A Novel Analysis Method on Satellite Linkage to a Vehicle based on Cost-effective GPS Signal Data Gathering

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***Abstract*— A new scheme is proposed and demonstrated where satellite visibility viewed from running vehicle is economically and effectively evaluated with such low cost GPS receivers like automobiles are equipped with. Our preliminary experiment articulated even economical L1 C/A GPS receivers can create enough precise database of ground feature blockage if only two statistical parameters we propose are adequately set. The geographical characteristics of satellite visibility are demonstrated in this scheme. A blockage database will be created in the cooperation with the government and the civil in the style of a low-cost and large-scale automatic survey. The blockage database will be cost-effective and useful in future's vehicular satellite communications, as it allows predicting the linkage block and achieving an adequate handover, only based on the economical database which is simply created by gathering the signal data not having contributed to the positioning the prevailing L1-band C/A GPS receivers.**

Keywords-component; Land Vehicle, Satellite Communications, Global Positioning System, Visibility, Blockage, Handover

I. INTRODUCTION

As one of high elevation satellite systems for land mobile satellite communications, QZSS (Quasi-Zenith Satellite System) has been discussed. QZSS uses inclined geostationary orbits. When observed from an adequate service area such like middle latitude areas, a satellite of QZSS traces a "figure of eight" pattern in the sky and provides elevation angle s as high as 70 degrees or more for eight hours a day. Thus, when three or more satellites are placed in adequate orbits, minimum elevation angle of as high as 70 degrees or more are available continuously. In this background it comes to be important to comprehend and evaluate the status quo of blocking by ground features such like buildings or mountains while vehicles drive on actual roads. However this was no adequate method to realize the demand in cost effective and simple way. In this context, a simple method is introduced to evaluate the satellite visibility at the sky above vehicles moving in real roads. A GPS receiver with a recorder on the vehicle collects the signal strength data of each GPS satellite with elevation angle of more than 0 degree. It also collects the azimuth and elevation angles of the GPS satellites. After collecting the data, the projected area in the sky is estimated in which the probability of signal blocking is less than 5 percent for the entire evaluation period using a reasonable threshold for the signal strength.

II. DATA COLLECTION

The specifications of Antenna in this experiment are as follows: A micro-stripped plane antenna of Right-Handed Circular Polarization (RHCP) is used, which has its sensitivity of -130 dBm. The size and weight is 54 (w) x 15.5 (H) x 58 (D) mm and 0.12kg respectively. The specifications of GPS receiver in this experiment are as follows: L1-band 1575.42MHz Coarse and Acquisition (C/A) code GPS standard positioning service receiver is used, which have parallel tracking ability of eight channels. The weight is about 0.55kg. The output is created at every second and it includes latitude, longitude, height, GPS Time, orientation of the vehicle, satellite ID, satellite elevation, satellite azimuth, signal strength. These antenna and receiver specifications are one of the most common specifications for the civil use GPS apparatus.

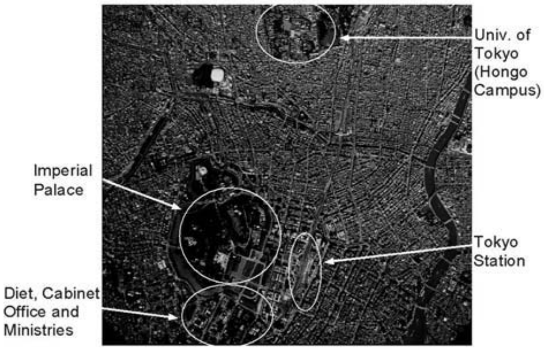

Figure 1. The Photograph of taken from an airplane [The heart of Tokyo]

With the road map matching mechanism, acceleration and velocity detectors, and a gyroscope, the GPS chipset made by Trimble is used. The apparatus used is one of most prevailing compositions for the civil use for vehicle navigation system based on L1 C/A GPS satellite signals. As the latest position and almanac data are stored as well, warm start condition is presumed whenever the vehicle starts the experiment. Latitude, longitude, altitude, GPS time and orientation of the vehicle are recorded every second, as well as GPS satellite ID, signal strength, elevation and azimuth as a result of positioning calculations.

