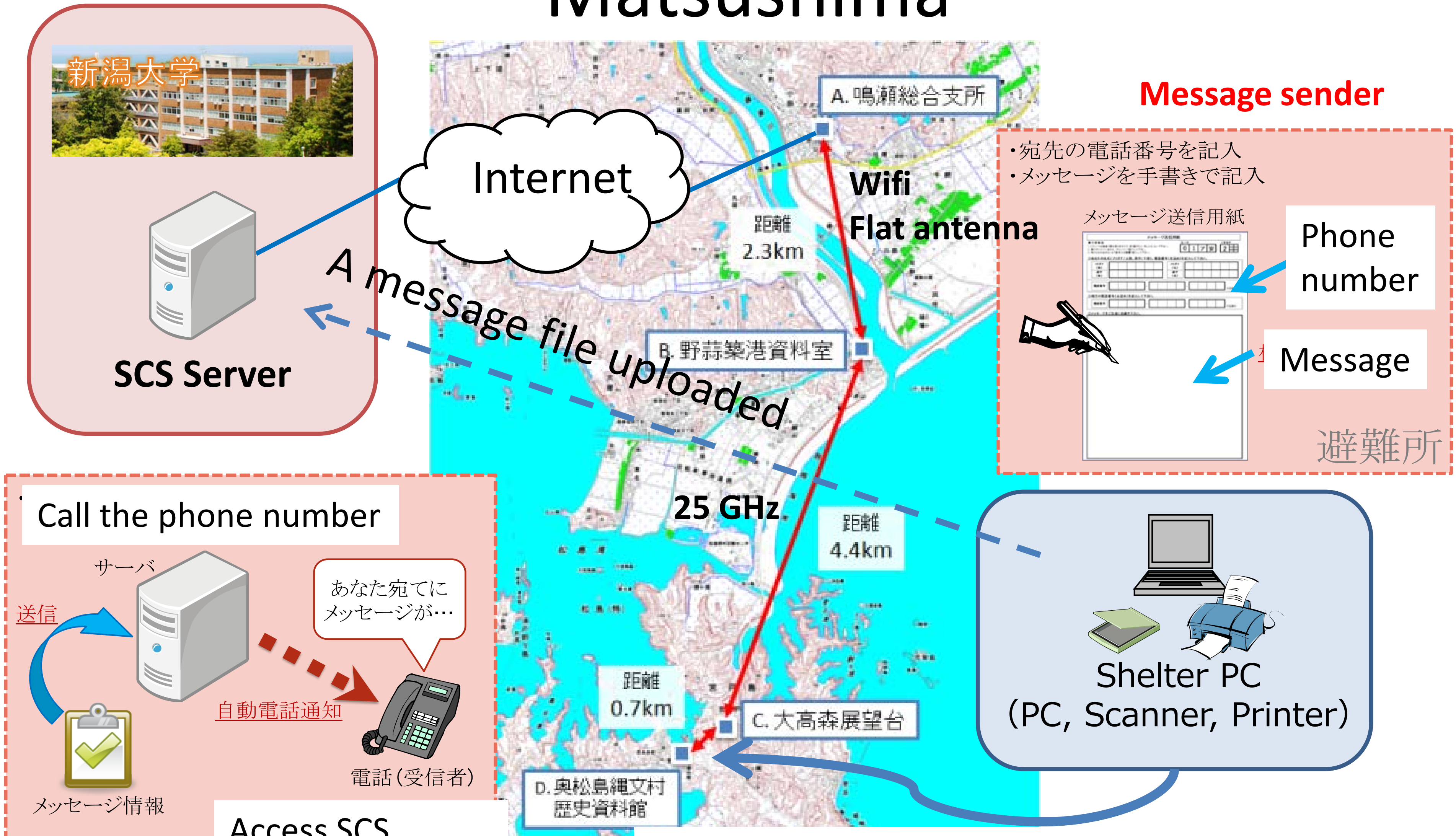
Practice 3: Construction of an emergency network on occasion of Great East Japan Earthquake 2011/3/11



Network facilities

① Disassemble
② Transported
③ Reassembled

Network configuration in Higashi-Matsushima

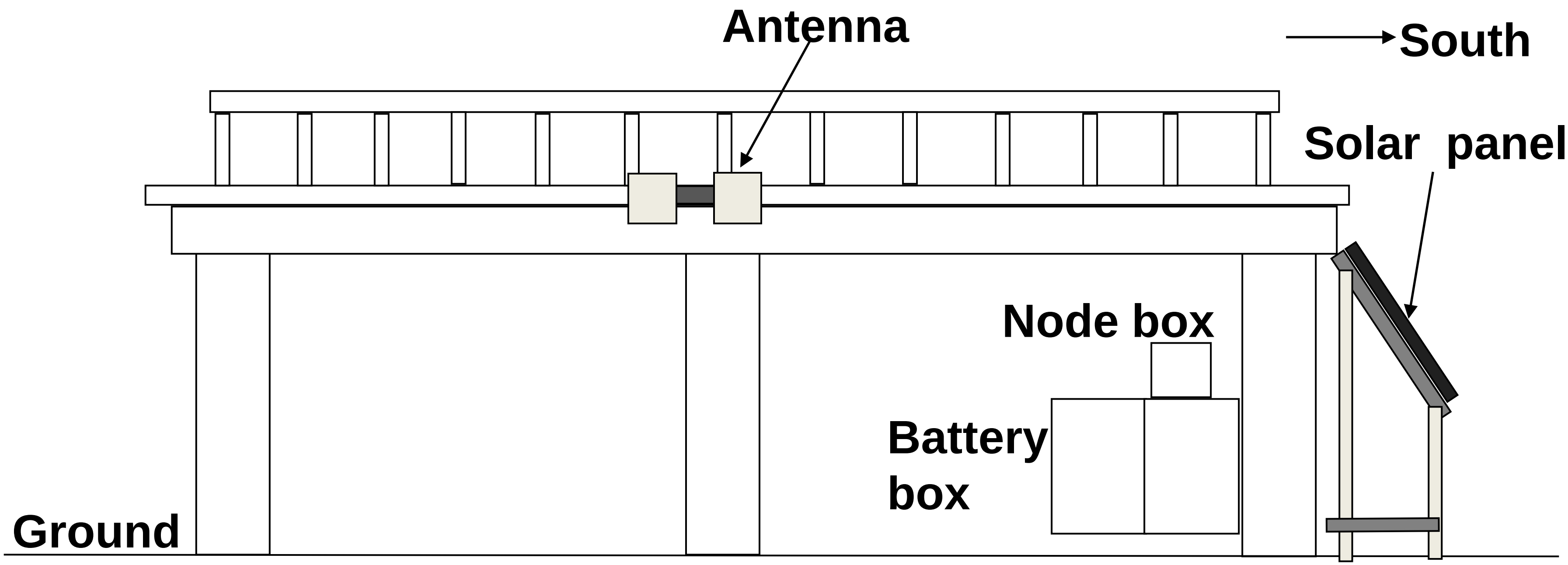


Message receiver

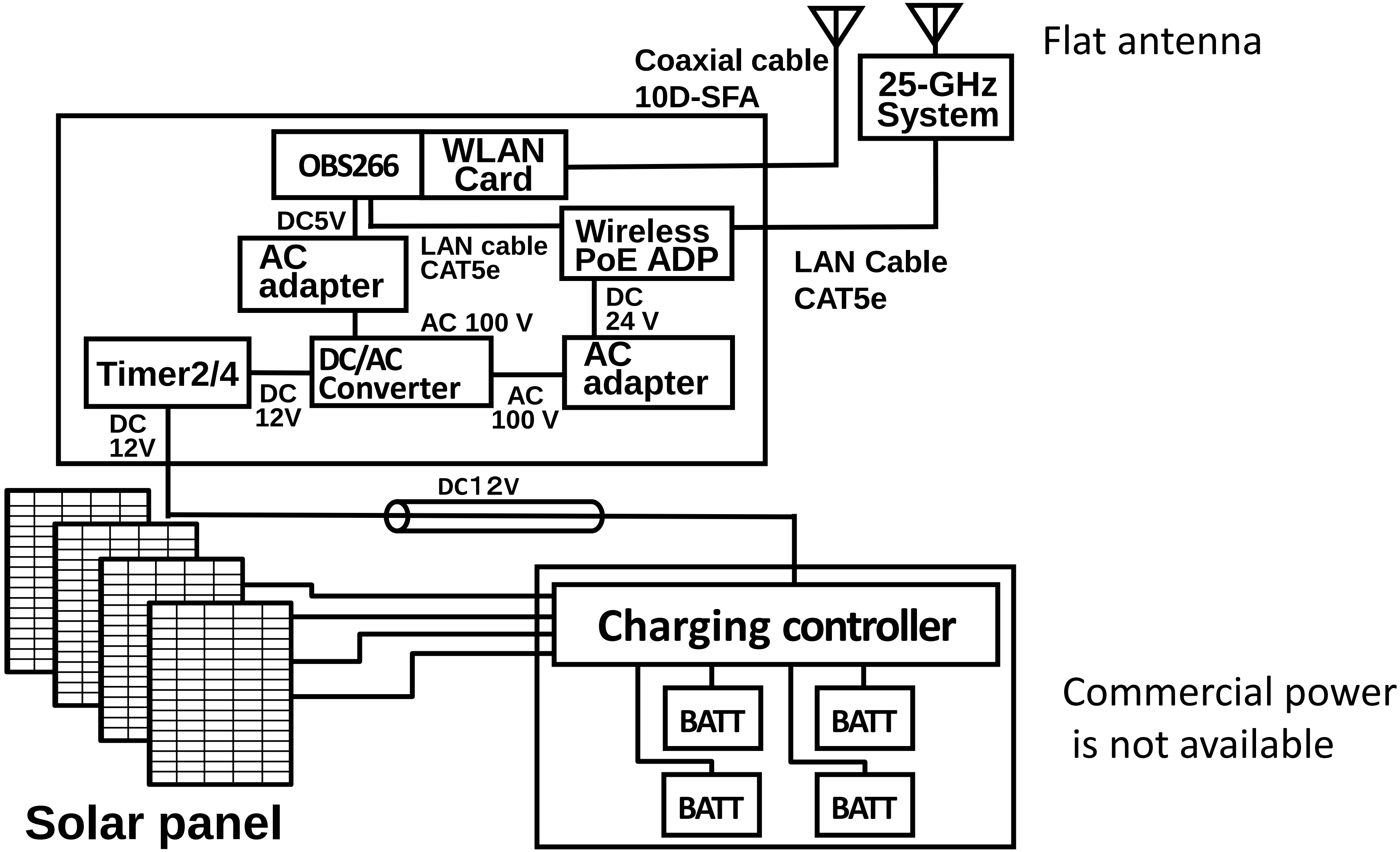
Access SCS
Receive an e-mail
Read a message

