GPS Signal Transmission Interval Optimization in Relay-Type GPS

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***Abstract*— Relay-Type GPS (Global Positioning System) has been proposed in order to improve the GPS positioning errors in urban areas, where many tall buildings block GPS signals. In Relay-Type GPS, it has been assumed popular mobile terminals around a target GPS receiver. They are called G-MTs. G-MTs transmit their own position information via the same GPS signal format always. it is necessary for them to transmit their own position information intermittently with certain intervals in terms of their battery power consumptions. In this paper, we optimize the GPS signal transmission interval of G-MTs in Nishi-Shinjuku area, Tokyo. We evaluate the probability of the time at that the target GPS receiver receives four or more GPS signals directly from both GPS satellites and G-MTs is defined as "the direct wave receiving time probability." The simulation results show that the longest interval with the direct wave receiving time probability of 100% is 13 minutes in Nishi-Shinjuku area. Moreover, for an example, when the CDF (Cumulative Distribution Function) of the positioning error is 70%, the positioning error of the Relay-Type GPS becomes 173.86m with the optimal interval of 13 minutes. This is 68.41m shorter than that of the conventional scheme using only GPS satellites.**

Keywords*— GPS, Positioning error, Relay-Type GPS, GPS signal transmission interval

I. Introduction

In recent years, Global Positioning System (GPS)[1] has become a worldwide positioning system. Although it must require the reception of GPS signals from four or more GPS satellites, it is difficult to receive GPS signals from more than four GPS satellites in urban areas with many tall buildings. To solve this problem, Relay-Type GPS[2] has been proposed to improve GPS positioning errors in urban areas. In Relay-Type GPS, it is possible to calculate target GPS receivers position with assistances of many mobile terminals around them. They are called G-MTs[2] which transmit their own position information via the same GPS signal format always. However, since Relay-Type GPS assumes smartphones or others such mobile devices as the G-MTs transmitting their own positioning information via the same GPS signal format always, it is necessary to transmit their own positions information intermittently with certain intervals in terms of their battery power consumptions. However, if G-MTs would transmit GPS signals intermittently, the number of GPS signals received simultaneously at the target GPS receiver would be decreased.

In this paper, the probability of the time that the target GPS receiver receives four or more GPS signals directly from both GPS satellites and G-MTs is defined as "the direct wave receiving time probability." It is clarified that the optimum GPS signal transmission interval of G-MTs achieving 100% of the direct wave receiving time probability in Nishi-Shinjuku area, metropolitan Tokyo. The Nishi-Shinjuku area is a 500m square area around Kogakuin University, including the west side of Shinjuku Station. Moreover, we evaluate the CDF (Cumulative Distribution Function) of positioning errors at the target GPS receiver with the optimum G-MTs transmission interval. When CDF is 70%, the positioning error of the Relay-Type GPS becomes 173.86m with the optimal interval of 13 minutes. This is 68.41m shorter than that using only GPS satellites.

II. Global Positioning System(GPS)[1]

It is necessary to receive GPS signals from at least four GPS satellites for latitude, longitude, altitude, and time. However, GPS positioning in urban areas is sometimes impossible due to obstacles such as tall buildings. GPS problem in an urban area is shown in Fig.1.

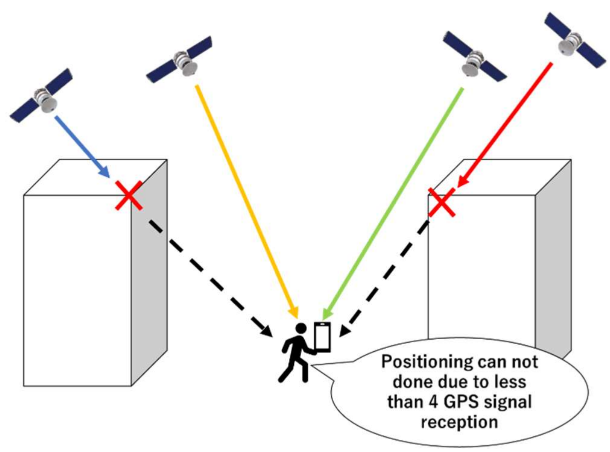


Fig.1 GPS problem in an urban area.

III. Relay-Type GPS[2]

Relay-Type GPS[2] has been proposed to solve the problem described in Chapter II. Overview of Relay-Type GPS is shown in Fig. 2. The operation sequence of the Relay-Type GPS is shown below.

① In Relay-Type GPS, a large number of mobile terminals are used, existing in the area. Smartphones, tablets and laptop computers so on are assumed as mobile terminals because they are currently widely used. The mobile terminals transmitting the GPS signals are called G-MTs (mobile terminal transmits GPS signals) in this paper.

② G-MTs do not hold their own position information in advance, so positionings are performed by using only GPS satellites.

