“The second phase of SIP- Automated Driving for Universal Services/ Research and Development on Traffic Signal Control using GNSS (location information) and other technologies”

Progress Report

Overview

UTMS Society of Japan

KOITO ELECTRIC INDUSTRIES, LTD.

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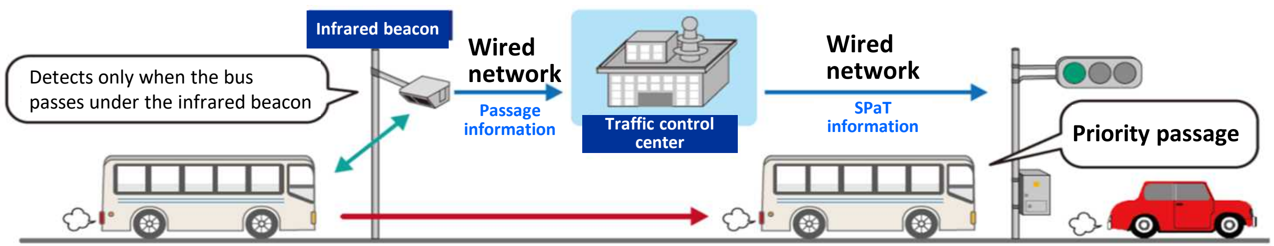
1. Overview of the research and development

The R&D aims to enable a broader societal implementation of real-time priority traffic signal control by linking prefectural police traffic control systems with public vehicles (automated driving buses, emergency vehicles, etc.) using location information from the Global Navigation Satellite System (the GNSS) and a mobile phone communication network.

Current priority traffic signal control

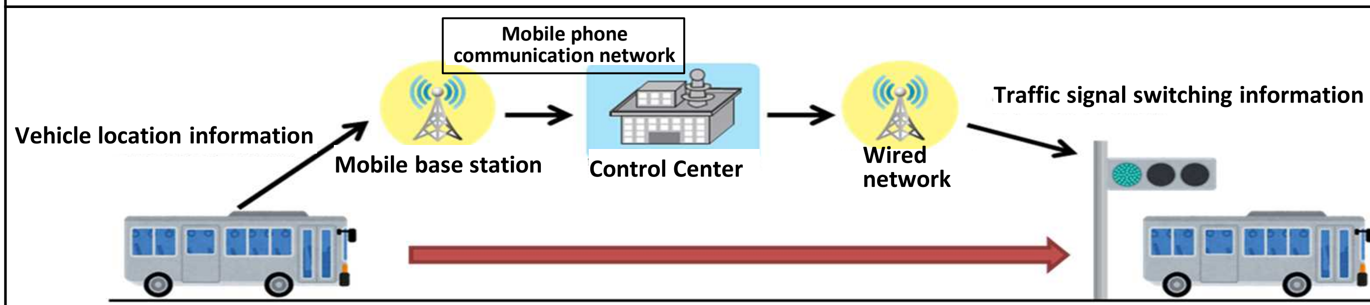
Priority traffic signal control is performed by detecting public transportation vehicles when they pass under an infrared beacon.



Problem: Fixed-point detection makes it impossible to respond to changes in traffic conditions (e.g., traffic congestion) after the detection.
Services can only be provided at locations where infrared beacons are installed.

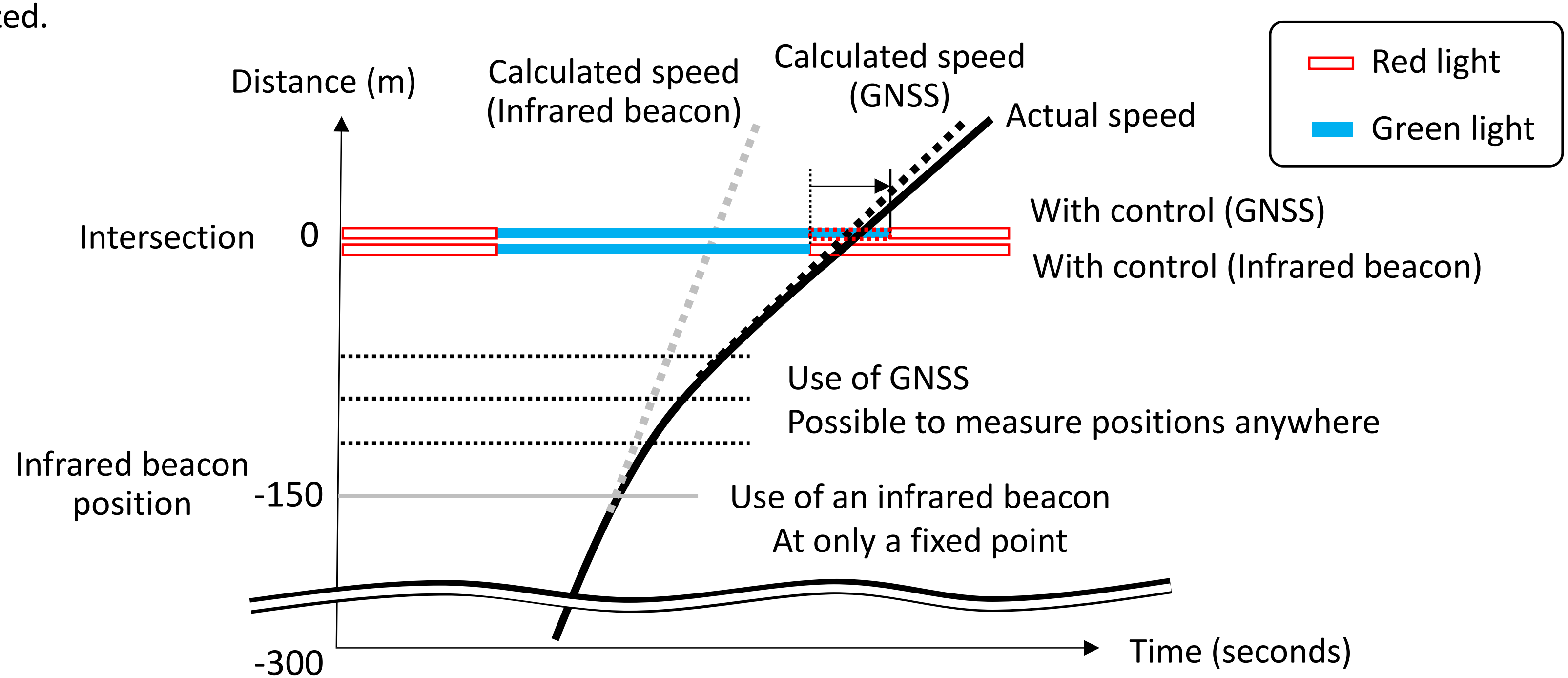
Priority traffic signal control using GNSS, etc. aimed at in this R&D

- Performs real-time traffic signal control by obtaining the location information of public transportation vehicles using GNSS, etc.
- The service can be provided even in places where infrared beacons are not installed.