III. DATA INTEGRATION

A. *Calibration of Signal Strength*

A preliminary calibration was carried out on output value of signal strength with a GPS signal generator, the GPS antenna and the GPS receiver described above. The correspondence between the receivers' output value and absolute power level right after 3dBi GPS antenna is shown in Figure 2. The horizontal axis is the unit which is specific to the apparatus model. The vertical axis is the estimated power level right after 3dBi GPS antenna. The conversion formula from relative value to absolute value was created in this process. In Figure 2, the upper curve is the data with two extension cables and the lower curve is data with no extension cables.

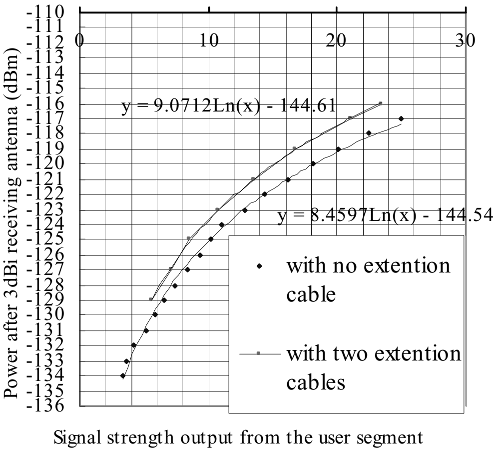

Figure 2. Calibration of signal strength output

B. *Coordinate in the Sky Hemisphere*

In this study, the sky hemisphere is divided into partly overlapping numerous small segments or circles in this study. Each circle has its center which corresponds to one of intersections of those great circles which pass both the zenith and nadir increasing its azimuth by 5 degrees and the concentric elevation contour circles increasing its elevation by 5 degrees. The length of its radius of each small circle is set to have the angular distance of 5 degrees. The angle distance between two points in the sky hemisphere, (a1, e1) and (a2, e2) in Horizon Coordinate System (azimuth, elevation), is:

$$\mathrm{acos}\{\cos(e1) * \cos(e2) * \cos(a1-a2) + \sin(e1) * \sin(e2)\}$$

Many GPS satellite signal data which happen to fall within the small circle whose radius has the angular distance of 5 degree from the one of centers described above are integrated as the values to represent the center orientation. GPS signal strength's dependency on GPS satellite elevation [1], which is shown in Figure 3, is also considered and properly corrected.

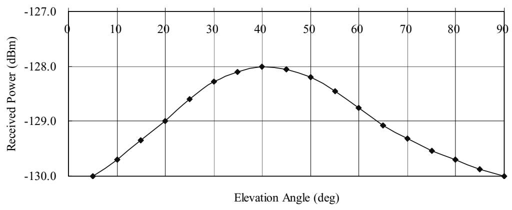

Figure 3. Minimum power of the near-ground user-received L1 signal as a function of satellite elevation

C. *Ratio of Inevitable Lock off due to Receiver Nature*

As this experiment uses an ordinary GPS L1 receiver not for any dedicated purpose but for the common use, the spontaneous lock off is a natural phenomenon. The ratio was measured that the power was less than the expected minimum power (-130dBm) with the path between the satellite and the antenna completely clear (shown as "Satellite in Visible State"). The ratio, f, was estimated as about 0.158 by the preliminary experiment as shown in Figure 4. On the other hand, the ratio that that the power was less than the expected minimum power with the path between the satellite and the receiver completely blocked (shown as "Satellite in Blocked State") is about 1.0 as shown in Figure 4.