③ G-MTs transmit their own position information via the same GPS format always.

④ Finally, the target GPS receiver simply receives GPS signals without changing positioning algorithm, so it performs positioning using GPS signals from both GPS satellites and G-MTs.

Although smartphones, tablets, notebook PCs, and other mobile terminals that are assumed to be used as G-MTs do not currently have GPS signal transmission functions, small GPS signal transmission modules have been developed, and an additional new GPS signal transmission functions will not lead to larger hardware of the mobile terminals[3].

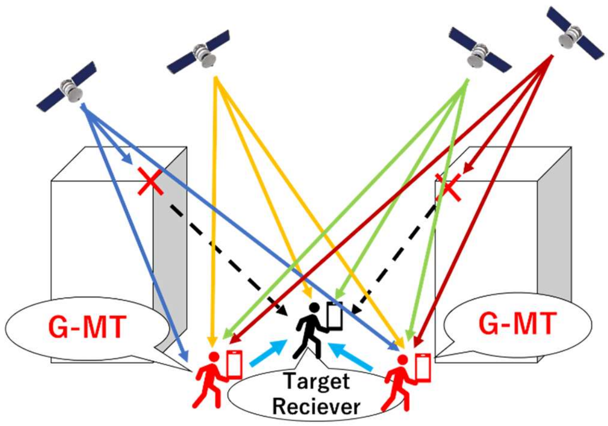


Fig.2 Overview of Relay-Type GPS.

Reference [2] shows that Relay-Type GPS complements the number of GPS satellites available for reception and improves positioning error by 60 m on average compared to that by using GPS satellites only.

IV. ISSUE FOR RELAY-TYPE GPS

In the studies so far, it has been assumed that G-MTs always transmit their own position information like GPS satellites [2]. However, as described in Chapter III, G-MTs are assumed to be popular mobile terminals, it is not desirable for the G-MTs to transmit signals always because of their power consumption. Therefore, it is necessary for the G-MTs to transmit their own positioning information intermittently at certain intervals.

However, if the G-MTs transmit GPS signals intermittently, the number of GPS signals received by the target GPS receiver at a time would be decreased. So far, the GPS signal transmission interval optimization of G-MTs has been limited to the investigation of a typical 16-billdings model[3].

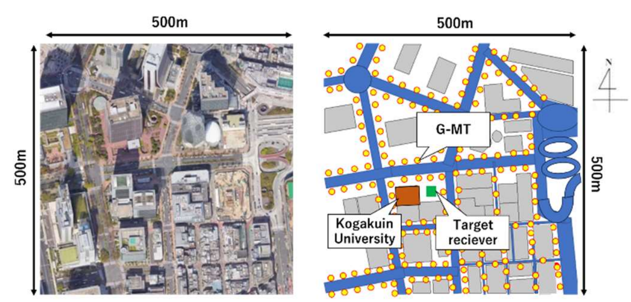
In this paper, the probability of the time that the target GPS receiver receives four or more GPS signals directly from both GPS satellites and G-MTs is defined as "the direct wave receiving time probability." Simulation model incorporates a real environment of Nishi-Shinjuku, and we consider the actual population density of Nishi-Shinjuku 1-chome[4]. The purpose of this study is to optimize the signal transmission interval of G-MTs transmitting GPS signals. The improvements of the positioning error of the target GPS receiver are evaluated quantitatively with an optimal interval of the GPS signal transmission from the G-MTs.

V. SIMULATION MODEL

Fig. 3 shows Nishi-Shinjuku model. (a) is an aerial photograph and (b) is a simulation model, respectively. Moreover, in Fig.3(b), the allocations of the G-MTs are also indicated. Table 1 shows the simulation parameters.

The Nishi-Shinjuku area is a 500m square area around Kogakuin University, including the west side of Shinjuku Station. The number of G-MTs is based on the daytime population density in reference [4]. But it includes both inside and outside of the buildings. Therefore, the people inside of the buildings are eliminated in this case, and 1100 of G-MTs are allocated on the sidewalks at the streets, outside of the buildings. The target GPS receiver is allocated in front of Kogakuin University, shown in a green mark in Fig. 3(b). Under these conditions, we evaluated positioning error performances of the target GPS receiver. The target GPS receiver uses the GPS signals from the GPS satellites as well as the G-MTs that are within the line of sight from the target GPS receiver.

In this paper, the evaluation is based on a single positioning method in order to quantitatively evaluate the pure improvement effect of the proposed method only. Therefore, the residual error is relatively large, but this error can be improved by relative positioning techniques such as A-GPS[5]. Combined evaluation is an item for future study.



(a) aerial photograph (b) simulation model

Fig.3 Nishi-Shinjuku model.

