

System Design and Performance Evaluation of High Altitude Platform: Link Budget and Power Budget

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Abstract— High altitude platform (HAP) is an emerging technology to cope with the increasing demand of multimedia applications, capacity and coverage of wireless service communication. The purpose of HAP is to provide broadband communication over wide area from a single node. Link budgeting, power system designing and planning for a 50 kg HAP has been presented. Moreover protocols for communicating with HAP are also investigated. The proposed link budget is based on simplex model over 31/28 GHz frequency band as this has been allocated by FCC as well as Frequency Allocation Board Pakistan for communication with HAPs. Power budget is presented for solar powered autonomous or unmanned airborne aircraft for line of sight (LOS) condition in the stratosphere at an altitude of 17 Km above ground level where air turbulence is nearly static and minimum cloud are present to maximize solar energy. Link budget with transmission power of 30 dBm using QPSK for varying code rates is proposed to minimize power consumption. The power system is designed for 10 hours of daylight and 14 hours of the night operation, direct energy transfer (DET) architecture is used with battery banks working at 80% depth of discharge (DOD). For communication, Digital Video Broadcasting protocol (DVB-S2) and Worldwide Interoperability for Microwave Access (WiMAX) 802.16e using QPSK modulation scheme are used. Number of simulations with varying code rates to minimize bit error rate, minimizing power consumption are carried out and results are presented. Results shows that DVB-S2 gives better performance with minimum signal energy which minimize power consumption.

Keywords— High altitude platforms HAPs, Digital Video Broadcasting, Link budget, Power budget.

I. INTRODUCTION

Since the use of radio wave in the 19th century, the communication systems are becoming a major necessity for not only military but also for civilians. This attracted research attention to study different methods for the provision of wireless broadband services which cover a large number of users with better spectral efficiency using aircraft.

HAPs (also known as stratospheric repeaters [1]) are airborne at the stratosphere with an altitude of 15 to 50 km above controlled airspace so that aeronautical regulations are not violated. International telecommunication union (ITU) defines HAP as a term referring to balloons that can provide communication services [2]. HAPs represent a new revolutionized technology that can make better utilize radio spectrum and improve payload carrying capacity [1]. Aforementioned altitude facilitated to provide more solar

energy avoiding clouds and wind turbulence. Advantages of HAP exceed benefits of both terrestrial and satellite systems (which are usually referred as ‘middle ground’ system) [1]. First, free space loss of a HAP (i.e., path loss) is comparable to the terrestrial system and second, delay of a signal to travel from transmitter to a user is very minimal than that of a satellite to user link based system. Signal received from a HAP system has better quality because the transmission line is mostly in the line of sight. This reduces shadowing effect compared with terrestrial communication systems.

Four categories can specifically define HAPs, which are manned plane, unmanned fuel plane, unmanned solar plane and unmanned autonomous solar airship.

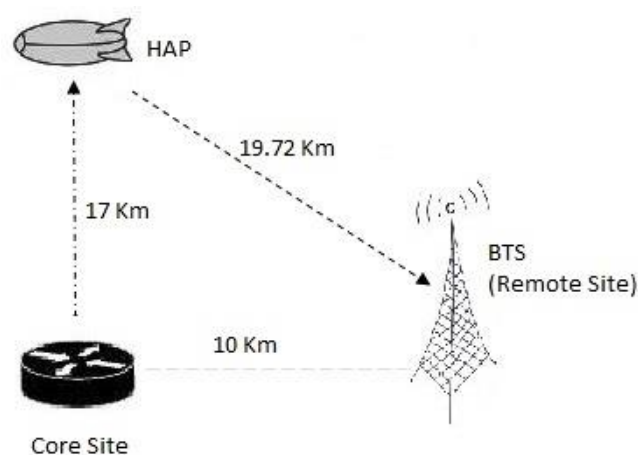


Figure 1. Simplex Communication model for HAP

Proposed model for simplex communication for a solar-powered autonomous airship is illustrated in Fig. 1. In the present study proposed solar powered HAP for backhaul communication is located in the stratosphere at an altitude of 17 Km above ground level. Link and power budgeting are carried out the operating frequency of 28 GHz and the transmission power of 30 dBm per carrier, respectively. Power requirements using DVD-S2 or WiMAX 802.16e with QPSK as modulation scheme is for LOS conditions. Signal carrier to noise power spectral density is evaluated and optimized for minimum signal power.

II. OPERATING ENVIRONMENT

The atmosphere around the Earth's surface is divided into several layers. This characterization of layers is based on wind speed and density, pressure and temperature. Number of air molecules per unit area decreases with an increase in altitude because of weakening of gravitational pull, air is more dense closer to Earth's surface than that of higher altitude [3].

More than half of atmospheric molecules are present inside 5.5 km radius from Earth's surface so air pressure decreases rapidly with first few kilometres in altitude, afterwards it decreases monotonously [4] as illustrated in Figure 2.

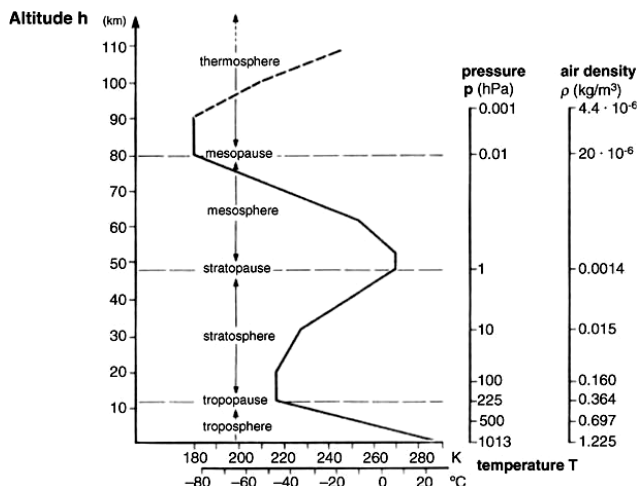


Figure 2. Air Temperature, Pressure and Density Profile [3].