Shelter communication service (SCS) was provided.

Node setup

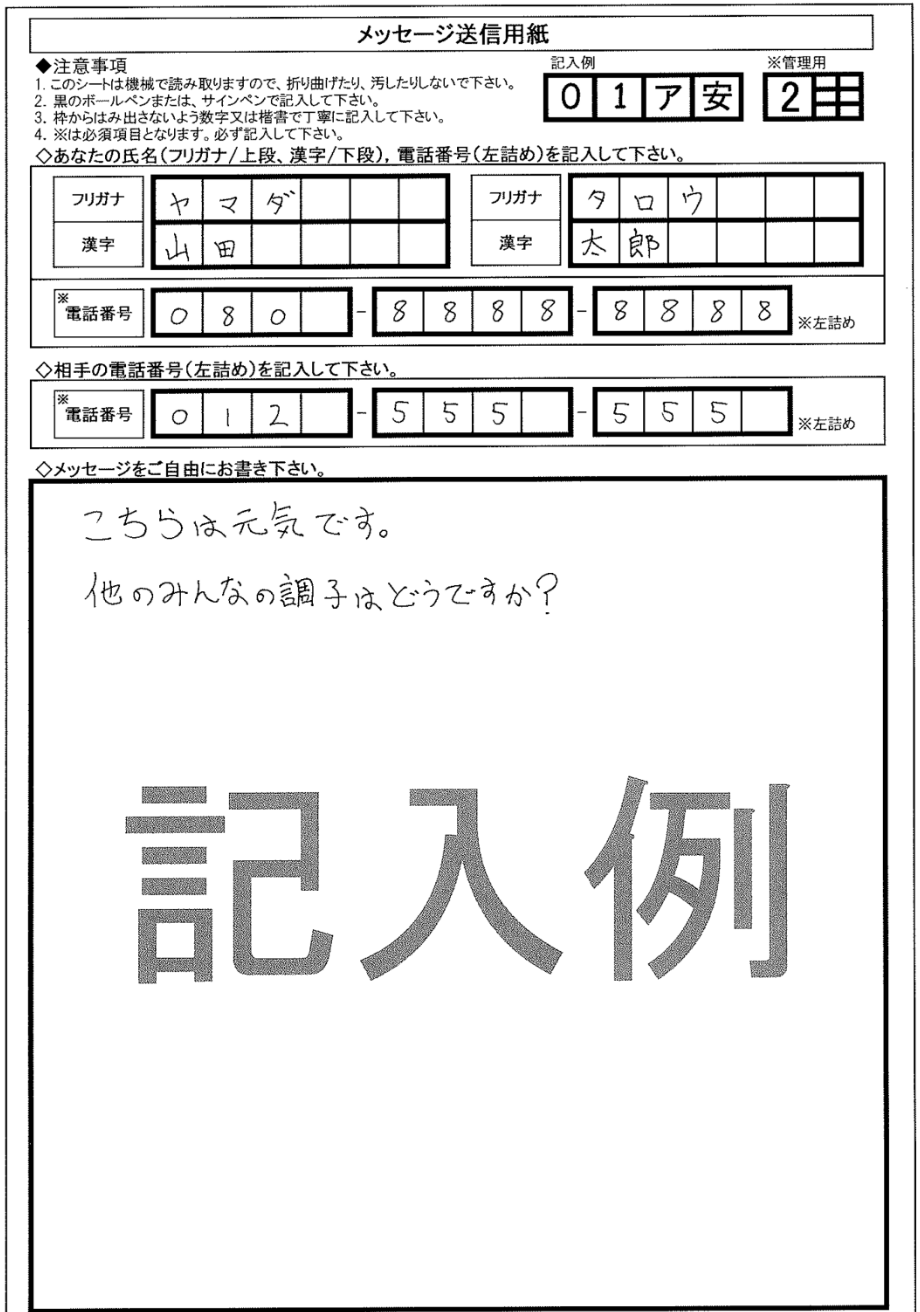


Node configuration



Battery capacity designed to allow three days and eight hours per day operation without sunshine.

Daily rebooting of the micro-servers and remote monitoring conducted.



メッセージ送信用紙

◆注意事項

1. このシートは機械で読み取りますので、折り曲げたり、汚したりしないで下さい。
2. 黒のボールペンまたは、サインペンで記入して下さい。
3. 枠からはみ出さないよう数字又は楷書で丁寧に記入して下さい。
4. ※は必須項目となります。必ず記入して下さい。

記入例 0 1 ア 安

※管理用 2

◇あなたの氏名（フリガナ/上段、漢字/下段），電話番号（左詰め）を記入して下さい。

フリガナ	ヤ マ ダ	フリガナ	タ ロ ウ
漢字	山 田	漢字	太 郎

※電話番号 0 8 0 - 8 8 8 8 - 8 8 8 8 ※左詰め

◇相手の電話番号（左詰め）を記入して下さい。

※電話番号 0 1 2 - 5 5 5 - 5 5 5 ※左詰め

◇メッセージをご自由にお書き下さい。

こちらは元気です。

他のみんなの調子はどうですか？

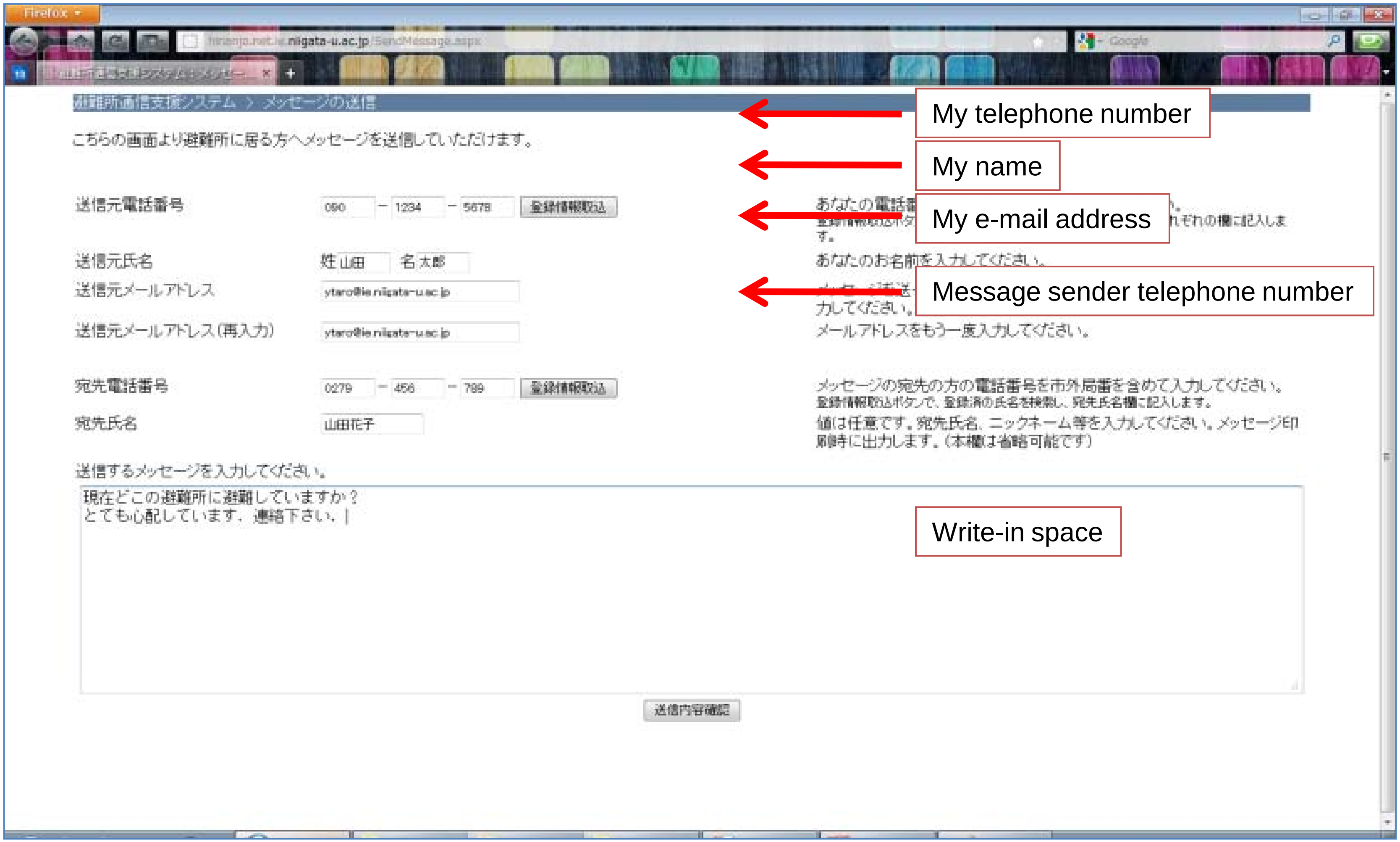
記入例

Message sender phone number

Message receiver phone number

Message space

Access the SCS Webpage to make a user account to read and reply to the message from a shelter



