A Geographical Location Based Satellite Selection Scheme for a Novel Constellation Composed of Quasi-Geostationary Satellites

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Abstract— **In order to realize the dream of global broadband coverage, the need for satellite communication systems has grown rapidly during the last few years. Several Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary(GEO) satellite constellations have been thus proposed in the recent literature. However, these constellations either require a potential number of satellites or are unable to provide data transmission with high elevation angles.**

This paper proposes a new satellite constellation composed of Quasi Geostationary Satellites. The main advantage of the constellation is in its ability to provide global coverage with a significantly small number of satellites while, at the same time, maintaining high elevation angles.

Since end-terminals can be simultaneously covered by plural satellites in the proposed constellation, a scheme is proposed to select the most appropriate satellite for communication. The selection is based on the geographical location information of end-terminals. The efficiency of the proposed scheme is verified through a set of simulations. Simulation results reveal the good performance of the proposed method in reducing the delay, the delay variation, and ultimately improving the overall quality of service.

I. Introduction

New multimedia services require more cost-effective, high-quality, and high-speed telecommunication technologies. Large-scale deployment of these wide-band services in a metropolitan area with a potentially large number of users is a challenging task for terrestrial technologies. Satellite network systems are seen as an attractive solution to realize the vision of a global broadband multimedia infrastructure [1]. This is because of their extensive geographic reach, flexible and rapid deployment features, and inherent multicast capabilities. Furthermore, given the recent advances and ongoing improvements in satellite technologies, broadband satellite based multimedia services are likely to open a promising and strong market for service providers and operators in the near future [2] [3] [4].

In the recent literature, a number of Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary (GEO) satellite constellations have been proposed to provide broadband services. For more than two decades, GEO satellite systems have been used for providing commercial services. They have, however, failed in providing data transmission with high elevation angles over high latitude regions. In Tokyo, for example, the elevation does not exceed 48°. In GEO systems, end-terminals, mainly mobile users, experience consequently frequent cut-offs of propagation signals due to high buildings and mountains. The proposed LEO and MEO satellite constellations require, on the other hand, a large number of satellites for global coverage. They are thus characterized by frequent handover occurrences [5] [6]. Additionally, their satellites can be used for only a short life span .

As a remedy to the above issues, this paper proposes a novel constellation composed of long-life span Quasi-Geostationary Orbit (Quasi-GSO) satellites. The strength of the constellation is in its ability to provide global coverage with a significantly small number of satellites while, at the same time, maintaining high elevation angles.

The architecture of the proposed constellation is dynamic in its nature, yet exhibits significantly less mobility than LEO or MEO constellations. Nevertheless, to deal with issues related to the initial set-up of connections or handover phenomenon, end-terminals should be acquired with the ability of selecting the most appropriate satellite. Applying the baseline satellite selection procedure [7], the most widely used method for research on LEO and MEO satellite constellations, to the proposed constellation results in unnecessarily longer delays and higher levels of delay variation. To deal with such an issue, the coverage area of the constellation is divided into a number of regions and a satellite selection scheme is developed based on information related to the geographical location of end-terminals.

The remainder of this paper is structured as follows. Section II gives a brief description of the Quasi-GSO satellite systems and highlights some of their main merits. The key design philosophy and distinct features that were incorporated in the proposed constellation are presented in Section III. Following this, Section IV portrays in detail the satellite selection scheme proposed for the considered Quasi-Geostationary satellite constellation. In Section V, the proposed satellite selection method is evaluated through a set of simulations. Simulation results are discussed in the same section. The paper concludes in Section VI with a summary recapping the main advantages and achievements of the proposed constellation.