2. [Features] Priority traffic signal control using GNSS and other technologies

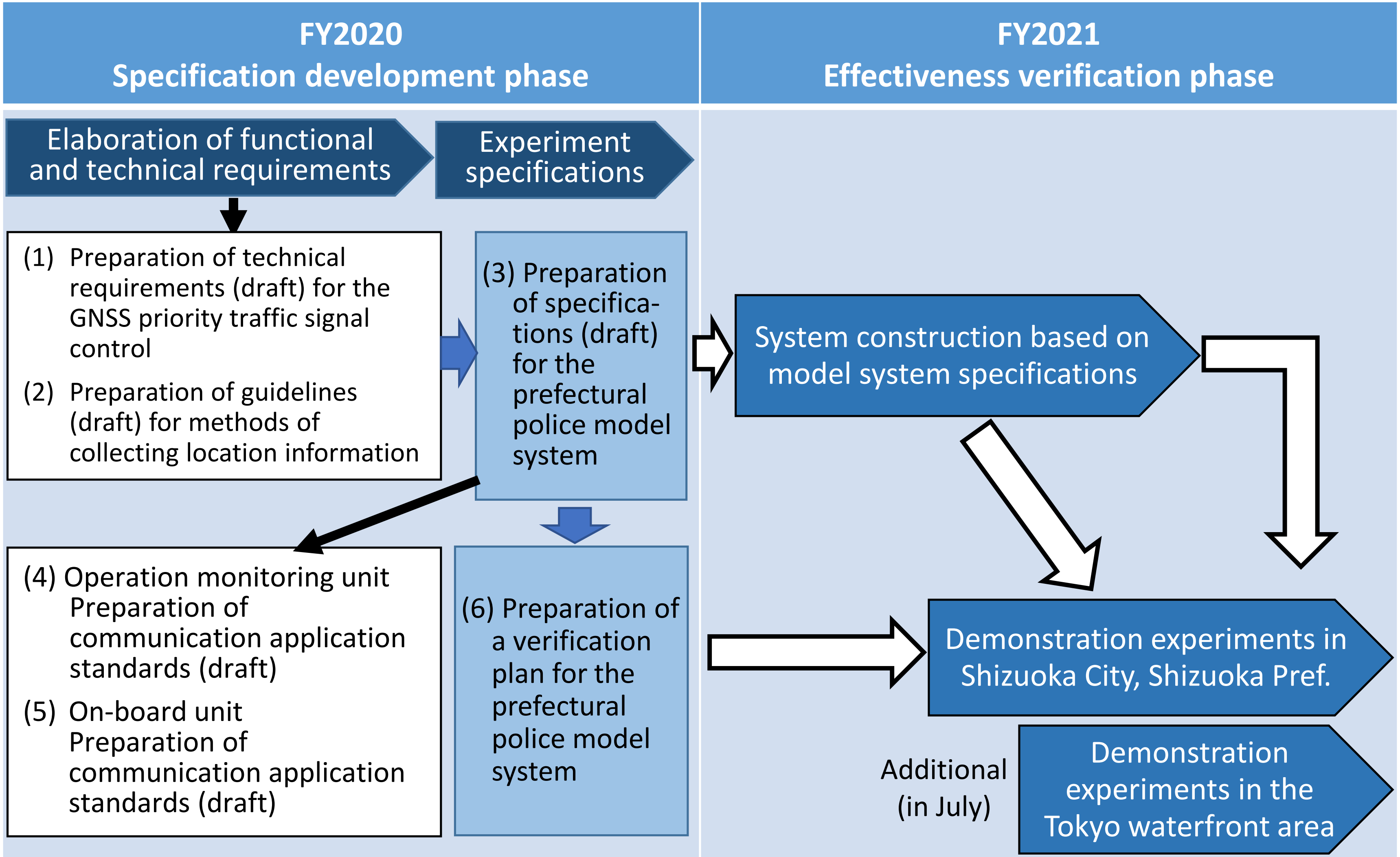
- To minimize the error of arrival time at intersections, priority traffic signal control using GNSS and other technologies **sets the final determination point to a position closer to the intersection** than infrared beacons.
- Since the arrival time is calculated based on the actual speed at the final determination point, the difference between the calculated speed and the actual speed can be suppressed, allowing the arrival time error to be minimized.



Comparison between with infrared beacon control and with control using GNSS, etc. (during traffic congestion)

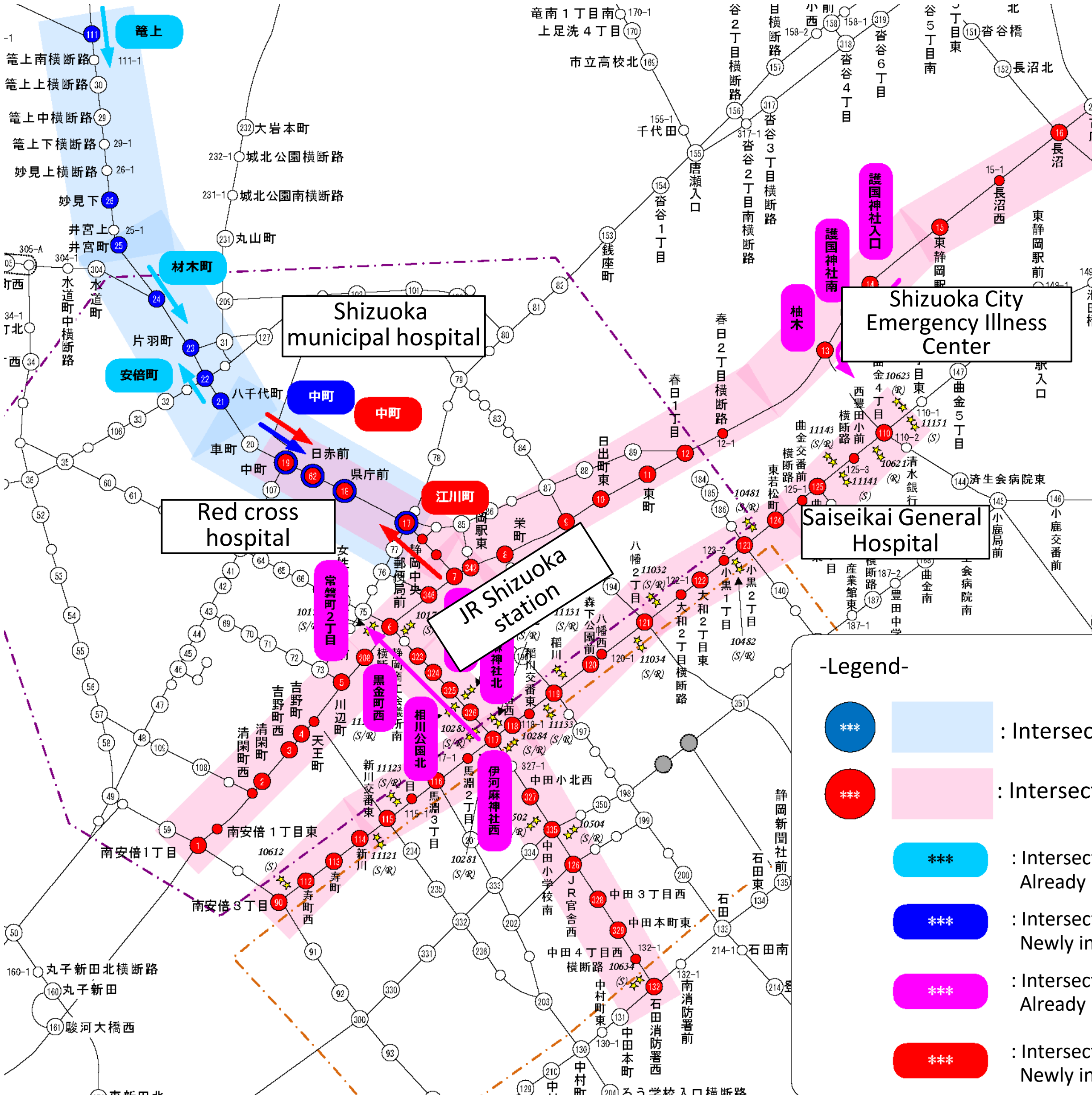
> ➢ Reduction of arrival time error is expected to shorten travel time and reduce congestion in the intersecting direction.
>
> ➢ **An easy-to-introduce system configuration will be examined by utilizing the current functions of signal controllers, control centers, etc.**
>
> ⇨ Aims to further expand the use of the system in areas around the city center where the system is currently implemented.

