Visibility Analysis of Satellite Based Automatic Identification System (SB-AIS)

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Abstract— AIS (Automatic Identification system) is an automatic and autonomous vessel tracking and identifying system that uses maritime VHF frequency band. AIS was developed for collision avoidance mainly. AIS transmit GMSK modulated signal using self organized form of TDMA. Its communication range is limited to 40 NM. SB-AIS can be proposed to overcome this limitation and create global surveillance. AIS signal strength can be received at LEO satellite up to 1000 km. satellite is not continuously visible to ships. So that is required to do visibility analysis. MATLAB simulation is done to find all parameters like path loss, received signal power, Doppler frequency, within visible duration only.

Key words: AIS, SB-AIS, LEO satellite, orbital parameters, visibility analysis

I. AIS (Automatic Identification System)

The Automatic Identification System (AIS) is an automatic tracking system used on ships and by vessel traffic system (VTS) for identifying and locating vessels in maritime VHF band. Information provided by AIS equipment such as unique identification, position, course and speed etc. The basic concept for this ship-to-ship communications system was introduced by the International Association of Lighthouse Authorities (IALA) in the early 1990's.Under requirements of the International Convention for the Safety of Life at Sea (SOLAS), the installation and use of AIS is mandatory on all ships of 300 gross tons or more engaged in international voyages. In 2008, all ships of 500 gross tons or more engaged in national voyages should also be equipped with AIS. Ships broadcast the fixed length (256 bits) digital information at a data rate of 9600 bits/second using Time Division Multiple Access (TDMA) technique in their respective fixed length time slots (26.67 ms) on two alternate VHF bands.

AIS parameters	Values
Frequencies	161.975 and 162.025 MHz
Transmit power	12.5 W(Class A); 2 W (Class B)
Antenna type	Dipole
Bandwidth	25 KHz and 12.5 KHz
Modulation	Gaussian Minimum Shift Keying
Modulation index	0.25 for 12.5 KHz and 0.5 for 25 KHz
Bit rate	9600 bit/sec
Message length	256 bits
Capacity	2250 messages/minute/channel
Access scheme	SOTDMA

Table 1: Summary of AIS Operational Characteristics [1]

II. Satellite Based Automatic Identification System

SB-AIS is solution to overcome limitation of VHF communication range and create global surveillance that very much useful to maritime security.AIS signal strength can be received at height of LEO satellite. Satellite receives those AIS signals that is transmitted by ships and relay it to ground station. Concept of SBAIS is shown in fig. 1.

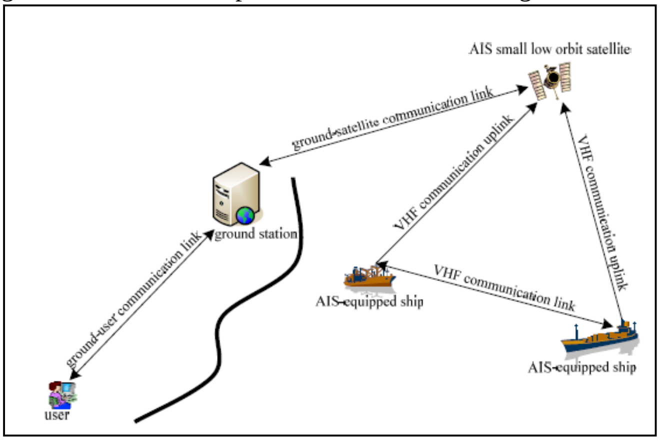

Fig. 1: Satellite Based AIS concept [3]

As satellite in LEO, it will be not continuously visible from ships. Visibility duration is around min. could be derived using equation,

III. Algorithm for Visibility Analysis

1) Simulate ground trace for LEO using orbital parameters [4]. This gives sub satellite points (latitude, longitude) of satellite.
2) Select any random location of ship.
3) Find the elevation between ship and sub satellite points.
4) **if** elevation angle> 0
   Then satellite is visible to ship
   Calculate all parameters like;
   Path loss, received signal power, Doppler frequency
   C/N0 and Eb/No
   Else
   Satellite is not visible to ship.