Access SCS webpage and read the message from the shelter

Results and considerations

- No information on the service recovery timetable was obtained from the network providers.
- Two and half months were needed to complete the network planning survey, contract of construction, and approval of use of the river area and licensing of the wireless transmission system.
- Wireless multihop network can save construction time.
- In ordinary days, trans-locatable network facilities should be widely deployed and used in major cities nation-wide. When a disaster occurs, these network facilities can be used to timely construct emergency networks in the disaster area.
- Node location planning for assuring line-of-sight between adjacent nodes can be pre-planned.
- Such preparatory emergency network planning greatly reduces time-lag for starting emergency communication services in the disaster areas.

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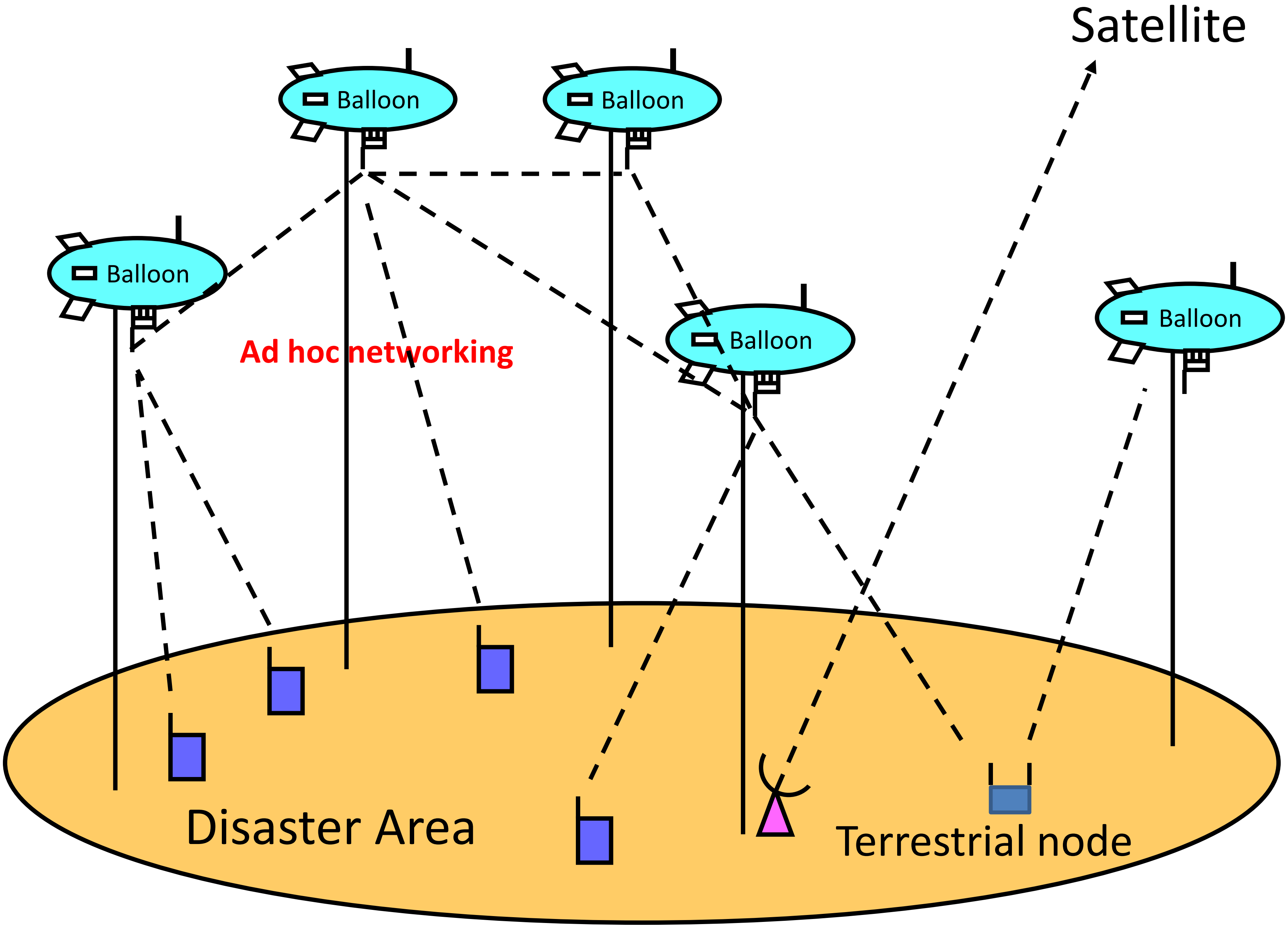
SKYMESH concept


Using a satellite link, the Skymesh can provide information exchange between disaster areas and outside.

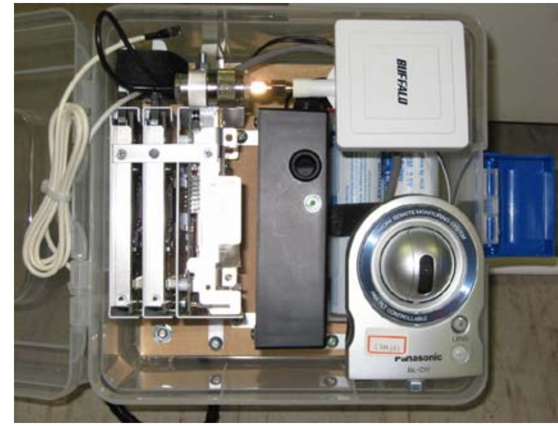
Network configuration of Skymesh



Node specification

Mini computer		ARM926EJ-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 (Balloon)	IF to node	Sleeve antenna, Gain: 5.5 dBi Half value angle: vertical 45° Horizontal omnidirectional antenna
	IF to terminal	Plain directional antenna Half value angle: 60°