3. Results of research and development



In FY2020, 6 documents including draft specifications were developed after obtaining approval from the "GNSS Utilization Committee."
In FY2021, demonstration experiments were conducted in Shizuoka City (priority signal control) and the Tokyo waterfront areas (location information distribution).
All items were completed as scheduled thanks to the cooperation of all parties concerned, despite being in the COVID-19 pandemic.

4. Overview of the demonstration experiments



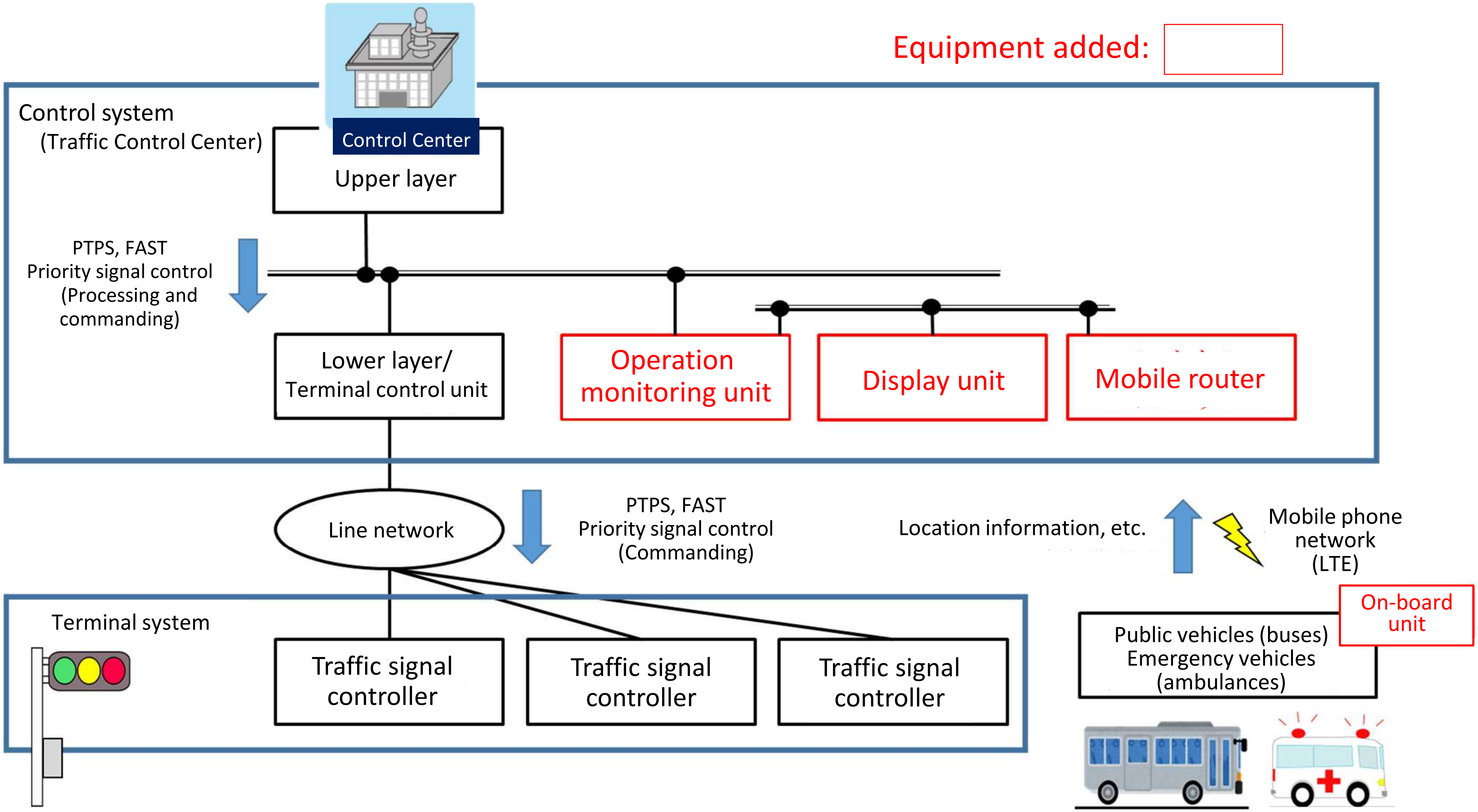
Item	Description
Purpose	Verify whether the control effect is equal or better than that of optical beacon control
Location	Shizuoka City, Shizuoka Pref.
Period	November 2021 – January 2011 (excluding year-end and New Year period)
Number of OBUs	・PTPS (buses) 3 ・FAST (ambulances) 3
Collection cycle	Every 2 seconds
Position error	10 m or less

-Legend-

- *** : Intersections and routes where is in operation (at present)
- *** : Intersections and routes where FAST is in operation (at present)
- *** : Intersections targeted for PTPS model system priority signal control Already installed 3 intersections
- *** : Intersections targeted for PTPS model system priority signal control Newly installed 1 intersection
- *** : Intersections targeted for FAST model system priority signal control Already installed 9 intersections
- *** : Intersections targeted for FAST model system priority signal control Newly installed 2 intersections