IV. Analyzed Parameters and Results

A. LEO Ground Trace [4]

Step to simulate ground trace of LEO satellite is as following

1) Convert time and date to Julian Time (JT).
2) Julian Time: Julian Time is a continuous count of days starting from noon Universal Time on January 1 of the year 4713
3) Using orbital parameter, find position of satellite in ECI (earth centered inertial) co-ordinate. ECI is stationary frame, x axis point towards vernal equinox.
4) Convert ECI (earth centered Inertial) to ECF (Earth Centered Fixed) co-ordinate. GMST is subtracted from azimuth of ECI co-ordinate. GMST (Greenwich mean sidereal time): Angle between Vernal equinox and Greenwich meridian. GMST is computed using JT.

Orbital parameters for simulation:
Altitude of satellite: 650 km
Inclination: 40^0
Eccentricity: 0 (circular orbit)

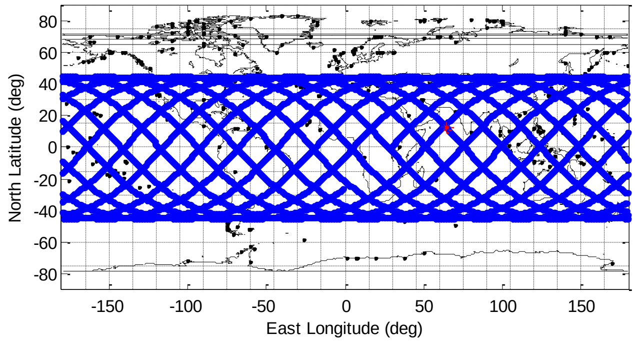

Fig. 2: Ground Trace of LEO Satellite

B. *Elevation Angle*

For visibility analysis, It is required to calculate elevation between ship and satellite. If elevation is more than 0˚, satellite is visible to ship. Equation to find elevation angle is as following [6],

$$\theta = \tan^{-1}\left(\frac{\cos(\gamma) - \frac{re}{rs}}{\sin(\gamma)}\right)$$

where,

$$\gamma = \cos^{-1}(\cos(Le)\cos(Ls)\cos(ls - le) + \sin(Le)\sin(Ls))$$

Le= latitude of ship terminal
le= longitude of ship terminal
Ls= latitude of sab satellite point
ls= longitude of sub satellite point
re= earth radius km
rs= height of satellite

Elevation angle plot is shown in fig. 3. LEO satellite's revolution time is around 100 min. so from any location from earth satellite is visible for maximum 14 times. Here for location 3 N, 70.5 S, satellite is visible for 9 times.

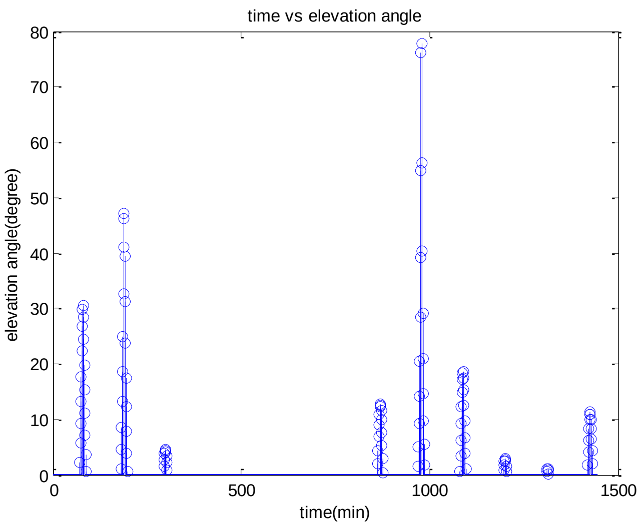

Fig. 3: Elevation Angle Profile (Only Positive Angles Are Shown.)