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



Lithium thionyl chloride battery × 4 (3.6 V, 8.5 Ah) → Eight hours operation

Balloon specification

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

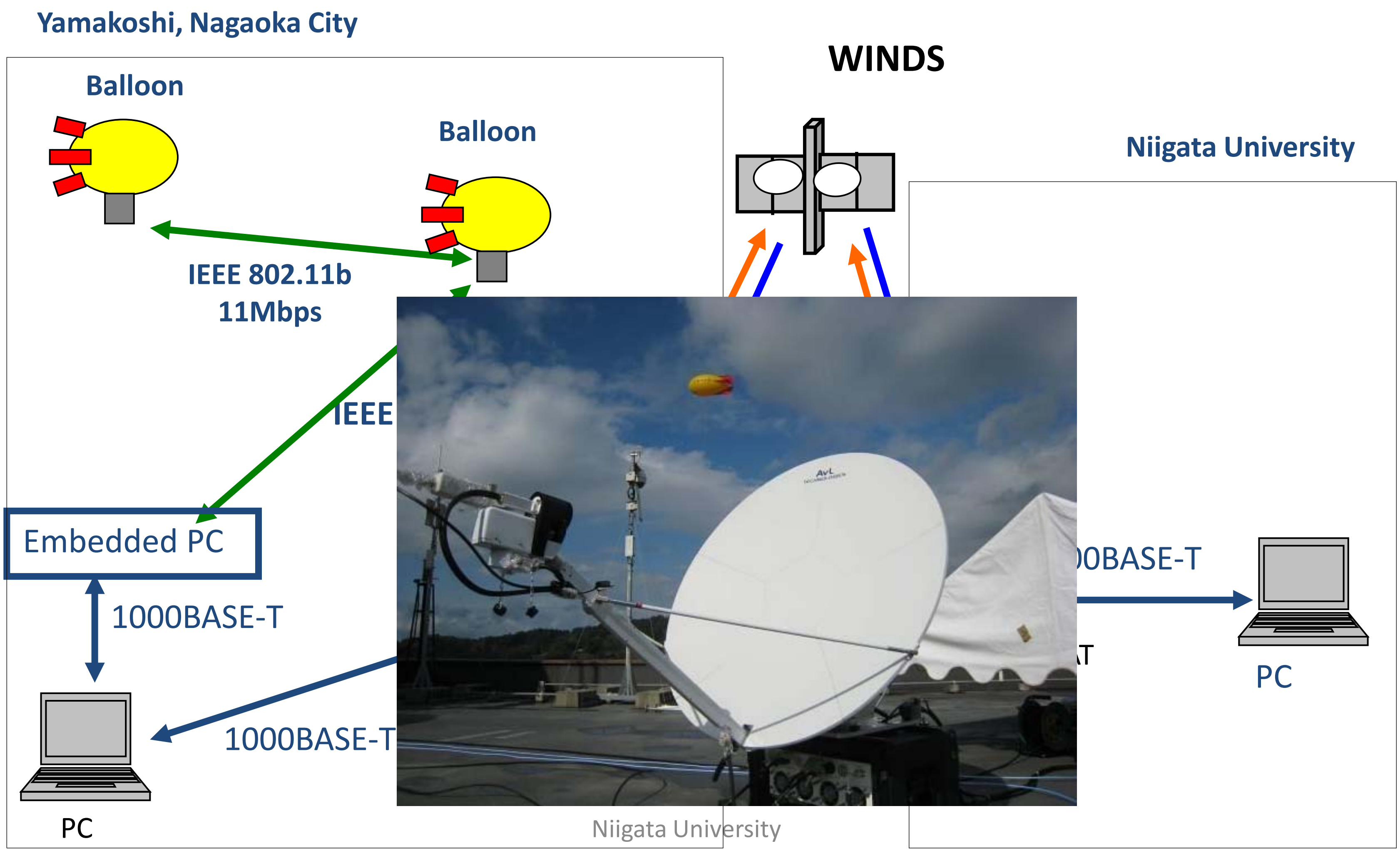
Experiment on October 2006

in Yamakoshi village, Nagaoka, Niigata, japan

A video picture taken by a camera on a balloon

Niigata University, Japan

Experiment on October 2008
Evaluating communication performance of a network composed of SKYMESH and WINDS



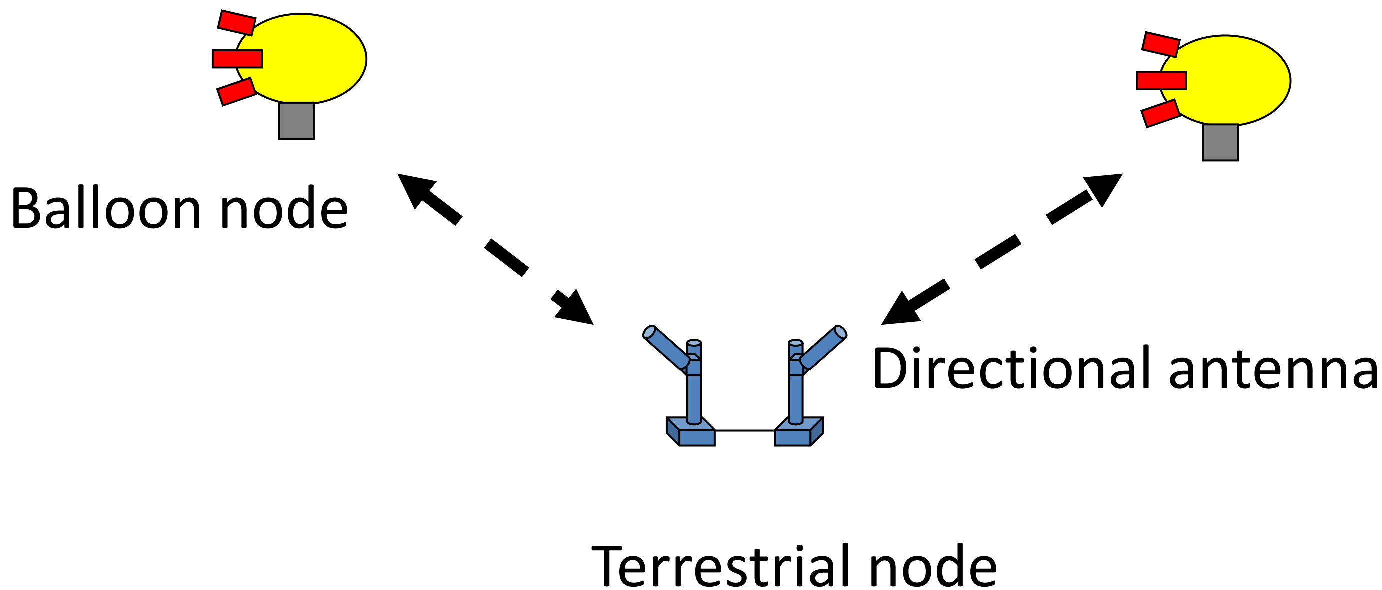
WINDS: Wideband Internetworking Engineering Test and Demonstration satellite

Video transmission experiment

USB Camera	Logicool Qcam pro for notebook
Protocol	TCP
Coding	JPEG
Resolution	640×480 pixel
Frame size	0.3Mbit
Frame rate	5fps
Required bandwidth	0.3Mbit×5fps=1.5Mbps
TCP window size	1MB
Number of Samples	11

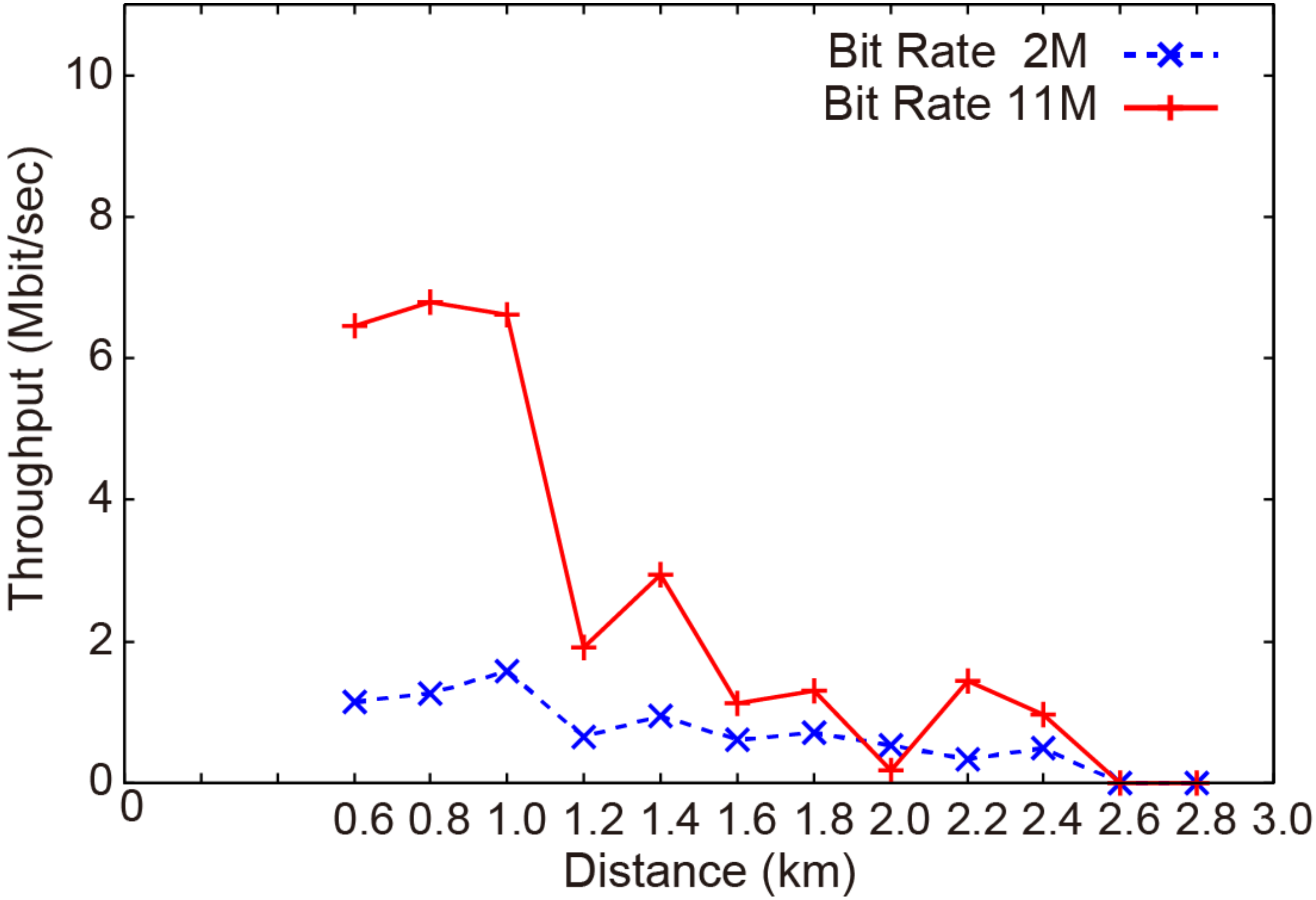
Combination of balloon and terrestrial nodes

- Line-of-sight can also be easily assured.
- The transmission range can be extended by using directional antennas for the terrestrial node.



Experiment on August 2010

Average UDP throughput between balloon and terrestrial nodes



Measurement tool	Iperf (UDP)
Measurement time	20 s
Number of experiments	20
Transmission bit rate	2 Mbps 11Mbps

- The longest transmission range between the balloon and terrestrial nodes is about 2.4 km.
- It is possible to communicate with high quality up to 1 km.