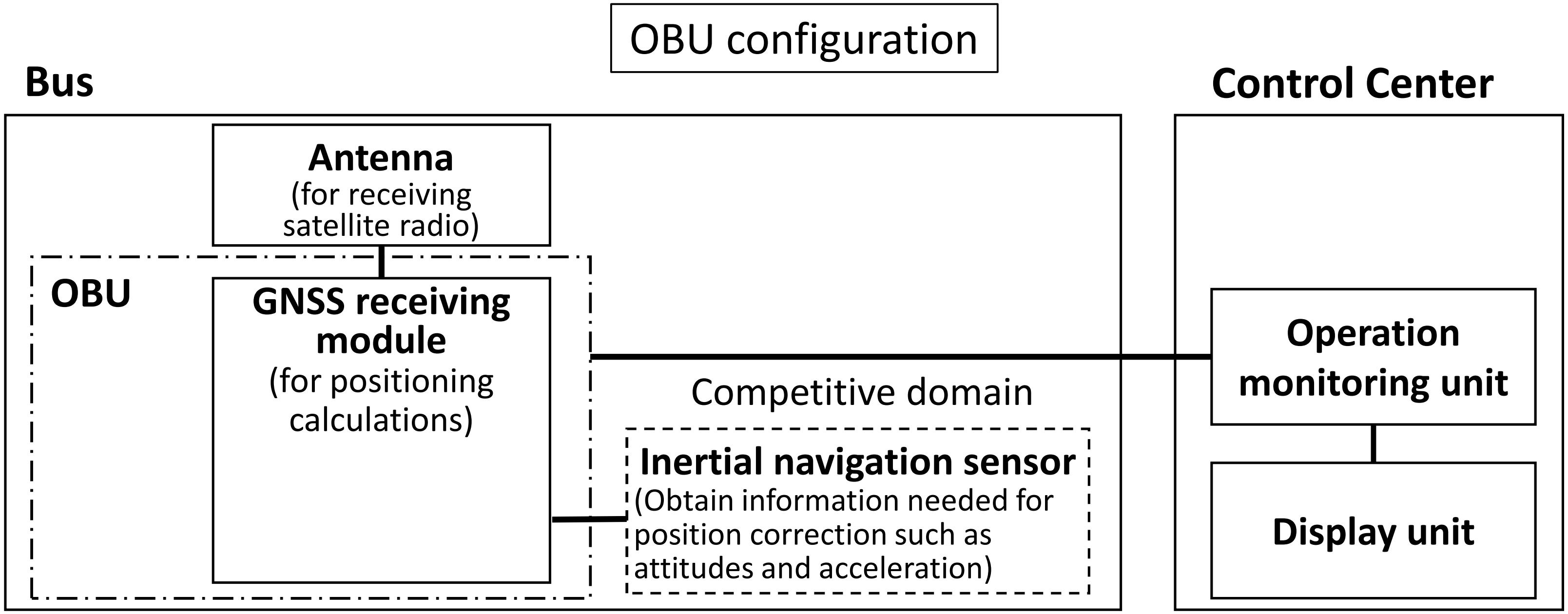
5. System configuration overview

In the draft specifications, several **units were added to the existing control system**, including an **“operation monitoring unit”** that has a function to collect bus location information and perform bus priority traffic signal control and an **“on-board unit”** that has a function to transmit location information, and the verification was conducted in demonstration experiments.



6. OBU performance requirements

Demonstration experiments were conducted with simple and minimum performance requirements.



Item	Performance requirement
Position error	10 m or less
Transmission cycle	2-second cycle (Up to 20 pieces of GNSS information can be stored)
Positioning method	RTK or DGPS
Position correction method	Arbitrarily selectable

7. Summary of verification purposes and results

No.	Verification item	Purpose/evaluation	Results
1	**Priority control operation**	Confirmation of basic operation of "green extension" and "red truncation" Basic operation: Equivalent to or better than infrared beacon control	Implemented priority control ("green extension and "red truncation") Reduction in stop line passing time differences Average -74.7 sec. Reduction of non-passage rate during green extension Average -88.9% Report 1
2	**Control effectiveness**	Confirmation of the effect of travel time reduction by implementing priority control Confirmation of impacts on cross-directional traffic Control effectiveness: Equivalent to or better than infrared beacon control	Reduction of intersection passage time Average 2.1 sec. Reduction of route travel time Average 8.1 sec. Reduction of wasted green extension Average 2.1 sec. Report 2
3	**GNSS accuracy**	Confirmation of location error on selected routes Location error: 10 m or less	Shizuoka City: Less than 10 m Tokyo Waterfront area: Sometimes 10 m or more in multipath environments Report 3
4	**Delay time**	Validation against the measurement cycle Communication and processing delay time from OBU to traffic light: less than 1 sec.	281 msec (Max. 960 msec.)
5	**Bus priority control operation when multiple buses pass**	Confirmation of operation when buses continuously approach Deceleration when stopping: 1.96m/s² (0.2G) or less	Maximum deceleration when bus stops 0.83m/s² (0.09G)
6	**Priority control conditions**	Confirmation of operation with the bus route when congestion in the intersecting direction extends. Priority control implementation is cancelled when the congestion length in the intersecting direction exceeds the set value.	Implemented cancellation of priority control at or above the set value (Confirmed cancellation at 100 m or longer against the set value of 100 m.)

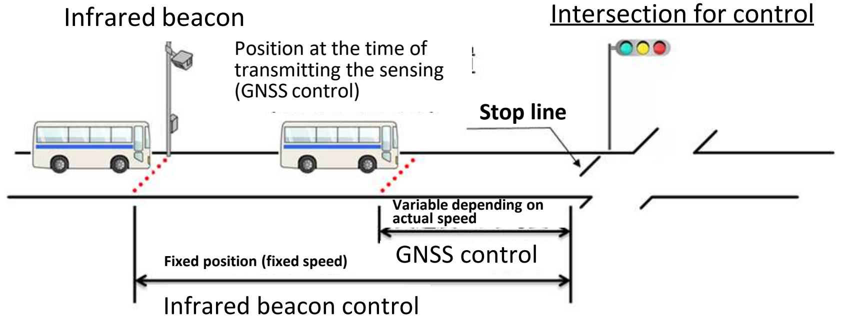
Verification results confirmed that the control effect is equivalent or better than the existing infrared beacon control.