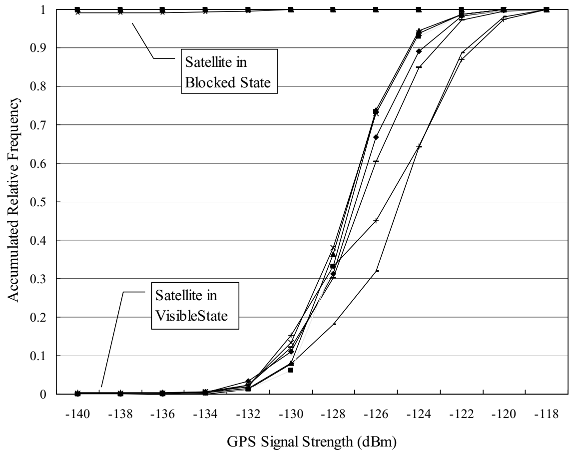

Figure 4. Accumulated Relative Frequency

The experiment is carried out in running situation. In this condition, data at an orientation must be mixture of visible and invisible situations. Therefore the signal strength data at a certain orientation should be considered as a mixture of 100*v percent of visible situation and 100*(1.0-v) percent of invisible situation. In this paper, v of 0.950 is supposed to be a main criterion.

D. *Ratio of Power Levels less than the Value*

When the ratio of the power level less than -130dBm observed from a running vehicle is called r, the relationship of r, v and f should be r = f * v + (1-v). When f is set 0.158 from the previous discussion and v is set 0.950 as described above, r is herein obtained as about 0.200. This means that if -130dBm or less satellite signal strengths ware observed in the probability of 20 percent or a lower probability than it for an orientation relative to the vehicle heading, the orientation is considered to be 95.0 percent visible during the running of the vehicle. Based on the consideration described above, the two thresholds are used to process the many data on GPS signal strength. One threshold is the signal strength of -130 dBm. The other threshold is the accumulated frequency of 0.200. If the form of accumulated frequency curve on signal strength data at an orientation satisfied the constraint composed by these two thresholds, the orientation is considered to be 95.0 percent visible during the running.

E. Evaluation Areas

In three areas the GPS signal strength data was gathered. As a major city, a highway and a small city, the heart of Tokyo, Higashi-Kanto Highway and Kashima city were selected respectively. The locations of the areas are illustrated in Figure 5. The length of the horizontal width of Figure 5 itself corresponds to about 140km long. The left-side driving rule is applied to all three areas.

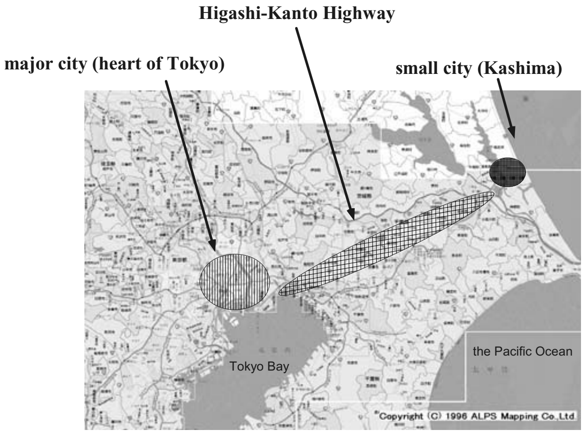

Figure 5. Three Evaluated Areas

F. Data Sampling Periods

In this Experiment, data sampling times are about 110 hours, 127 hours and 50 hours for the major city, the highway and the small city respectively. Those data sampling periods corresponds to more than eight times longer, more than ten times longer, and more than thirty times longer, respectively, than the data sampling periods of the areas in the previous report in Takahashi [2]. As the data is output at every second from the GPS apparatus, the total numbers of the data for statistical analysis are about 396000, about 457200 and about 180000 respectively. The expected values of the numbers of data falling into one of the 1296 small segments created by the grid of azimuth and elevation lines both incrementing by 5 degrees in the sky hemisphere is more than 300, more than 350 and more than 135 respectively.

IV. Methodology – Application Phase

Once the blockage database is built, there emerge many applications in the possible combinations of the blockage database or layer, satellite, stratosphere-platform or celestial movement layer and ground vehicle movement information layer.