Results and considerations

- Balloons can be used to hold an ad hoc network in air.
- Node equipment downsizing is important for real use.
- Balloons swing in the wind, resulting frequent link disconnection.
- Link-by-link transport or application-level retransmission is useful to allow a large number of hops.
- Combination of balloon and terrestrial nodes is promising to extend the transmission range.
- Recently balloon networking is also being developed in industries (ie., Google project loon)

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Automobile node networking

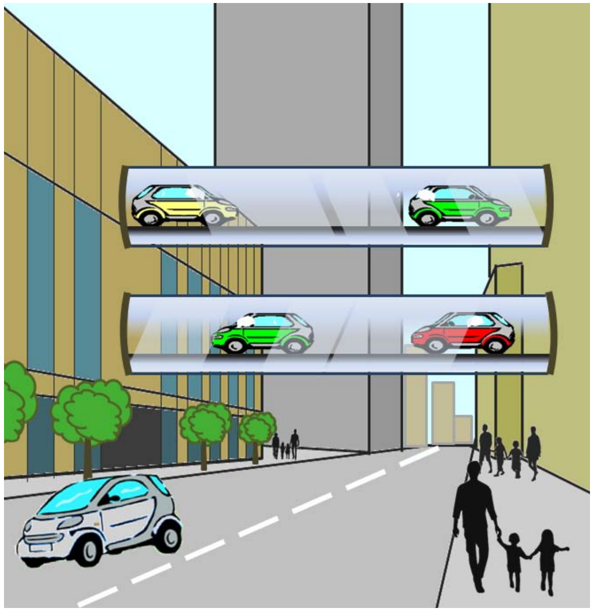
- Vehicular ad hoc network (VANET) has been studied within the framework of ITS.
- A vehicle is equipped with a node to form a MANET with other vehicles.
- In VANET, gasoline-powered vehicles have been assumed.
- A gasoline-powered vehicle has a small-capacity battery and cannot work as a communication node when the engine is switched off.
- The applications of a VANET while driving are of major interest.
- Geographic routing protocols are favored in VANET environment.

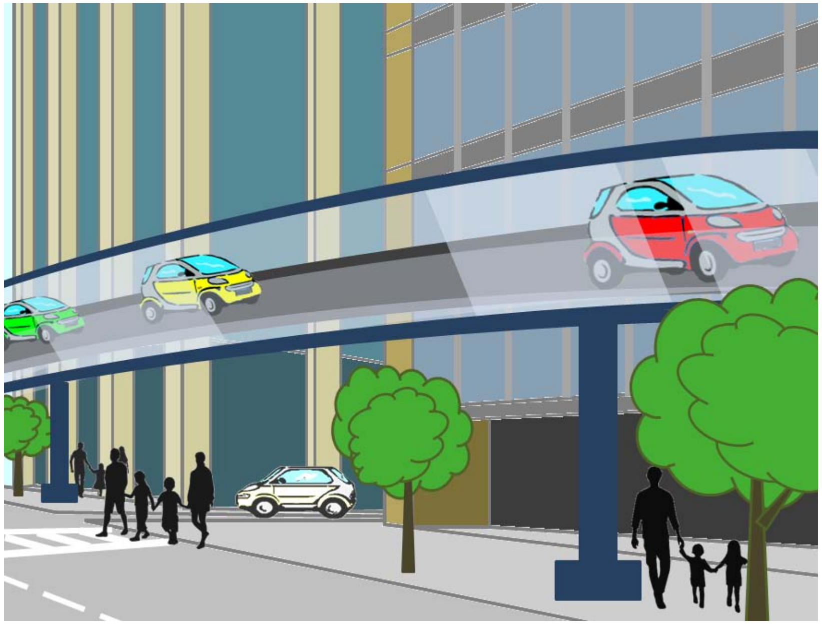
✓ Frequent link disconnection

✓ No stable end-to-end path

Electric Vehicle (EV) industry and market

- Automobile exhaust has been a major cause of air pollution worldwide. The EV is free of exhaust and promising to contribute to the realization of 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 contributes to further expand the market.
- Large capacity battery of EVs can be used for various applications.





EV-based ad hoc networking

- EVs 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.
- EVs can be recharged using local power generation facilities and usable under disaster recovery.

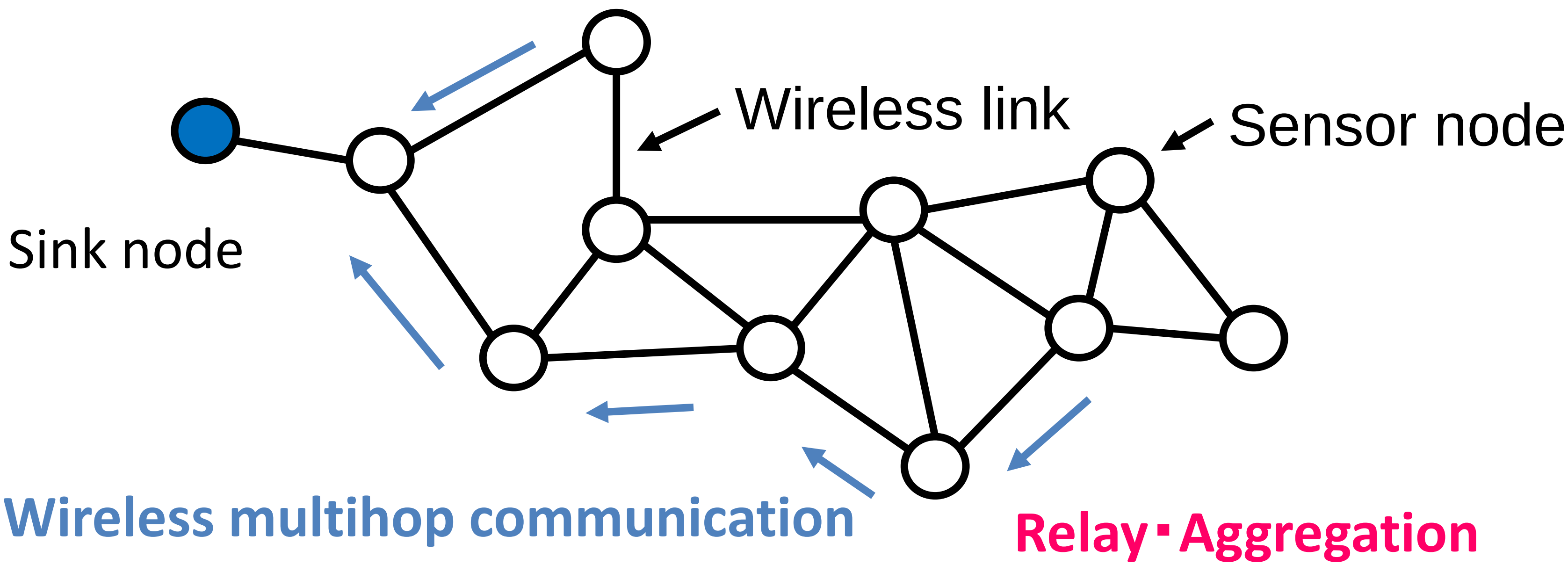
Comparison of VANETとEVANET

	Exhaust	Ventilation	Networking	Applications
VANET	Yes	Required	During driving	Driving support
EVANET	No	Not necessary	Always	General

Community networking can easily be provided.

Wireless Sensor Network (WSN)

- ✓ Deployment of many small and power saving sensor nodes
- ✓ Wireless multihop sensor data transmission
- ✓ Autonomous decentralized network formation
- ● Standardization is in progress in recent years.
- ● Typical applications
  - ▪ Environment monitoring, Agricultural monitoring, Wild life habitat monitoring, Smart meter monitoring

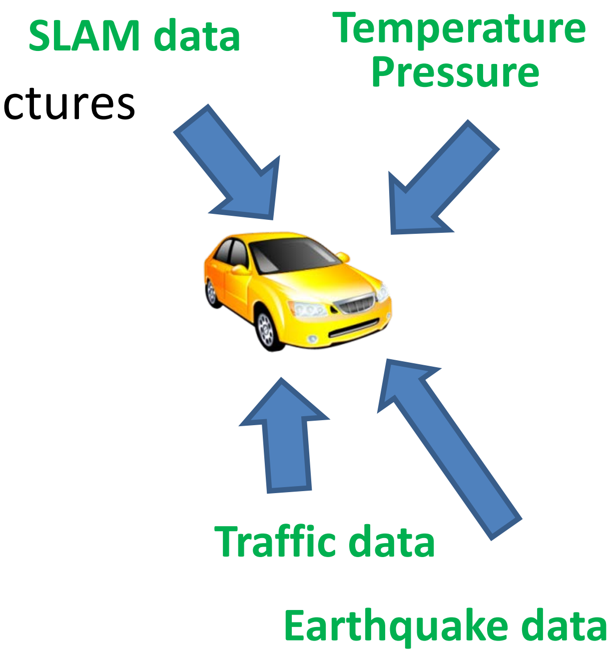


EVANET-based WSN

Advantages

- No consumption of bandwidth of existing infrastructures
- Low cost collection of environmental information
  - EVs will be prevailing in the community.
  - Sensors are attached on EVs
  - Sensor data collection can be performed

    using inter-vehicle communication



Usage examples

* Simultaneous Localization and Mapping

- **Real-time traffic data collection and improvement of driving comfortability, safety and energy efficiency**
- **Old infrastructure monitoring**
- **City environment improvement and crime prevention**
- **Collection of weather information, which is used for clean energy production and utilization optimization, and disaster prevention**

VANET routing protocol as a WSN platform

Type	Sensor data delivery	Networking	Routing
1	On demand from sensor node	V2V	Unicast
2	To the interest group (Neighborhood, Specified area)	V2V	Broadcast Geocast
3	To the database via a roadside unit	V2I V2V2I	Unicast

Taxonomy of Various Geographic Unicast Routing Protocols in VANET

Geographic Routing

- **Proactive**
  Path selection data are ready.
  - GPSR
  - GPCR
  - GPCRJ+
  - GeoDTN+Nav
  - GSR
  - SAR
  - A-STAR
  - STAR
  - CBF
  - CLA-S
  - CBRP
  - DGR
  - GyTAR
  - E-GyTAR
  - LOUVRE
  - VADD
  - ACAR
  - VVR
  - RBVT-P
  - RIVER
  - SADV
  - ETGR
  - SNMR
- Reactive
  Path selection data are acquired on-demand.
  - CAR
  - GV Grid
  - TrafRoute

Input:
- Street map
- Position of destination
- Traffic information (optional)

Weakness of the reactive approach.
- Path discovery may not work well under low or intermittent traffic conditions.
- Frequent loss of RREQ and RREP packets.
- Significant delay of RREQ and RREP packets If carry & forward are employed.