II. Quasi-Geostationary Orbit Satellite System

For more than three decades, satellite systems have been successful in providing some commercial services. Currently, there are two types of broadband satellite systems: low-altitude earth orbit and geostationary satellite systems. The former requires a huge infrastructure investment and has created some doubts on its economical practicality mainly after the recent financial failure of the Iridium system. The latter, on the

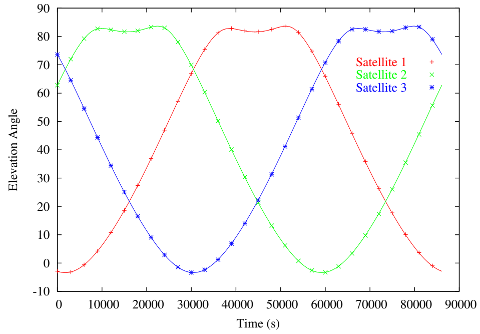


Fig. 1. Elevation angle variation of the three satellites observed from Tokyo

other hand, fails to provide a consistently high-elevation angle and consequently experiences frequent incidences of signal propagation cut-off due to tall buildings or mountains. Needs for a system where satellites have a clear "line of sight" to the ground, in conjunction with coverage of high latitude regions, have sparked the development of new cost-effective satellite communication systems called Quasi-Geostationary Orbit satellite systems [8].

Quasi-GSO satellite systems provide constant coverage over a particular area of the Earth through employment of a series of satellites. The Quasi-GSO satellites complete one full orbit per day in synchronization with the Earth's rotation, describing a north-south figure of eight locus centered around a point on the equator. The Quasi-GSO satellite system consists of at least three satellites placed in circular orbits at an inclination angle of approximately 45° relative to the geostationary orbit. The satellites are placed in orbit such that one would be positioned almost directly above the target area at any given point in time. The Quasi-GSO satellites guarantee a minimum angle of elevation of at least 60° and higher values of elevation angle can be achieved by using more than three satellites. Fig.1 shows the variation of the elevation angles of a Quasi-GSO system made of three satellites observed by a terminal in Tokyo.

Quasi-GSO satellite systems are a promising alternative to conventional satellites in geostationary or low-altitude orbits. They can deliver huge amounts of broadcasts at high speed with high quality, and without being obstructed by tall buildings. They have been considered efficient for vehicular satellite communications, frequency sharing in fixed satellite communications, positioning systems, and north and south polar regions observation. In addition, they are particularly well suited to the provision of video-on-demand, a service where signal propagation blockings are not tolerated. It should be stressed that the inherent issues with latency of Quasi-GSO satellites should not pose challenges for delivery of high quality multimedia. This paper aims to study how a constellation of these satellites could be used to provide global broadband coverage.

III. Overview of the Quasi-GSO Satellite Constellation

The abstract configuration of the constellation is conceptually depicted in Fig. 2. The figure portrays the orbits of six

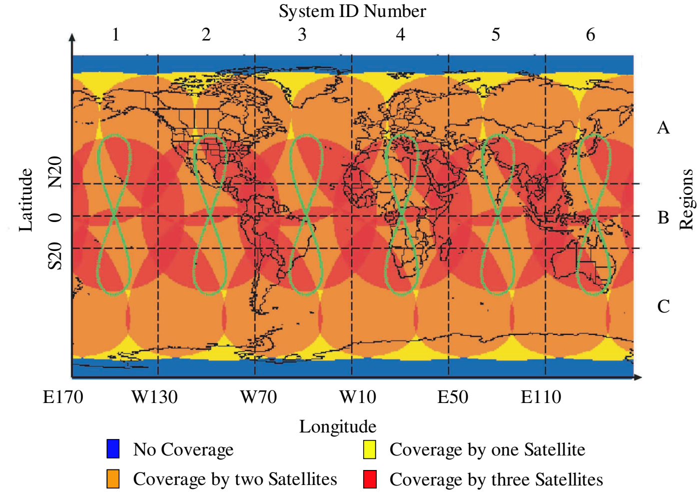


Fig. 2. Illustration of the proposed Quasi-GSO constellation (This is an edited image, generated by the Satellite constellation Visualizer (SaVi), at http://sourceforge.net/projects/savi/.)

Quasi-GSO systems. Each system consists of three satellites, giving rise to only 18 satellites in the whole constellation. Setting the minimum value of the elevation angle to 40°, the constellation can provide coverage to the whole globe. It should be emphasized that the constellation can provide elevation angles largely higher than 40° over middle-latitude regions.