C. *Doppler Frequency [5]*

As satellite in LEO, relative motion between ship and satellite, Doppler frequency is present.

$$\Delta f = -\frac{fc}{c}\frac{r_E r \sin(\psi - \psi(t_0))\cos(\cos^{-1}(\frac{r_E}{r}\cos\theta_{max}) - \theta_{max}) w_F(t)}{\sqrt{r_E^2 + r^2 - 2r_E r\cos(\psi - \psi(t_0))\cos(\cos^{-1}(\frac{r_E}{r}\cos\theta_{max}) - \theta_{max})}}$$

where,
r_E = earth radius km
$\dot{\psi}(t)$ = the angular velocity of the satellite in ECFframe;
$\dot{\psi}(t) = w_F(t)$
$w_F(t)$ =the angular velocity of the satellite in the ECF frame
c=light velocity

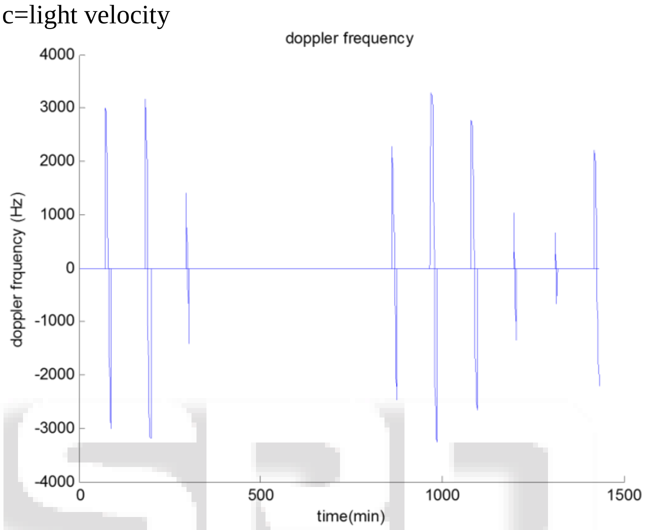

Fig. 4: Doppler Frequency Profile for Visible Time

D. *Path Loss [6]*

$$TPL = FSL + PL + AA$$

Where,

$$FSL = \left(\frac{4\Pi d}{\lambda}\right)^2$$

$$d = \sqrt{(re^2 + rs^2 - 2 \cdot re \cdot rs \cdot \cos(\gamma))}$$

d= distance between ship and satellite
λ= wavelength
FSL= free space loss
PL=polarization loss 3 dB (considering satellite antenna having circular polarization)
AA= atmospheric attenuation (0. 5 dB)