Comparison of Proactive Geographic Routing 1

Routing protocols	Map Required	Street aware	Traffic aware(vehicle density, speed, etc.)		Packet aware(delay, delivery ratio, connectivity, etc.)			Distribution		
			Statistics	Monitor-ing	Estimation	Monitoring		Broadcast	Unicast	Flooding
						Passive	Active			
GPSR										
GPCR		✔								
GPCRJ+	✔	✔								
GeoDTN+Nav		✔	✔							
GSR	✔	✔								
SAR	✔	✔	✔							
A-STAR	✔	✔	✔							
STAR	✔	✔		✔						✔
CBF		✔								
CLA-S	✔	✔								
CBRP	✔	✔	✔							
DGR										
GyTAR	✔	✔	✔							
E-GyTAR	✔	✔	✔							
LOUVRE	✔	✔		✔				✔		
VADD	✔	✔	✔		✔					
ACAR	✔	✔	✔	✔	✔				✔	
VVR	✔	✔				✔		✔		
RBVT-P	✔	✔	✔				✔			✔
RIVER	✔	✔				✔	✔		✔	
SADV	✔	✔	✔		✔	✔				✔
ETGR	✔	✔		✔					✔	
SNMR	✔	✔				✔	✔		✔	

Comparison of Proactive Geographic Routing 2

Routing protocols	Greedy forwarding + Routing failure avoidance						Next hop selection		Improved greedy forwarding	
	Perimeter mode	Compute path				Carry-and-forward	Beacon exchange	Content-ion-based	Position prediction	Directional forwarding
		Source/ local max	Junction node	Every node	Static node					
GPSR	✔						✔			
GPCR	✔						✔			
GPCRJ+	✔						✔			
GeoDTN+ Nav	✔					✔	✔			
GSR		✔					✔			
SAR		✔				✔	✔			
A-STAR		✔					✔			
STAR		✔	✔				✔			
CBF								✔		
CLA-S		✔						✔		
CBRP			✔			✔		✔		✔
DGR						✔	✔		✔	✔
GyTAR			✔			✔	✔		✔	
E-GyTAR			✔			✔	✔		✔	✔
LOUVRE		✔	✔			✔	✔			
VADD			✔			✔	✔			
ACAR		✔				✔			✔	
VVR	✔	✔					✔			
RBVT-P				✔				✔		
RIVER		✔	✔				✔			
SADV					✔	✔	✔			
ETGR					✔					
SNMR					✔	✔	✔			

Results and considerations

- A WSN platform supported by vehicular ad hoc networking is one of the major ITS applications.
- The performance of geographic routing is significantly affected by the street environments and vehicle traffic conditions.
- In addition to the minimum requirement of street-awareness based on street maps, traffic and packet-awareness are considered essential for achieving acceptable packet delivery performance.
- In particular, in addition to statistical information, real-time information on traffic and packet-awareness is indispensable for making routing protocols feasible and effective.

Outline

- ICT and ITS evolution
- Ad hoc network and routing protocol
- A concept of wide area ad hoc network (WANET)
- Fixed node networking
- Balloon node networking
- Automobile node networking
- Unmanned Aircraft (UA) node networking
- Perspective
- Conclusions

Unnamed Aircraft (UA) node networking

Attention arises on the realization of various services using Unmanned Aircrafts (UAs).

UA category	Power	Size	Speed	Hover -ing	Wind resistance	Operati on time	Take-off & landing space
Fixed wing (Airplane)	Oil Battery	Fair	High	No	Fair	Limited	Runway
Single-Rotor wing (Heli-copter)	Oil Battery	Fair	Low	Yes	Limited	Limited	Fair
Multi-rotor wing (Multi-copter)	Battery	Small	Low	Yes	Limited	Limited	Small
No wing (Airship)	Oil Battery	Big	Low	Yes	Fair	Fair	Wide ground space

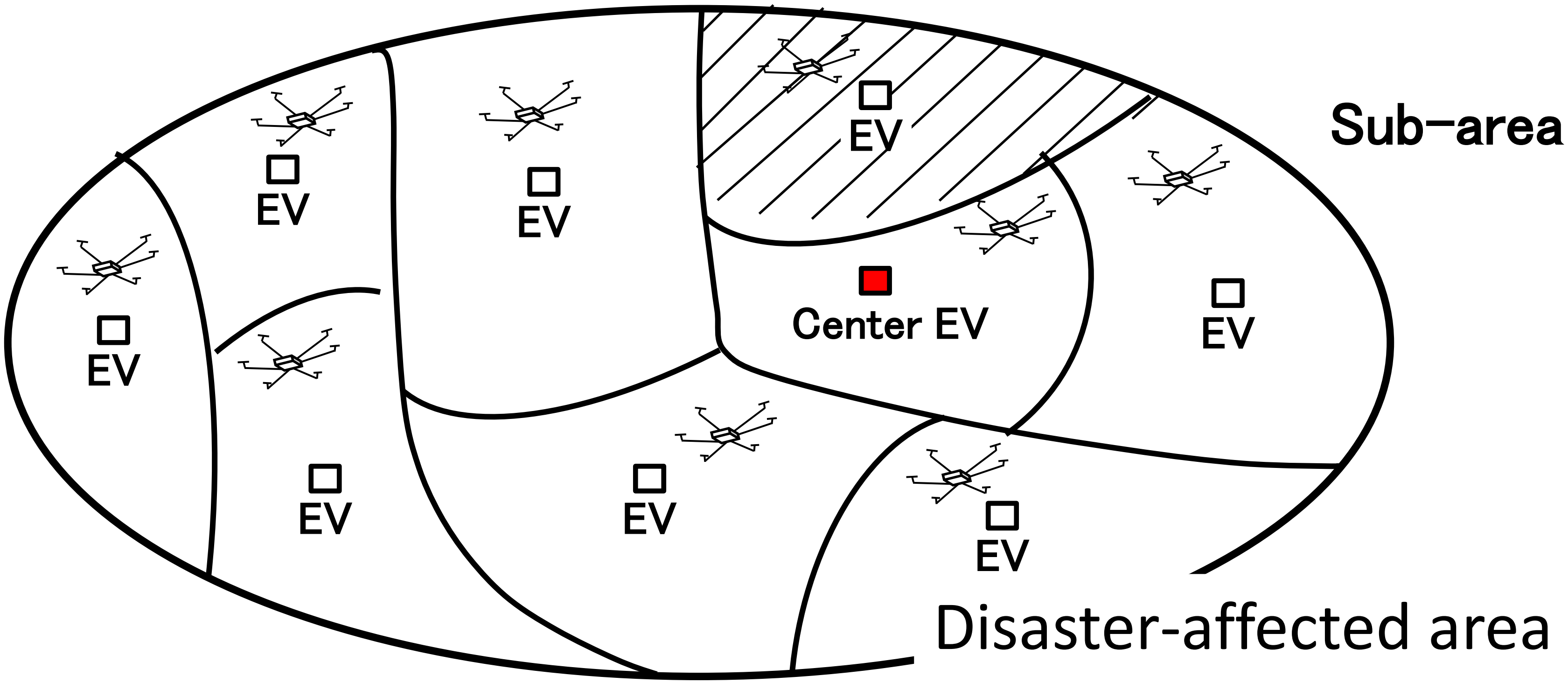
Surveillance

- One of the applications of EVANET-based WSN is surveillance for disaster recovery.
- EVANET-based WSN can be powered up by adding surveillance capability from the air.