8.1 Verification results [Report 1] Priority control operation (1/2)

Comparison of infrared beacon-based control and GNSS-based control

Condition: Weekdays 09:00 – 16:00 (during less congested hours)

Reduction of arrival time error
- Evaluation of arrival time errors based on differences in passing through stop lines at target intersections.
- Evaluation of priority signal control implementation rate
- Evaluation of non-passage rate during green extension



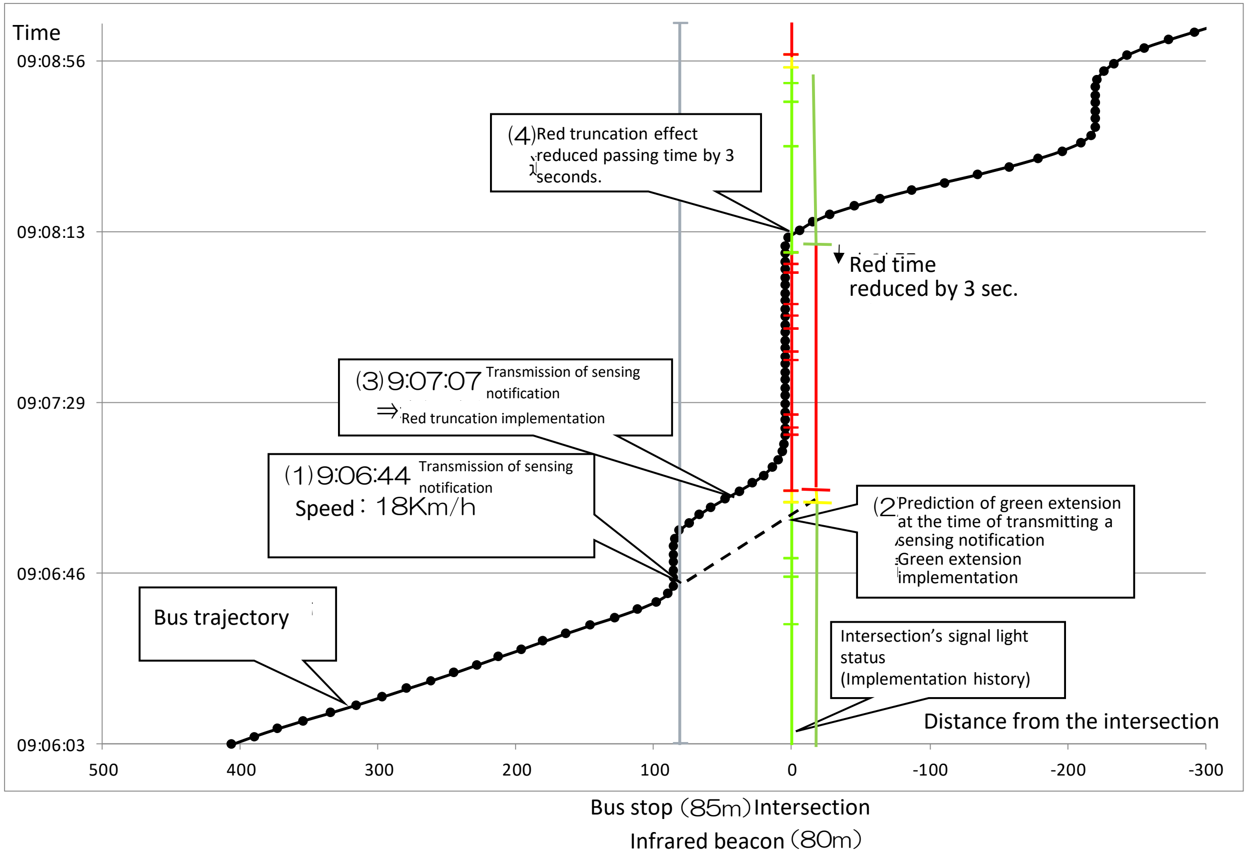
	Number of measurements	Stop line passage difference (sec.)			PTPS control implementation status						
		Average value	Maximum value	Minimum value	Number of control implementations	Control implementation rate	Number of green extensions	Green extension implementation rate	Red truncation implementation rate	Number of non-passages during green extension	Rate of non-passages during green extension
Infrared beacon control	539	21.0	105.0	0.0	140	26.0%	67	12.4%	73	6	9.0%
GNSS control	592	18.9	91.0	0.0	187	31.6%	87	14.7%	100	7	8.0%
Comparison results	—	-2.1	-14.0	0.0	—	5.6	20	2.3	27	1.0	-1.0

- GNSS-based control **reduces time error by predicting arrival time using actual vehicle speed every 2 seconds.**
- Bus arrival time differences: Differences in passing through the stop line (differences between the predicted arrival time at the stop line and the actual arrival time)
  => Comparison results: Reduction of average 2.1 sec. and maximum 14.0 sec.
- Priority control implementation status: Control implementation rate (Number of control implementations/number of measurements)
  => Comparison result Improvement of 5.6 points
- Red truncation implementation status: Number of red truncation implementations
  => Comparison results: Improvement of 27 times of implementation **(Cases are introduced on the next page)**
- Bus non-passage rate: Rate of non-passages during green extension (Number of non-passages during green extension/Number of green extensions implemented) => Comparison results : Improvement of 1.0 point

8.2 Verification results [Report 1] Priority control operation (1/2)

[Case] **Additional** priority control **operation** after the bus stops at a bus stop close to an intersection (a unique feature of GNSS-based control)

- Infrared beacon control cannot perform additional operation because the bus location after passing the beacon cannot be determined.
- GNSS control can perform additional operation of red truncation, because it is able to know that the bus has not yet passed through the intersection.



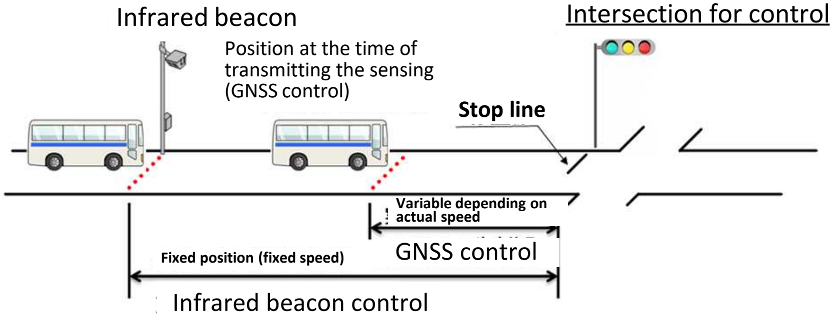
The additional implementation of red truncation reduced intersection passing time of buses by 3 seconds.