A. Point Evaluations

The blockage database can provide communication path existence information in the azimuth elevation coordination at the sky of a ground point on a road. This system may open a door to governance by empowered individuals on sky path resource management. For example, the system enables us to detect illegal buildings which previously were not, blockage effects of foliages by seasons and specific points of multi-path. In this Point Evaluations, the blockage database system can naturally represent the real blockage aspect of the sky hemisphere above the ground point such like the effects of land vehicles running and airplanes flying by the point, which are not taken into account usually as unexpected factors. In this sense, the blockage database allows us to analyze the statistical blockage effects of tall tracks or buses running or sometimes almost crawling in the traffic jams, which is familiar in cities and sometimes highways. In the same sense, it also allows us to evaluate the statistical blockage effects of airplanes departing and touching down from/to a large airport near the point. The blockage system can also consider the blockage effects by overhead architectures of road and railway proper without any special measurement of the size and precise location of them. The precise evaluation of the blockages based on the measurement of those architectures by the height, width and location relative to the road are not so easy. Therefore usually evaluations of blockage effects by those can not be carried out by GIS only. However those effects are so important for vehicular satellite communications that the blockage database which is created in a cost effective way and is able to deal with all blockage features in a consistent principle of superposition will be highly helpful.

In practical senses, the main idea of this research framework is as follows: (1) The sky hemisphere viewed from a ground point is divided into small segments. (2) GPS satellite signal data whose azimuth and elevation is within one of the small segments are regarded as the representative values for the communication path of the small segment. (3) The GPS satellite signals are expected to have a certain reception level even if the attenuation margins, including elevation dependency and rain attenuation, are deducted. If most signal strength data in a small segment are less than the expected level, the segment should be considered to be blocked by obstacles including buildings. A segment, where signal strengths more than the expected level are observed in a higher probability than one certain rate would be considered as a clear path. A small segment, where signal strengths more than the expected level are observed in a lower probability than another certain rate, should be considered to be blocked. A small segment not to be one of those cases should be considered to be indefinite and to be waited for more data. The rates described above should be decided depending on purposes of the blockage database.

B. Area Evaluations

The blockage database system is extendable to the blockage study on a geographically interested area such like a metropolitan area, an urban area and a highway. It would be extendable to a future detailed geographically interested area such like a housing district, business district and industrial district. In this sense, the blockage database has a possibility to provide a useful fact data to promote the researches on the geographical area analysis. In this context, the experimental results are shown in the figures in horizontal coordinate system, each correspond to the data acquired on a highway, in the heart of a metropolitan, and in a urban city. In the drawings, concentric circles represent elevation angles by the five degrees. The radii represent azimuth relative to the heading of the running vehicle by the five degrees. At the elevation angle of 47 degrees, geostationary satellite's location is highlighted. At the elevation range from 70 to 78 degrees, the effective location of QZSS satellites is also highlighted.

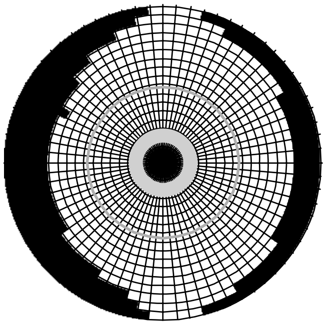

Figure 6. Projection of the sky hemisphere where the blocking probability is less than 5 percent [Highway (Higashi-Kanto Expressway)]

1) Characteristics of Blocking on a Highway

Highways are often bordered by barricades for noise protection, and due to the left-side driving rule in Japan, the effective elevation angle viewed from the vehicle is greater on the left side than on the right. Figure 6 shows that tendency. The blocked region on the left (15 to 30 degrees) is greater than that on the right (5 to 15 degrees). Figure 6 is based on the data taken along a typical Highway, connecting between Tokyo and a small city, about 100km long.