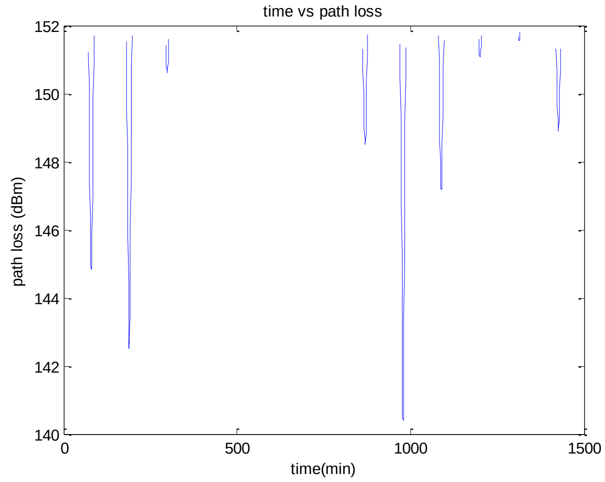

Fig. 5: Path Loss Profile During Visible Time

E. Received Power

$$Pr = EIRP - TPL + G_r$$

$$EIRP = Pt + Gt$$

Where,
G t =2.15 dB
Gr=0 dB

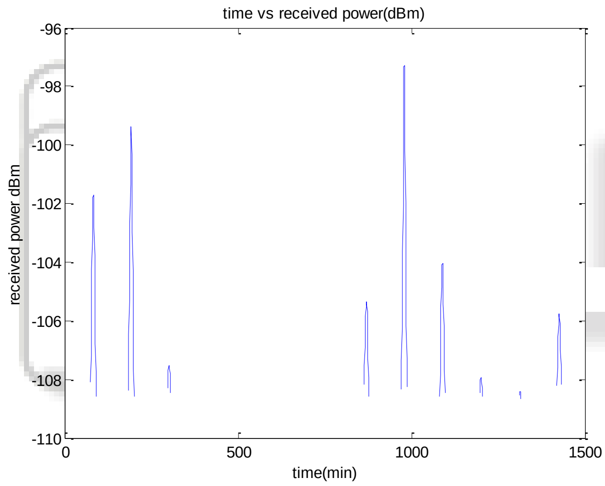

Fig. 6: Received Power Profile During Visible Time

F. Uplink Power Budget [6]

$$\left[\frac{C}{No}\right] = \left[\frac{Pr}{kT_{sat}}\right]$$

$$\left[\frac{Eb}{No}\right] = \left[\frac{C}{No}\right] - rb$$

Where,
Tsat= satellite temperature
k=Boltzmann's constant
rb=Bit rate

visibility analysis

start time	end time	max. ele	max. range(nm)	min. range(nm)	max loss(dB)	max_doppler(Hz)	min_doppler(Hz)
1:12: 0	1:28: 0	30.53	1919.96	869.04	151.70	3008.31	-3009.70
3: 1: 0	3:18: 0	47.03	1917.43	665.43	151.69	3173.07	-3195.97
4:55: 0	5: 3: 0	4.50	1894.71	1697.09	151.58	1424.34	-1423.91
14:23: 0	14:36: 0	12.86	1926.12	1327.25	151.73	2291.40	-2459.01
16:10: 0	16:27: 0	77.81	1865.29	523.21	151.45	3276.92	-3270.07
18: 1: 0	18:16: 0	18.51	1920.47	1140.77	151.70	2762.29	-2650.65
19:57: 0	20: 4: 0	2.85	1917.93	1784.47	151.69	1051.46	-1343.87
21:52: 0	21:56: 0	1.03	1940.63	1887.62	151.79	674.24	-674.46
23:40: 0	23:52: 0	11.29	1839.46	1387.59	151.33	2219.13	-2222.02

Table 2: Visibility Analysis

link budget

start time	end time	EIRP(dBW)	G/T(dB/k)	path_loss(dB)	C/NO(dB-Hz)	Eb/NO(dB)	margin(dB)
1:12: 0	1:28: 0	11.12	-27.86	151.70	67.04	27.22	7.34
3: 1: 0	3:18: 0	11.12	-27.86	151.69	69.36	29.54	7.35
4:55: 0	5: 3: 0	11.12	-27.86	151.58	61.23	21.41	7.45
14:23: 0	14:36: 0	11.12	-27.86	151.73	63.37	23.54	7.31
16:10: 0	16:27: 0	11.12	-27.86	151.45	71.45	31.63	7.59
18: 1: 0	18:16: 0	11.12	-27.86	151.70	64.68	24.86	7.33
19:57: 0	20: 4: 0	11.12	-27.86	151.69	60.79	20.97	7.35
21:52: 0	21:56: 0	11.12	-27.86	151.79	60.31	20.48	7.24
23:40: 0	23:52: 0	11.12	-27.86	151.33	62.98	23.16	7.71

Table 3: Uplink Budget

V. CONCLUSION

In paper visibility analysis is done for SB-AIS. As LEO satellite is not continuously visible from ships, it's required to do visibility analysis. Visibility duration is around 15 to 18 min. uplink budget proves that signal strength is enough to receive at LEO satellite as required Eb/No is 13 dB. This analysis is also useful to decide location of ground station. Hence when ground station is visible to satellite then satellite sends data to it.

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