Table 1 Simulation parameters

Simulation area	500m × 500m
Number of GPS satellites	32
Daytime population density	212,800/㎢ [4]
Number of G-MT	1100
GPS Signal transmission interval	0 to 40 minutes
Simulation time	24 hours

VI. Simulation Result

First, the longest interval at which the direct wave receiving time probability of 100% is considered to be the optimal interval.

Fig.4 shows GPS signal transmission interval versus direct wave receiving time probability. In Fig.4, the direct wave receiving time probability decreases as the interval is increased. The reason for this may be that the number of G-MTs transmitting GPS signals simultaneously becomes smaller. This leads lower direct wave receiving time probabilities. The direct wave receiving time probability for GPS only is about 18%. On the other hand, the Relay-Type GPS always outperforms GPS only, even when GPS signal transmission interval is up to 40 minutes set to G-MTs. The longest interval with a direct wave receiving time probability rate of 100% is 13 minutes. Therefore that the optimal interval is decided to be 13 minutes.

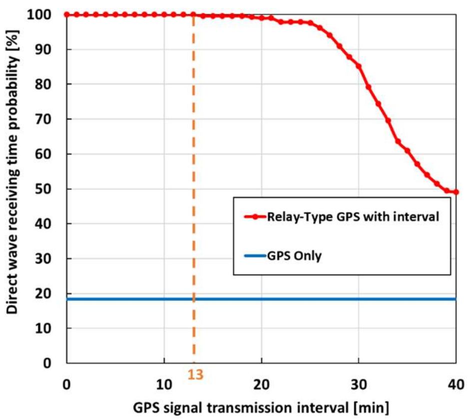


Fig.4 GPS signal transmission interval versus direct wave receiving time probability.

Next, the positioning error of the target GPS receiver is then evaluated when the optimal interval is applied. Fig.5 shows Distribution of positioning results for target GPS receivers.

The left side figure shows the case by using GPS satellites only, and the right side figure shows the case by also using G-MTs with the optimal interval of 13 minutes in addition to GPS satellites. From these figures, the distribution of positioning results with G-MTs are more concentrated to the true coordinates of the target GPS receiver than those by GPS satellite only.

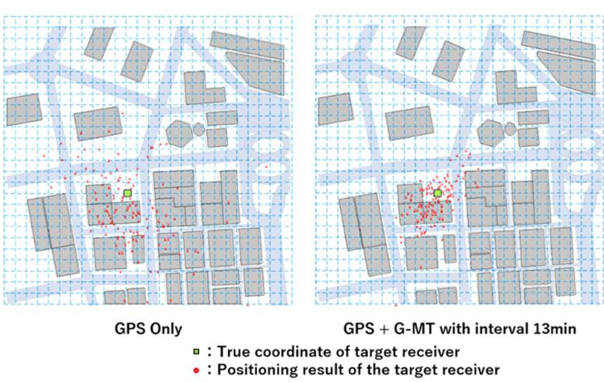


Fig.5 Distribution of positioning results for target GPS receivers.

Next, Fig.6 shows the positioning error CDF characteristics of Relay-Type GPS with the optimal interval of GPS signal transmission. The horizontal axis shows the positioning error of the target GPS receiver and the vertical axis shows the CDF of the positioning error. The red line is the CDF for Relay-Type GPS and the blue line is the CDF for GPS only.

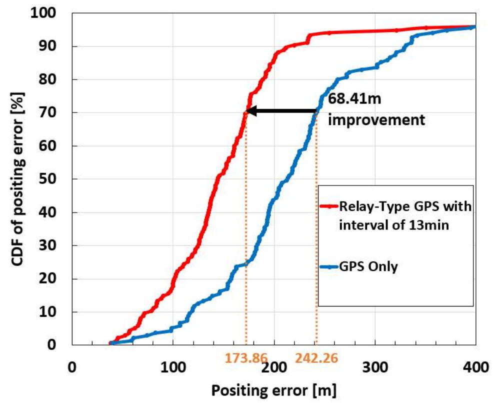


Fig.6 Positioning error CDF characteristics of Relay-Type GPS with optimal interval of GPS signal transmission.

In Fig.6, for example, when the CDF of the positioning error is 70%, the positioning error by using GPS satellites only is 242.26 m. On the other hand, the positioning error of the Relay-Type GPS with interval of 13minutes becomes 173.86 m of the positioning error. This is 68.41 m improvement of the positioning error in Nishi-Shinjuku model.

VII. Conclusion

In this paper, we have optimizes the GPS signal transmission interval of G-MTs in Relay-Type GPS. The evaluations in Nishi-Shinjuku area have performed as a feasibility study. The simulation results have shown that the longest interval with a 100% direct wave receiving time probability is 13 minutes. Relay-Type GPS with the optimum interval of 13 minutes can obtain 242.26 m of the positioning error, less than 68.41m compared to that by using GPS satellites only. Evaluation combining relative positioning and other technologies is an item for future study.

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