8.3 Verification results [Report 1] Priority control operation (2/2)

Comparison of infrared beacon-based control and GNSS-based control

Condition: Weekdays 07:00 – 09:00 (during congested hours) <u>Simulation results</u>

<u>“Simulation used actual traffic volume data”</u>



Reduction of arrival time error

- Evaluation of arrival time errors based on differences in passing through stop lines at target intersections.
- Evaluation of priority signal control implementation rate
- Evaluation of non-passage rate during green extension

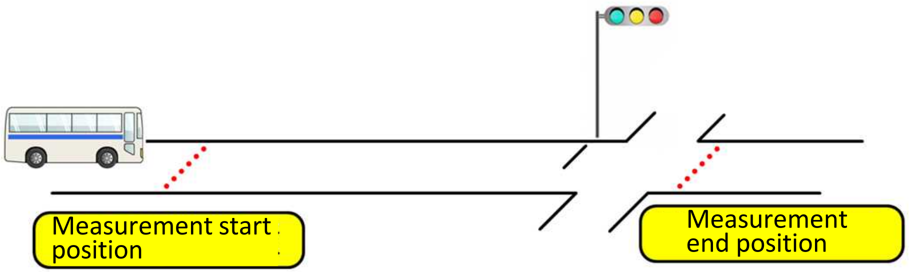
	Number of measurements	Stop line passage difference (sec.)			PTPS control implementation status						
		Average value	Maximum value	Minimum value	Number of control implementations	Control implementation rate	Number of green extensions	Green extension implementation rate	Red truncation implementation rate	Number of non-passages during green extension	Rate of non-passages during green extension
Infrared beacon control	133	88.1	202.6	1.3	32	24.1%	10	7.5%	22	10	100.0%
GNSS control	140	13.4	123.7	2.2	40	28.6%	9	6.4%	31	1	11.1%
Comparison results	—	-74.7	-78.9	0.9	—	4.5	-1	-1.1	9	-9	-88.9

- GNSS-based control **<u>reduces time error by predicting arrival time using actual vehicle speed every 2 seconds.</u>**
- Bus arrival time differences: Differences in passing through the stop line (differences between the predicted arrival time at the stop line and the actual arrival time)
  => Comparison results: Reduction of 74.7 sec. in average value and 78.9 sec. in maximum value
- Priority control implementation status: Control implementation rate (Number of control implementations/number of measurements)
  => Comparison result Improvement of 4.5 points
- Red truncation implementation status: Number of red truncation implementations
  => Comparison results: Improvement of 9 times of implementation
- Bus non-passage rate: Rate of non-passages during green extension (Number of non-passages during green extension/Number of green extensions implemented) => Comparison results : Improvement of 88.9 points

8.4 Verification results [Report 2] Control effectiveness

Comparison of the infrared beacon-based control and the GNSS-based control

Decrease in route travel time
- Evaluation of intersection passage time (between measurement start position and measurement end position) (4 target intersections)
- Route travel time is evaluated by accumulating the passage time at the target intersections. (3 target intersections on an inbound line)



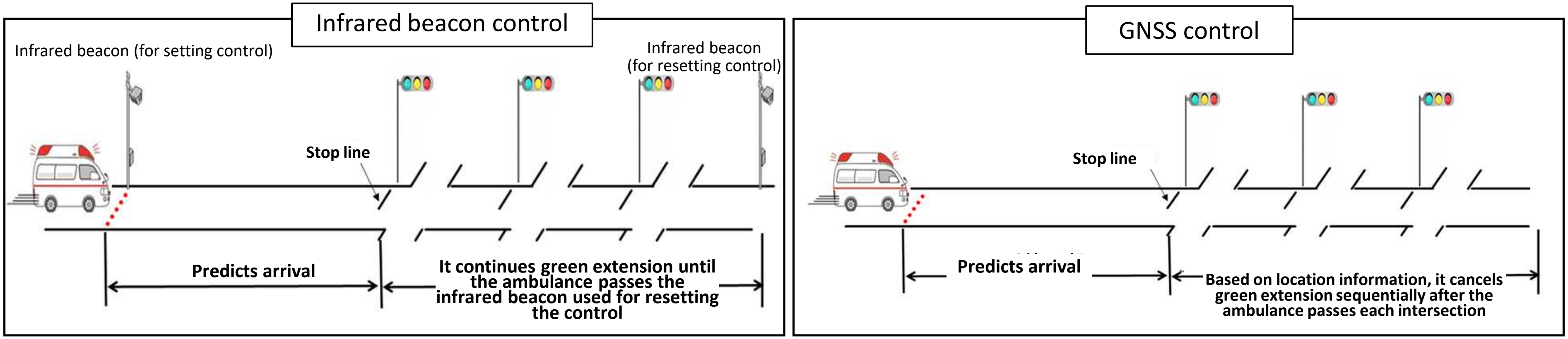
		Number of measurements	Intersection passage time (sec.)			Route travel time (Accumulation of intersections)		
			Average value	Maximum value	Minimum value	Average value	Maximum value	Minimum value
Infrared beacon control		539	34.1	104.1	7.7	102.6	245.5	33.3
GNSS control	Sec.	592	32.0	87.8	8.0	94.4	235.0	34.4
Comparison results	秒	—	-2.1	-16.3	0.3	-8.1	-10.5	1.1
	%	—	-6.7	-18.6	3.8	-8.6	-4.5	3.2

GNSS **control improves the priority control implementation rate and the rate of passing through intersections within the green time by predicting arrivals every 2 seconds using the actual vehicle speed**
- Intersection passing time: (GNSS control – Infrared beacon control)
  => Comparison results: Decrease of 2.1 sec. (6.7%) in average value, 16.3 sec. (18.6%) in maximum value
- Route travel time: (GNSS control – Infrared beacon control)
  => Comparison results: Decrease of 8.1 sec. (8.6%) in average value, 10.5 sec. (4.5%) in maximum value

8.5 Verification results [Report 2] Control effectiveness

The GNSS control senses the passage of an ambulance through an intersection and cancels the green extension control (a function unique to GNSS control).

- The infrared beacon control cancels the green extension control after an ambulance passes under an infrared beacon used for resetting the control which is located ahead of multiple intersections.
- The GNSS control is able to cancel the green extension control each time an ambulance passes through an intersection because it can recognize the position of the ambulance.



	Number of measurements	FAST control implementation status		
		Number of implementations	Number of green extensions	Wasted green time (average value)
Infrared beacon control	180	42.0	35.0	5.0
GNSS control	165	40.0	33.0	2.9
Comparison results	—	—	—	-2.1

- Reduction of wasted green time (GNSS control – Infrared beacon control)
  Because GNSS can determine the location of an ambulance, the GNSS control cancels the green light extension control immediately after the ambulance passes through the intersection.
  => Comparison results: Average decrease of 2.1 seconds

8.6 Verification results [Report 3] GNSS accuracy

Verification of GNSS accuracy in different environments in Shizuoka City and the Tokyo waterfront area

	Shizuoka City	**Tokyo waterfront area**
Environment		
	Easy to receive GNSS satellite signals stably	**Includes highway underpasses and environments with a high density of buildings**
Horizontal position error	• **<u>Confirmed that the positional error within the verification route is 10 m or less, which is the target performance</u>** • The error outside the verification route could be 10 m or greater due to multipath.	The error could be 10 m or greater in the multipath environment.
(Reference) Vertical position error	• Confirmed that the error within the verification route is smaller than ±10 m. • The error outside the verification route could be 10 m or greater due to multipath.	