The longer life span of satellites in geosynchronous orbits, in conjunction with the small number of required satellites, makes the cost of the whole constellation more reasonable than most proposed LEO or MEO systems. Moreover, due to the insignificant mobility characteristic of the constellation, the mobility management related cost of the system becomes cheaper also.

Concerning inter-satellite links, two types are considered: Intra-System and Inter-System links. Intra-System links refer to the three links that connect the three satellites of a given system, and are dubbed *Intra-System Inter-Satellite Links* (Intra-SISLs) throughout this paper. Conversely, Inter-System links represent the three links that joint between a satellite of a given system and its correspondent in the neighboring system. Inter-System links are referred to as *Inter-System Inter-Satellite Links* (Inter-SISLs) throughout this paper. It should be noted that Inter-SISLs are of fixed length, whereas Intra-SISLs vary in length. For ease of illustration of Fig. 2, both Inter-System and Intra-System links are not plotted.

System	Orbital Latitude	Number Satellites	Elevation Angle	coverage (%)
Iridium	LEO	66	8.2°	100
NeLS	LEO	120	20°	79
Teledesic	LEO	288	40°	100
Skybridge	LEO	64	10°	86
Celestri	LEO	63	16°	73
Globalstar	LEO	48	10°	83
Orbilink	MEO	7	10°	60
GEO(3)	GEO	3	20°	79
Quasi-GSO	GEO	18	40°	96

TABLE I

Comparison with other satellite constellations

Table I compares the proposed constellation to other satellite constellations. The Quasi-GSO constellation is capable of providing almost global coverage with less number of satellites and high elevation angle. The frequency of handover occurrences in the constellation is significantly lower compared to that of LEO or MEO constellations (3 to 6 handovers per day). The network topology is hence simple and easy to manage. On the other hand, the round trip propagation delay is around 250 ms. The constellation is thus not suitable for delay-sensitive applications. It can be, however, a good candidate for the provision of applications that are not affected by long latency [9]. Notable examples are Video-on-Demand (VoD), live broadcasting, distance learning, online radio, messaging, and Global Positioning System services (GPS).

Although the mobility of the proposed Quasi-GSO satellite constellation is insignificant in comparison with LEO or MEO constellations, end-terminals are not always continuously connected to the same satellite in the constellation during the entire communication time. Handover of *Ground to Satellite Link (GSL)* to a new satellite may be thus required during the connection time. Having the minimum elevation angle set to 40°, diversity coverage becomes rife in this type of constellation. Fig. 3 shows the variation of the diversity coverage of one Quasi-GSO satellite system over a time interval of eight hours[1]. To cope with this diversity coverage issue, the baseline satellite selection procedure simply selects the satellite with the highest elevation angle during the initial set-up of connections or upon a handover occurrence [7]. Applying such a mechanism to the proposed constellation results in long delays and significant delay variations, mainly when the connection is set between two geographically close terminals. Furthermore, since handovers occur rarely in the proposed constellation, the selection of an inappropriate satellite may influence the overall connection performance for a long period of time. In other words, till the chosen satellite falls below the elevation mask and the next handover takes place. In short, a more accurate satellite selection scheme is required for the considered constellation. The next section describes in detail the satellite selection scheme proposed for the Quasi-GSO constellation.

IV. Satellite Selection Scheme for the Quasi-GSO Satellites Constellation

This section gives an operational overview of the proposed satellite selection scheme. Before delving into details of the scheme, the following observations should be made. Firstly, since the six Quasi-GSO systems, considered in the constellation, are similar, focus is on only one of them. The length of GSL links, l, can be calculated as follows:

$$l = \frac{H}{sin(\varepsilon)} \tag{1}$$

where H and ε denote the satellite altitude and the elevation angle to a satellite from the terminal, respectively. Since the satellite altitude of the constellation is high, the length of GSL varies drastically upon a small variation in the elevation angle. This ultimately affects the propagation delay. The elevation angle should be thus maximized to reduce the propagation delay variation.