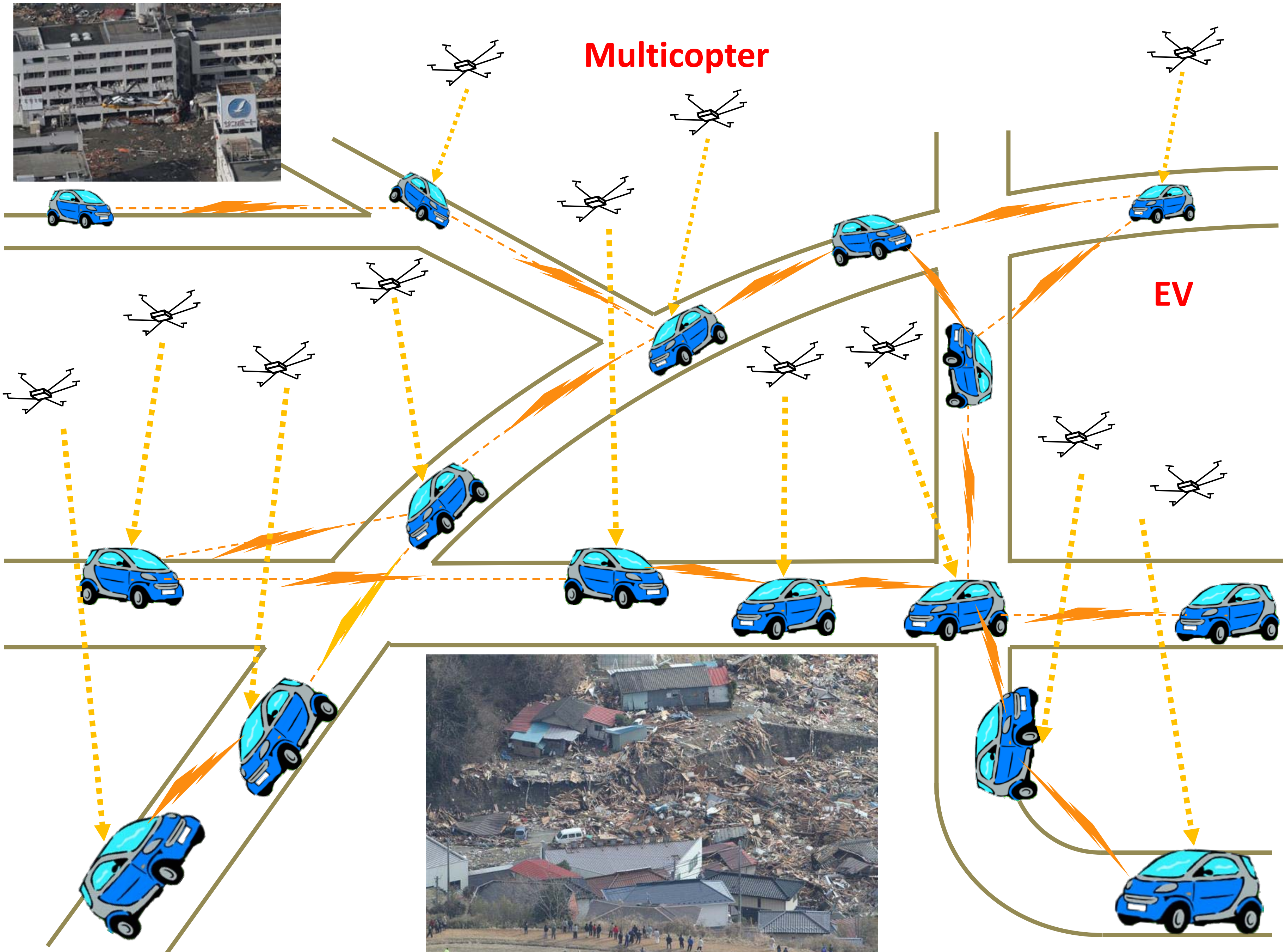
  (3 Dimensional Mobile Surveillance: 3DMS)
- Multicopters are attractive in terms of the efficient surveillance, low investment and operational ease.

Surveillance architecture

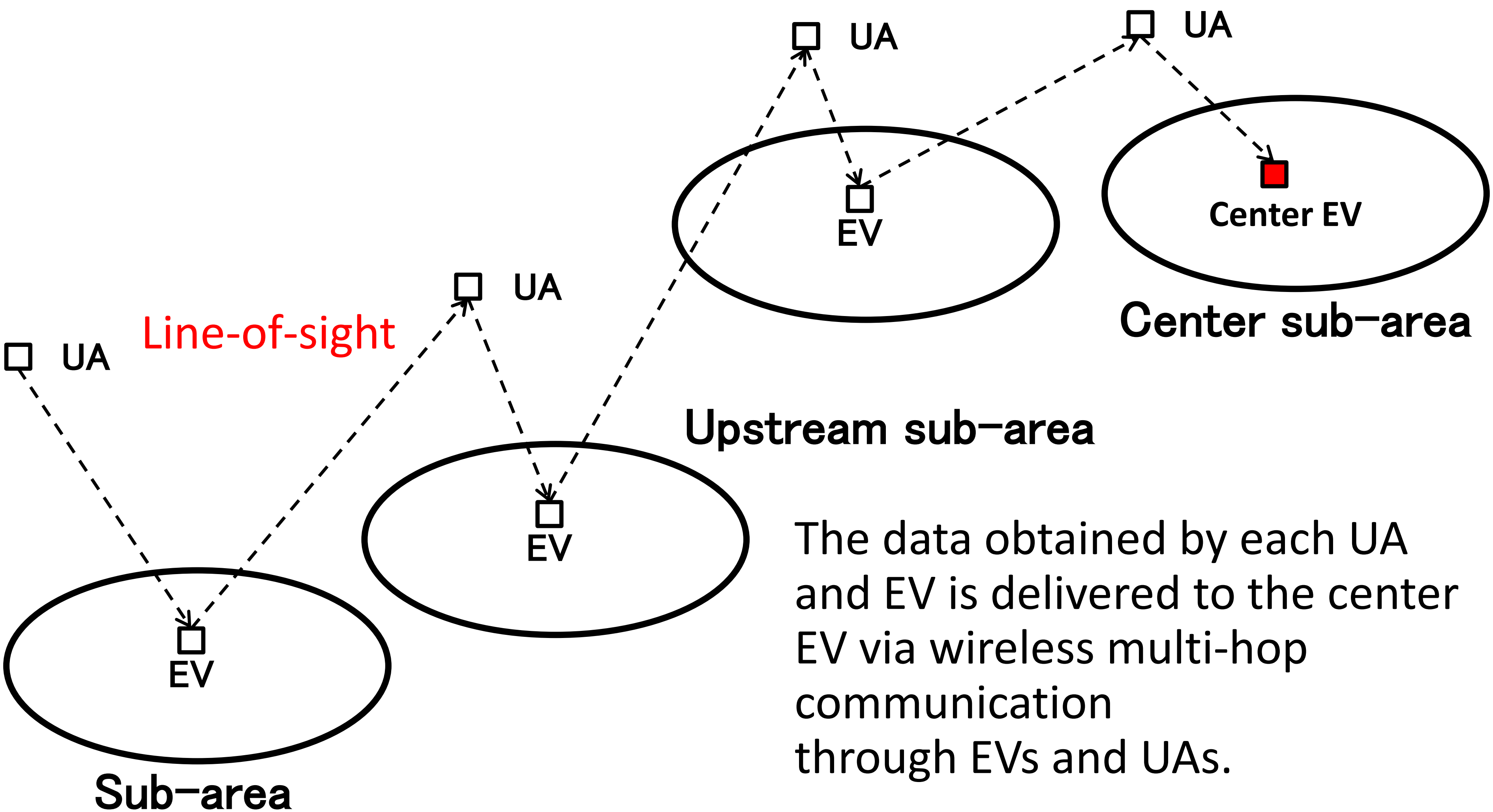
- An entire surveillance area is divided into sub-areas.
- An EV and UA pair is assigned to each sub-area.
- Each EV carries its partner UA and is parked at its target position.
- Each UA flies over the assigned area to conduct surveillance.
- An EV supports automatic piloting and energy for its partner UA.
- Center EV works as the data collection point of the area and delivers the data to the remote disaster recovery headquarter.



3 Dimensional Mobile Surveillance（3DMS）



Data delivery over wireless multi-hop communication



The data obtained by each UA and EV is delivered to the center EV via wireless multi-hop communication through EVs and UAs.

Results and considerations

- A time-efficient and pervasive surveillance capability can be provided based on the collaboration of multiple EVs and UAs.
- An EV can be used to supports automatic piloting and provides energy for the UA.
- A wireless link should be established between a UA and its partner EV, as well as between an EV and its immediate upstream UA for forming a wireless multi-hop path toward the center EV in the area.
- Area division principles are needed for considering cost minimization as well as the requirements of allowable surveillance time, and transmission range and effective bandwidth of the wireless link.

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Perspective I

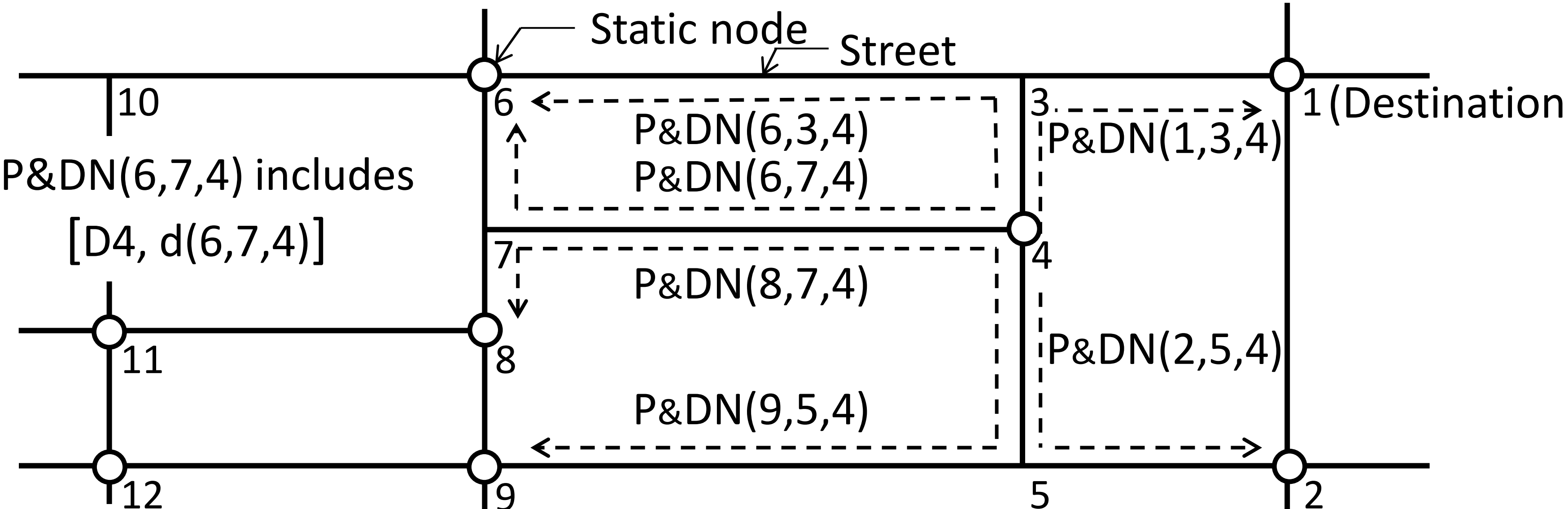
Static-Node Monitored Routing (SNMR)

Static nodes can be used to power up the EVANET-based WSN.