Horizontal position error and vertical position error of 10 m or greater occur due to "continuous multipath environment" or "stopping in multipath environment"
=> When selecting routes, measures need to be considered for sections that are susceptible to multipath environments.

9.1 Cost comparison between infrared beacon control and GNSS control

Comparison based on the system configuration of the infrared beacon control and the GNSS control verified in the Shizuoka City demonstration experiment.
The results are shown as the ratio of costs of the GNSS control when the infrared beacon control is set at 100%.

[Estimation conditions] (Approximate average number of units per prefecture in Japan)

- Number of vehicles on which the OBU is installed => Bus: 300, ambulance: 200
- Number of intersections where the priority controls are implemented => Bus priority control: 100 intersections, Emergency vehicle priority control: 350 intersections
- Period of use => 10 years (From useful life of telecommunications equipment)

(1) Each prefectural police

Unit [%]

Item	Bus priority			Emergency vehicle priority		
	Infrared beacon (1)	GNSS (2)	Difference (3) [(2)-(1)]	Infrared beacon (1)	GNSS (2)	Difference (3)[(2)-(1)]
Initial	100	20	△80	100	17	△83
Running	100	4	△96	100	3	△97
Total	**100**	**15**	**△85**	**100**	**13**	**△87**

(2) Each bus operator

Unit [%]

Item	Bus priority		
	Infrared beacon (1)	GNSS (2)	Difference (3) [(2)-(1)]
Initial	100	101	1
Running	100	1,933	1,833
Total	**100**	**312**	**212**

(3) Each fire department

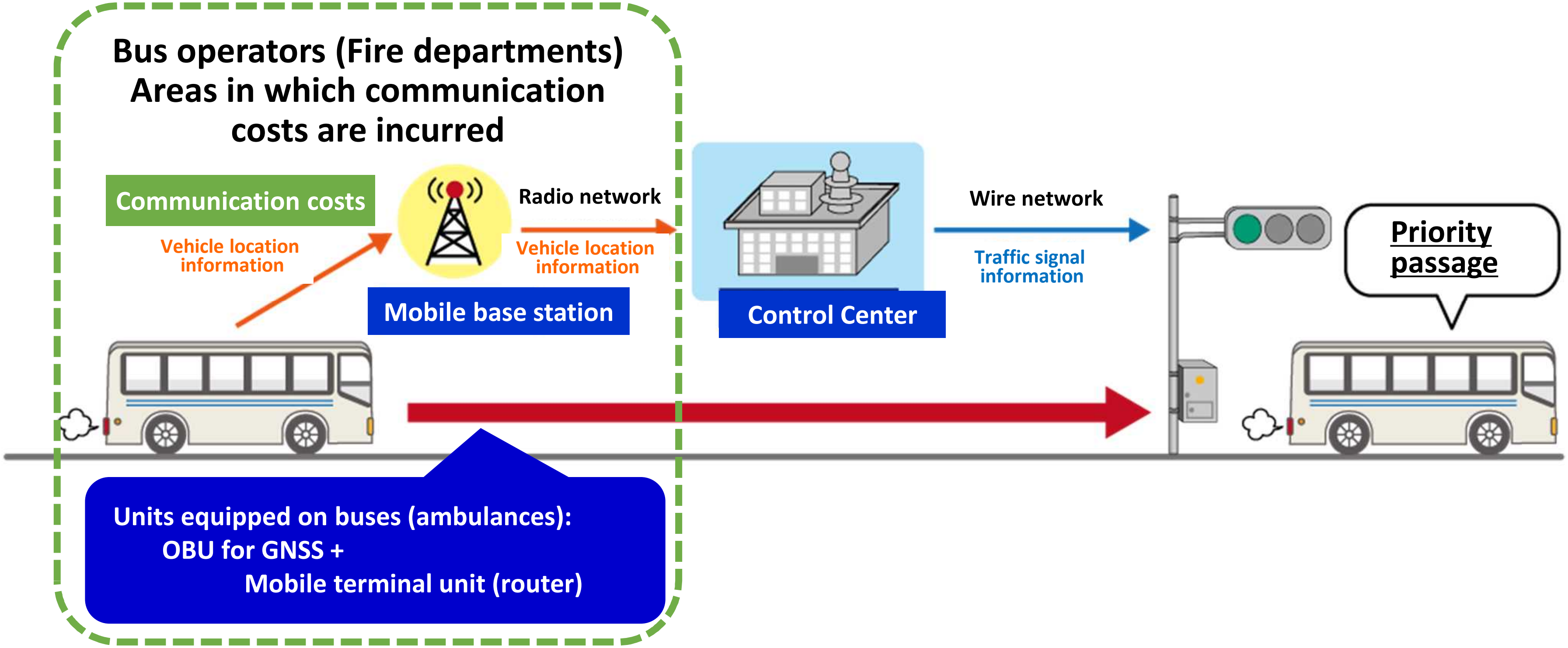
Unit [%]

Item	Bus priority		
	Infrared beacon (1)	GNSS (2)	Difference (3) [(2)-(1)]
Initial	100	101	1
Running	100	1,933	1,833
Total	**100**	**246**	**146**

The issue is to reduce new communication costs (higher running costs) incurred by bus operators and fire departments.

9.2 Installation cost estimation　Communication costs of GNSS OBU equipped on buses

1. Areas in which communication costs are incurred



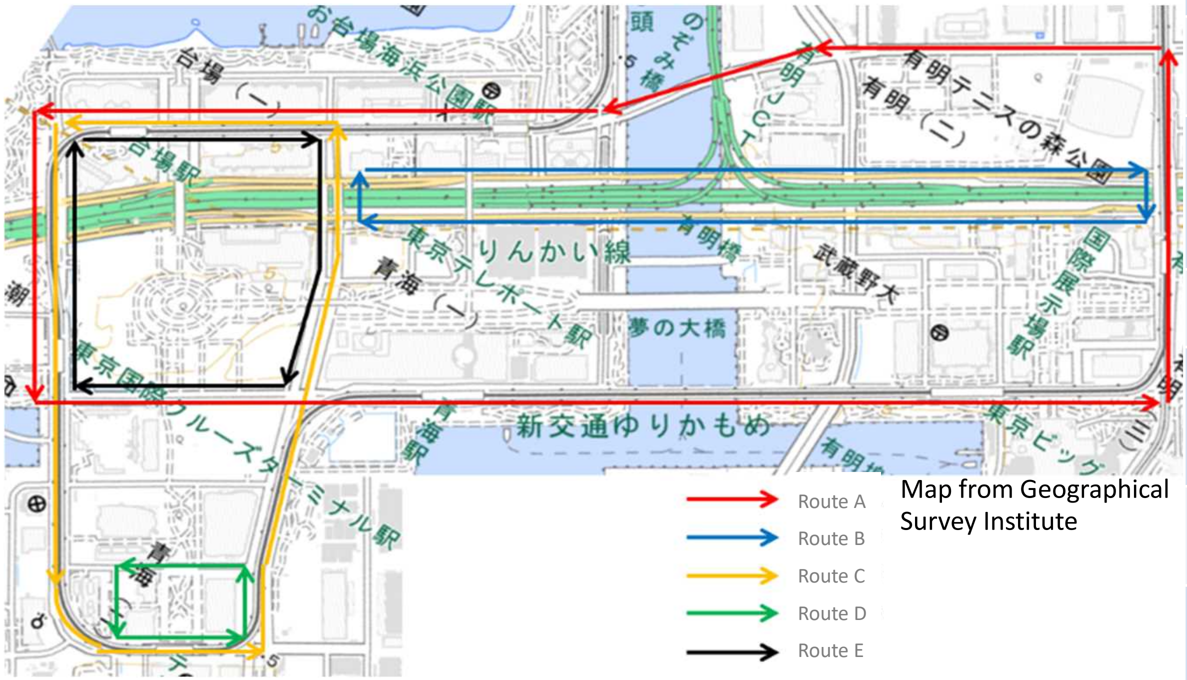
2. Communication costs (per 1 GNSS OBU)