In the Quasi-GSO orbit, the vertical speed of satellites relative to Earth is not stable. For example, satellites move faster near the center of the locus, and slow down at the orbit upper and lower tip. To deal with such an issue, the minimum elevation angle should be dynamic and should take different values for different latitudes. Using one minimum elevation angle for the whole constellation, as in the baseline method, results in drastic delay variation over the Quasi-GSO Satellite constellation.

The coverage area of a single Quasi-GSO system is divided into three regions such that each region is covered by only one satellite. Recall that the coverage area of one system is 60° in latitude and 30° in longitude from each side of the locus center. Based on latitude, the three regions are determined as follows (Fig. 2):

- Region R_{Ai}: Terminals in the northern part of the globe with latitudes greater than $Northern$ 20° ($N20° \geq$ latitude)
- Region R_{Bi}: Terminals with latitudes within the $Southern$ 20° and $Northern$ 20° ($S20° <$ latitude $< N20°$)
- Region R_{Ci} : Terminals in the southern part of the globe with latitude smaller than $Southern$ 20° (latitude $\leq S20°$)

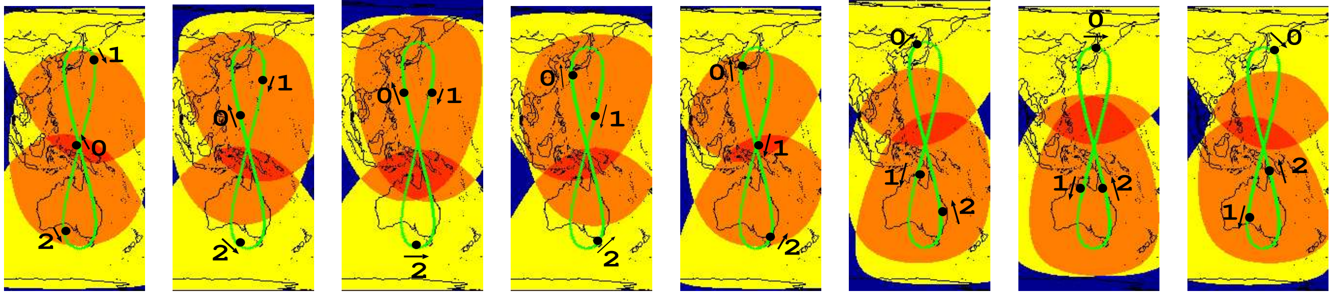
where i identifies the number of the system in the constellation. Northern latitude 20° and southern latitude 20° are selected as boundaries for the three regions as two satellites of the system line up on N20° or S20° every four hours. Terminals in both regions R_{Ai} and R_{Ci} perform handover of GSL every eight hours, whereas users in region R_{Bi} perform handover every four hours.

Upon handover occurrences, end-terminals use function Φ to select the most appropriate satellite to communicate through. The selection depends intuitively on the region end-terminals are located in and the time of the handover. Function Φ is formed from three sub-functions. Each sub-function concerns end-terminals in a specific region. Terminals belonging to different regions get connected always to different satellites. The satellite selection function, Φ, is defined as:

$$\Phi(X_k, Y_k, t_c) = \begin{cases} f_A(t_c) & R_{Ai} \\ f_B(t_c) & R_{Bi} \\ f_C(t_c) & R_{Ci} \end{cases} \tag{2}$$

where X_k and Y_k denote the longitude and latitude of terminal k, respectively. t_c denotes the current time of the day. Outputs of Φ are 0, 1, or 2. These values correspond to the ID of the satellite a terminal should get connected to at time t_c. Satellites are identified as follows. In a system with a locus center at longitude $\theta°$, the initial state of a satellite (at time T) and its correspondent identifier are given in Table II. Depending on the initial positions of satellites and the time required by each

[1]The constellation returns back to its initial position every eight hours.