2) Characteristics of Blocking in a Major City

In large cities, except the orientations along and against the heading, satellite visibility is extremely limited especially in both sides. In other words, blocking is expected to be severe due to high-rise buildings on both sides of a vehicle at ground level. Figure 7 indicates this character well. The 95 percent clear path elevation's limit on the graph are closer to the zenith on the left and right (25 to 55 degrees) than at front and rear (10 to 30 degrees). This characteristic may be called metropolis-type blocking. Due to the left-side driving rule in Japan, the effective elevation angle viewed from the vehicle is greater on the left side than on the right. Besides, the graph clearly shows the severer restriction of left side blockage (40 to 50 degrees) than right side (25 to 40 degrees). It is considered to be due to the left side traffic rule in Japan as well. It may be able to be called metropolis-type blocking. Making high-rise buildings has been promoted as a policy of Japanese government.

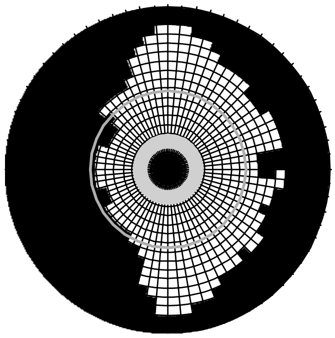

Figure 7. Projection of the sky hemisphere where the blocking probability is less than 5 percent [major city (heart of Tokyo)]

3) Characteristics of Blocking in a Small City

The result in a small city is also characteristic as indicated by Figure 8. It is anticipated that reliable or 95 percent acquisition can be achieved in all directions for geostationary and QZSS satellites. The data of Figure 8 is taken at the small city "Kashima" which has the population of about 62000, located at 100km east from Tokyo. There is no specific blockage tendency which strongly depends on any specific azimuth orientation. This blockage tendency reflects lower artificial buildings and housings and wider roads in the area than the large city.

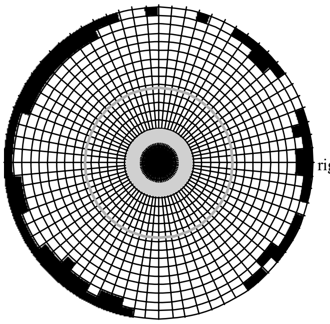

Figure 8. Projection of the sky hemisphere where the blocking probability is less than 5 percent [small city (Kashima)]

Although being simple method, this framework enables us to evaluate the satellite visibility at the sky above vehicles moving in real roads in a city, an expressway and a rural area. There are considered to be geographical patterns of satellites' visibility at the sky above vehicles running in those areas respectively. To be common to any cases, however, QZSS is more suitable for land-mobile satellite communications than a geostationary satellite in terms of fewer blockages by features on the ground.

C. Route Evaluations

This blockage database framework has characteristics extendable for the study on durability of vehicle satellite communication link, as already demonstrated in Takahashi [3], at a specified road in a time span. It has the merit to be able to reflect the real traffic jam and go-stop effects in the roads. This method has another merit to be able to analyze the tendency of the future's vehicle satellite communications based on real satellite signal before the launch. This scheme provides an excellent simulation platform to discuss the feasibility of future's vehicular satellite communication systems and its design choice because it can include the real vehicle movement as well. The histogram study created by Takahashi [3] enables the studies on the parameters abstracted by the fitting of the distribution forms of histogram. Those parameters are considered to be related to building height, road width, and degrees of the traffic jams. The scheme allows us to make the parametric research based on the cycles of anticipation and confirmation at the experiments in other cities or satellites. The blockage database can also support design choice on the vehicular communication satellite system and the best route selection in the route guidance mechanism from the viewpoint of the seamless vehicular satellite communication.