Communication cost details	Amount	Remarks
Contract administration fee	**About 3,000 yen**	**Initial line activation cost**
Purchase of mobile terminal unit (router)	**About 25,000 yen**	
Mobile line (7GB plan)	**About 2,000/month**	**Monthly fee after the line is activated**

※Communication cost in the installation cost estimation includes the initial cost at the time of line activation.

10. Overview of the experiment to deliver location information of simulated emergency vehicles

An experiment to deliver location information of simulated emergency vehicles was conducted in the SIP Automated Driving "Tokyo Waterfront area demonstration experiment" which was implemented separately.



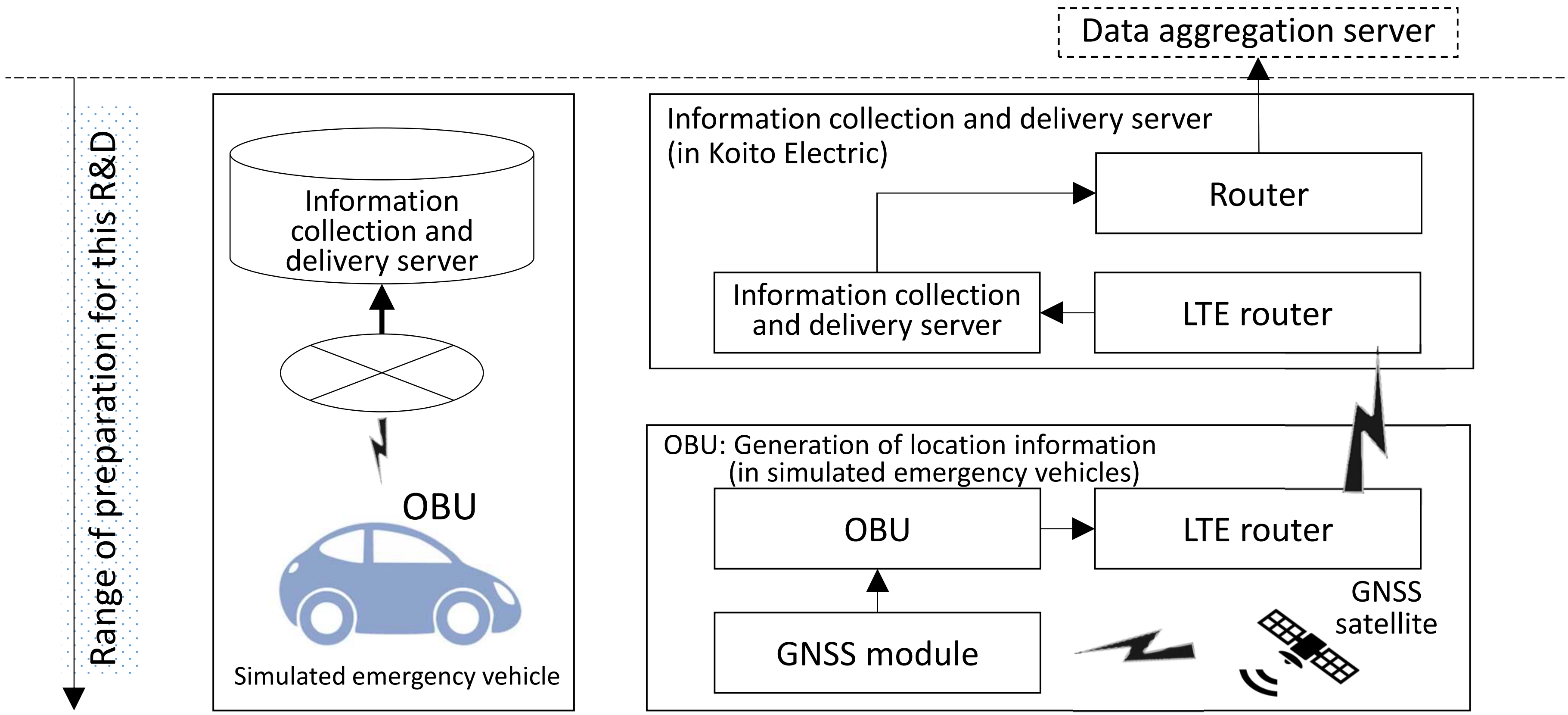
Map from Geographical Survey Institute

Item	Content
Purpose	Verification of information provision to automated driving vehicles, etc.
Location	The new Tokyo waterfront subcenter district, Tokyo
Period	10 weekdays during the period from January 10 to 21, 2010
Time	From 10:00 to 16:00
Number of OBUs	1 on-board unit on each of the two simulated emergency vehicles
Travel route	5 routes from route A to E
Collection cycle	Every 2 seconds

As one of the use cases of providing a diversity of traffic environmental information (traffic signal information, traffic congestion information by lane, etc.) over a wide area, the location information of emergency vehicles was provided in cooperation with the V2N data distribution project, which is an aggregated project in another SIP program.

11. Overview of the system configuration for the experiment to deliver location information of simulated emergency vehicles

In this experiment, the results of this R&D project was utilized by mounting the “OBUs” developed for priority signal control on simulated emergency vehicles, and by preparing and installing the “information collection and delivery server” as follows which was diverted from the operation monitoring unit.



Connection image diagram

System configuration diagram

The delivery and utilization of the location information by automated driving vehicles were confirmed with the confirmation screen (the dynamic map viewer) which is linked with the 3D maps equipped on automated driving vehicles.

This report documents the results of Cross-ministerial Strategic Innovation Promotion Program (SIP) 2nd Phase, Automated Driving for Universal Services (SIP-adus, NEDO management number: JPNP18012) that was implemented by the Cabinet Office and was served by the New Energy and Industrial Technology Development Organization (NEDO) as a secretariat.