(a) t=T (b) t=T+1h (c) t=T+2h (d) t=T+3h (e) t=T+4h (f) t=T+5h (g) t=T+6h (h) t=T+7h

Fig. 3. Coverage variation of a Quasi-GSO System, T:Time the constellation is in initial position, t:Time elapsed in hours (These are edited images, generated by the Satellite constellation Visualizer (SaVi), at http://sourceforge.net/projects/savi/.)

to cross a given region (Fig. 3), functions $f_A(t_c)$, $f_B(t_c)$, and $f_C(t_c)$ are defined as follows:

$$f_A(t_c) = \begin{cases} 1 & t_c < T+2 \\ 3/2\lambda^2 + 5/2\lambda + 1 & t_c \geq T+2 \end{cases} \quad (3)$$

where $\lambda = \{(t_c - T - 2)/8 + 1\}\ mod[3]$.

$$f_B(t_c) = \begin{cases} 0 & t_c < T+2 \\ \{(t_c - T - 2)/4 + 1\}\ mod[3] & t_c \geq T+2 \end{cases} \quad (4)$$

$$f_C(t_c) = \begin{cases} 2 & t_c < T+6 \\ 2 - \{(t_c - T - 6)/8\}\ mod[3] & t_c \geq T+6 \end{cases} \quad (5)$$

Satellite ID	Initial longitude of satellite	Initial latitude of satellite
0	$\theta°$	0°
1	$(\theta + 9.3)°$	N37.8°
2	$(\theta - 9.3)°$	S37.8°

TABLE II

SATELLITES IDENTIFICATION AND THEIR INITIAL POSITIONS

Information on the geographical location of terminals and the current time are required to select the most appropriate satellite. In the recent literature, several approaches have considered the inclusion of geographical location information in terminal addresses [10] [11]. In addition, a satellite selection method based on geographical location information is proposed in [12]. Current time can be easily obtained from the system clock of the terminal.

The above approach can be fairly implemented in end-terminals. Terminals will be accordingly able to select the most appropriate satellite to communicate via. In case of fixed terminals, handovers can be initiated by satellites. Satellites should keep thus track of the next handover time. This operation can be programmed in advance in the satellites. Handovers occur when two satellites of the same system line up at latitudes N20° or S20°. At this time, the Intra-SISL delay between the two satellites takes its shortest value. This minimizes the communication overhead (in terms of time and system cost) caused by the handover. In case of mobile terminals, handovers can be initiated by terminals when they enter the coverage area of another satellite.

V. EVALUATION OF THE PROPOSED SCHEME

Having described the proposed satellite selection scheme, focus is now on evaluating its performance. Evaluation relies

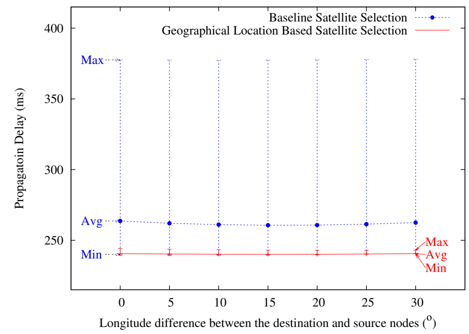


Fig. 4. Delay variation experienced by UDP connections in region R_{A6}

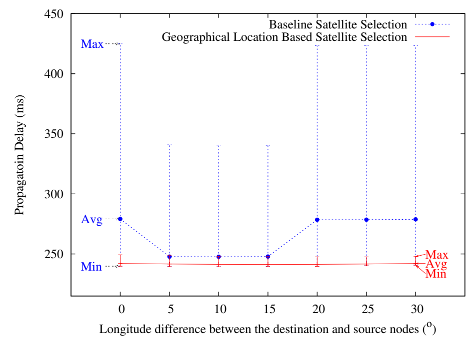


Fig. 5. Delay variation experienced by UDP connections in region R_{B6}

on computer simulation, using Network Simulator-2 (NS-2) [13]. Since the Quasi-QSO satellite system is symmetrical around the equator, simulations are conducted considering the case of only northern latitude regions R_{A6} and R_{B6}.