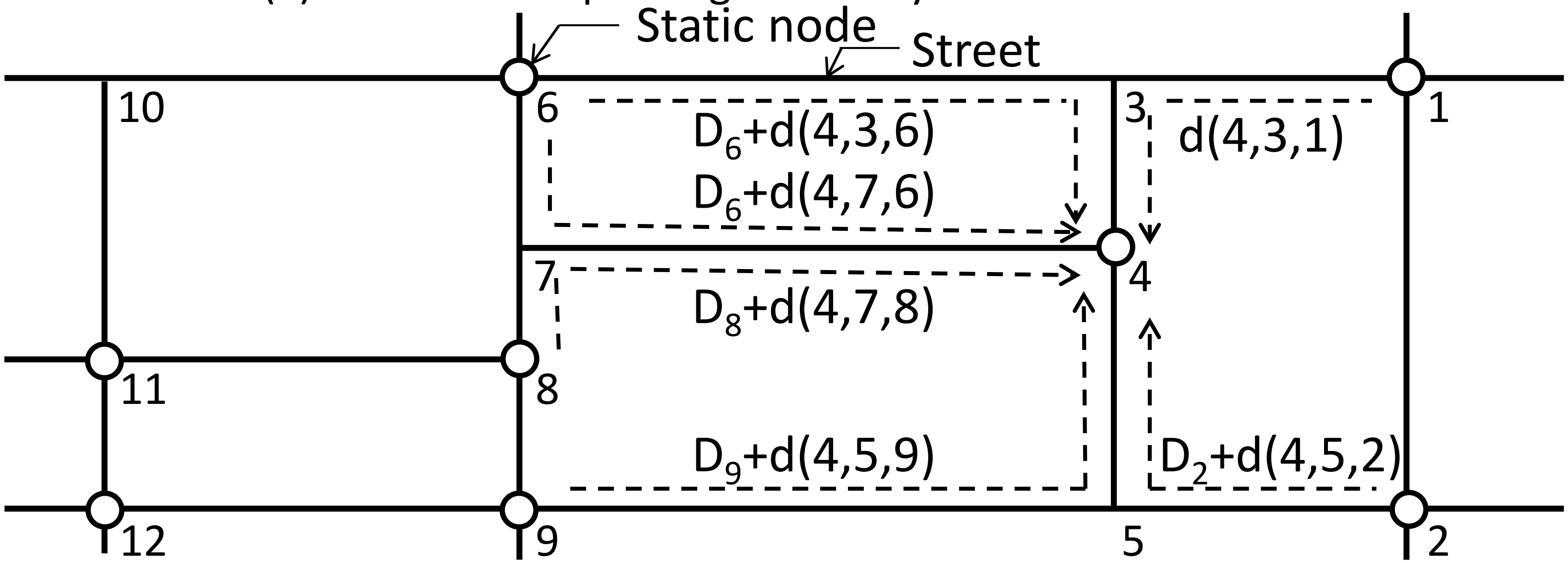
- A static node can be used as the temporal storage of packets when a packet-carrying node cannot find any appropriate next hop nodes.
- Proactive path computation can be performed periodically based on the latest traffic- or packet-level information. Using this information, the nodes can save load and time of path computation.
- Static nodes can monitor traffic- and packet-level information continuously and periodically at the fixed locations, improving monitoring accuracy and efficiency.
- Packet retransmission can be implemented between adjacent static nodes on the path.

SNMR should work under partial deployment of static nodes.

SNMR (Static-Node Monitored Routing)



(a) Street-based probing and delay notification.



if d(4,3,1) < D_2+d(4,5,2), D_6+d(4,3,6), D_6+d(4,7,6), D_8+d(4,7,8),D_9+d(4,5,9)
then $D_4 \leftarrow$ d(4,3,1) Select path(4,3,1) (b) Path selection by SN_4

Perspective II
Comparison of airship and multirotor-wing UA

- A multirotor-wing UA (MRW-UA) and an airships have different features.
- Combined use of them could pick the best of both.

	MRW-UA	Airship
Payload	Less than 10 kg	Tens of kilograms
Flight duration	Less than an hour	Hours
Velocity	50 km/h	More than 50 km/h
Wind tolerance	10 m/s	More than 10 m/s
Flight stability	Low	Medium
Flight power	Battery	Oil/Battery
Space for taking off and landing	10 m^2	100 m^2
Work load for taking off and landing	0–1 person	3–5 persons

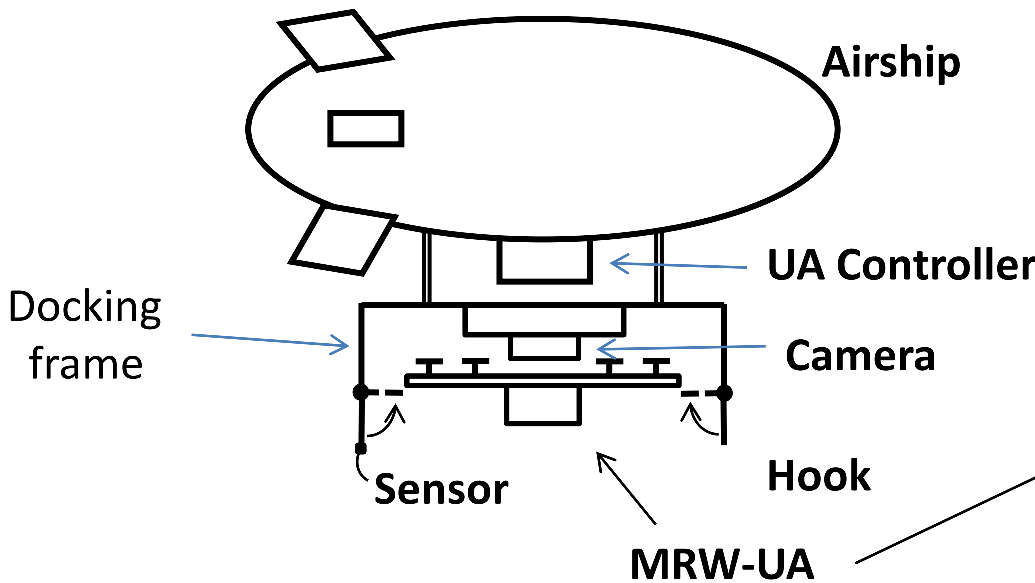
Airship-Assisted UA System (AA-UAS)

A UA can be assisted by an airship in three ways.

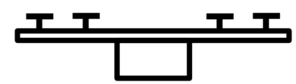
- Carry service
  - The duration of flight of a UA is limited, only applicable for relatively short distance mission.
  - Airship can be used to carry a UA to its mission area.
- Energy supply service
  - An airship can be used to replace the used battery of a UA and to recharge used batteries.
- Networking service
  - When multiple airships stands still in the similar altitude, line-of-sight can be assured between adjacent airships.
  - Directional antennas can be used between adjacent airship to extend transmission range.
  - Stable ad hoc networking is provided among multiple airships.
  - UAs use airship-based ad hoc network as the communication backbone.

An operation image of AA-UAS

An airship suspends a docking frame
that holds a body of MRW-UA.



The airship supports
the MRW-UA flight control.



2: The MRW-UA is released
and flies in the mission area.

Long distance

1: An airship carries it pair MRW-UA
to the mission area.

In the mission area

3: Completing the mission,
the MRW-UA returns to the airship.

Application examples

- Package distribution
  - In contrast of package distribution on roads, UA-based distribution gets rid of traffic jam and is more free in selecting shorter paths to the destination.
  - UA-based home delivery is under investigation by major players such as Amazon and Google, applicable only for short distance.
  - An airship has a longer flight range, but is not appropriate to deliver packages to the final destination.
  - AA-UAS-based distribution service can be applied for wide areas, enlarging business opportunities.
- Disaster area surveillance
  - AA-UAS-based 3DMS can be realized, replacing EVs with airships.

Conclusions

- A concept of wide-area ad hoc network (WANET) was presented.
- Fixed node networking, balloon node networking, automobile node networking, and UA node networking were examined and discussed mainly based on real world prototyping and experiments.
- ITS evolution is expected based on WANET.