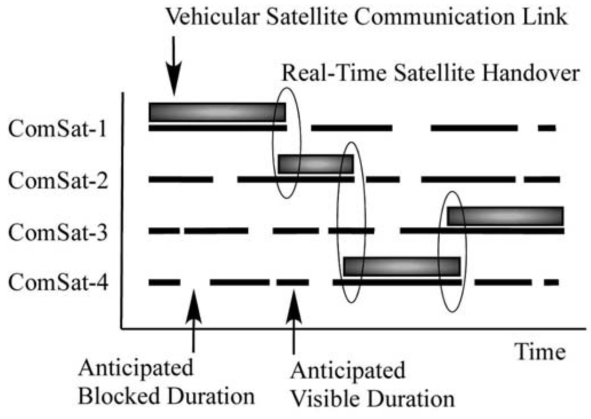

Figure 9. The Concept of Real-Time Handover in Vehicular Satellite Communications by the Blockage Anticipation using the Blockage Database created in this framework

D. Real-Time Handover Scheduling

The blockage database will serve as one of the useful GIS (Geographical Information System) layers. One of its important applications will be the real-time satellite handover control to a running vehicle anticipating the coming blockage on the link between the vehicle and the satellite while the vehicle runs along the guided route generated by its navigation system. It would be especially useful for the activities of rescue vehicles right after the large scale natural disasters which often bring the failure of the terrestrial power supply.

V. Discussion

Today numerous vehicles are equipped with L1-band C/A GPS antennas and receivers. Those almost homogeneous GPS user segments possessing locomotive ability could be taken advantage of as excellent and irreplaceable distributed sensors for the large-scale and low-cost survey for satellite signal blockages in the real roads on the almost all surface of the earth. Thanks to the prevalence of GPS user segments, those sensors has come to be enough accurate to create the blockage map in the each sky hemisphere if only a few statistical parameters we proposes are adequately set. The civil spontaneous activities contribute to create the global database of sky visibility above the real roads. This framework is interesting due to its cost-effective-ness as well as and the feature of citizen participation. As to the cost-effectiveness, the first reason is that almost no additional cost is required except for the slight modification on GPS user segments if any. The data transfer will be supported by the Intelligent Transportation System infrastructure build in near future. The data governance authority should only integrate the gathered data to the blockage database. The second reason is that there is no extra cost for the drivers as the civil spontaneous activities are only required.

For the future work, the followings are considered. Efforts of standardization on the data transfer are required in cooperation with the industrial and government sectors. Further comparative studies of the method to fisheye method are planned. The research on data conversion from L1-band 1.5 GHz to other frequency band, especially issues of knife edge effects on the building blockage, is planned.

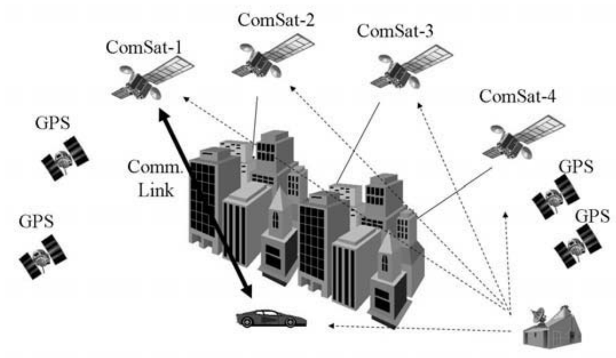

Figure 10. Satellite Visibility Prediction based on Blockage data and Handover Control

VI. Conclusion

A novel scheme is proposed and demonstrated where satellite visibility viewed from running vehicle is economically and effectively evaluated with such low cost GPS receivers like automobiles are equipped with. Our preliminary experiment articulated even economical L1 C/A GPS receivers can create enough precise database of ground feature blockage if only two statistical parameters we propose are adequately set. The geographical characteristics of satellite visibility are demonstrated in this scheme. A blockage database will be created in the cooperation with the government and the civil in the style of a low-cost and large-scale automatic survey. The blockage database will be cost-effective and useful in future's vehicular satellite communications, as it allows predicting the linkage block and achieving an adequate handover, only based on the economical database which is simply created by gathering the signal data not having contributed to the positioning the prevailing L1-band C/A GPS receivers.

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