A UDP packet is sent from a source to a destination every minute during a time period of 24 hours (1440 packets). Maximum, minimum, and average path propagation delays are calculated for the transmitted 1440 packets. Similar simulations are carried out for various source and destination pairs with different latitudes. In region R_{B6}, source and destination latitudes are varied from the Equator to northern latitude 20° with an interval of 5° (Fig. 2). As for terminals within region R_{A6}, latitudes are varied from northern latitude 20° to northern latitude 50° with an interval of 5°. The longitude difference between a source and a destination is varied from E125° to E155° with a 5° interval for each source and destination pair. The longitude of the center of the Quasi-GSO system locus is set at E140° (Fig. 2). The performance of the proposed scheme is compared to that of the baseline satellite selection approach.

In all conducted simulations, the results show that the proposed scheme achieves significant reduction in both delay and delay variation for terminals in both regions R_{A6} and R_{B6}. Figs. 4 and 5 are two examples (among many) that illustrate the good performance of the proposed scheme over the baseline approach in reducing the delay and delay variation. The two figures show the delay and delay variation of two UDP connections established over regions R_{A6} and R_{B6}, respectively. In Fig. 4, the source is fixed at N30° and E125°. The latitude of the destination is set at N45°, whereas its longitude is varied. The X axis denotes the difference between the longitudes of the destination and source nodes. The source in Fig. 5 is set at N5° and E125°. The latitude of the destination is fixed at N15° while its longitude is varied.

When the baseline satellite selection scheme is used, terminals are connected via either the same satellite or two different satellites. In case of the baseline satellite selection scheme, the maximum delay values in Figs. 4 and 5 depict the delay when terminals are connected to different satellites, while the minimum values show the delay when terminals are connected to the same satellite. The two figures show that the average delay of the proposed method is always close to the minimum delay of the baseline method. This result indicates that the proposed scheme succeeds in making terminals communicate via the same satellite. In both cases, the proposed scheme achieved a reduction of over 90% in the delay variation. Reduction in the average delay was of about 10%.

Terminals belonging to two different regions usually communicate via two different satellites. Consequently, in case of two terminals belonging to two different regions, yet geographically close to each other, an ISL will be required for communication. This will intuitively lead to higher propagation delays. A remedy to this issue can be made by including latitude difference (between two terminals) as a parameter in the satellite selection function Φ.

VI. Conclusion

In this paper, a novel satellite constellation was proposed. The constellation comprises six Quasi-GSO satellite systems. Each Quasi-GSO system consists of three satellites. The positions of the systems are decided in a manner that most dense cities with high buildings (i.e New York City) or mountainous regions are entirely covered by the systems. The constellation would be able then to cover most populated regions of Earth with only 18 satellites. Observing that the 1^{st} and 3^{rd} systems (Fig. 2) cover the Pacific and Atlantic oceans respectively, and since signal blockings are not an issue in such areas, the number of satellites in the constellation can be further reduced to 12 by removing the two systems from the constellation. The constellation maintains transmission with a minimum elevation angle of 40°. High latitude regions that have been deprived from transmission with high elevation angles, should no more experience signal blockings. Furthermore, the constellation is fairly easy to manage because of its small number of satellites and less mobility characteristic. The constellation can be seen as a good infrastructure for providing delay-insensitive multimedia applications, such as VoD and distance learning.

A satellite selection scheme for the Quasi-GSO constellation was also proposed. The coverage area of each Quasi-GSO system was divided into three regions such that each region is covered by at least one satellite at any given time. Selection of the most appropriate satellite depends on the geographical location of terminals and the handover occurrence time. The performance of the proposed scheme was evaluated and compared to that of the baseline satellite selection scheme. Extensive simulation results elucidated the better performance of the proposed scheme in reducing both the overall delay and delay variation. Another credit of the proposed scheme consists in eliminating the last hop ambiguity that exists in LEO and MEO constellations. Indeed, since terminals in a geographical location should be necessarily connected to a known satellite, packet forwarding among satellites can be performed according to a geographical location based routing protocol as proposed in [11]. This will significantly reduce the additional overhead that may be due to routing procedures.

Finally, it is our hope that the findings in this paper may contribute in the construction of a new constellation and help to a better understanding of Quasi-GSO systems while stimulating further work in the area.

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