Earth absorbs heat from the Sun and convection make the air relatively hot, this decreases the air density and air molecules move upward. However the behaviour of air temperature is not monotonous with altitude. Air molecules in atmospheric layers also absorb sunlight and raise temperature but due to inversion temperature phenomena in the stratosphere that temperature decreases with the decrease in altitude from upper stratosphere to lower stratosphere restrict ascending hot air from troposphere to go higher [5]. Due to which clouds do not form in stratosphere and weather is stable.

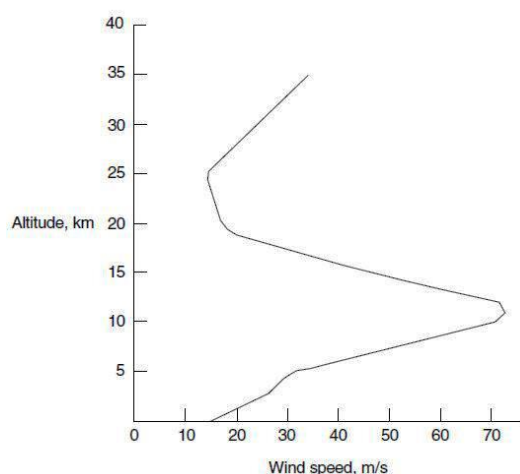


Figure 3. Wind Profile [5]

Air quality improves with altitude because of reduction in water content in the stratosphere. Comparison with other atmospheric layers, conditions are stable with no or mild turbulence. Wind speed increase with an increase of altitude until Tropopause is reached. Wind speed decreases significantly in the lower stratosphere as depicted in Figure 3 [5].

TABLE 1. LINK BUDGET

Operating Frequency	28 GHz
Power per backhaul carrier	30 dBm
Antenna Beamwidth	5°
Antenna Efficiency η	0.95
Antenna Gain G	32.638 dBi
EIRP	62.6 dBm
Free Space Loss	147.3 dB
Atmospheric Loss	0.8 dB
Cable Loss	2 dB
Antenna Feed Loss	1 dB
Antenna Noise Temperature T	300 K
Thermal Noise Temperature N_0	-173.8 dBm/Hz
Receiver Noise Figure NF	5 dB
Receiver Noise Density N_T	-168.8 dBm/Hz
Receiver Interference Noise Density (IN_0)	-168.8 dBm/Hz
Total effective noise density ($IN_0 + N_T$)	-165.8 dBm/Hz
$C/(N_0 + I_0)$	258 dBHz
Modulation Scheme	QPSK
E_b/N_0	7.8 dB
Bandwidth	50 MHz
Roll-off Factor γ	25%
Data Rate	76 dBbit/sec
$C/(N_0 + I_0)$ for QPSK	83.8 dBHz
Allowed Losses	258-83.8 = 174.2 dB
Power Margin: Allowed Losses – FSL	26.2 dB
Minimum Power Required	3.8 dBm
Rain Attenuation 99.90%	10 dB
Rain Attenuation 99.00%	2.6 dB
Received margin 99.90%	16.2 dB
Received margin 99.00%	23.6 dB
Minimum required transmit power 99.90%	13.8 dBm
Minimum required transmit power 99.00%	6.4 dBm

III. LINK BUDGET

The distance of HAP to a user can be determined by Pythagoras theorem as shown in Figure 1. Transmission power of 30 dBm is presumed and Link budget parameters are shown in Table 1.

Losses occurred due to multipath phenomenon consisting of fading, reflection, refraction and diffraction. This have an immense effect on frequencies less than 10 GHz. HAPs have millimetre wavelength bands at 31/28 GHz, thus multipath losses are negligible. This is because multipath losses decrease at elevated frequency. Therefore LOS condition guarantees high quality signal reception [1]. Atmospheric losses occurred because of scattering and absorption into gasses. These losses are environment dependent, hence accumulative atmospheric loss is assumed to be 0.8 [6]. Rain attenuation values for 99.90% and 99.00% are used on ITU climate zone (Istanbul) recommendations [6].

It is assumed that the receiver interference noise density is equal to the noise density, this is the worst case scenarios for a noise limited situation because it will reduce the transmission power which will, in turn, reduce carrier to noise power spectral density. To support this link budget DVB-S2 and WiMAX 802.16e are simulated to evaluate BER over a range of SNR (i.e., E_b/N_0). Electric Power System is explained in next section.

IV. POWER SYSTEM

The electric power system is divided into four main steps as shown in Figure 4.

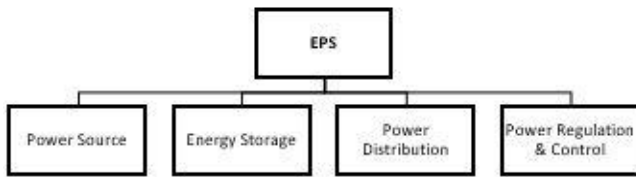


Figure 4. Electric Power System [7]

The main focus of this paper is the selection of power source and energy storage devices. The selection of power source is based on the amount and duration of required electric power. Power estimation is carried for various tasks of HAP. Provided the power consumption of the payload, power requirements are estimated in earlier stages of spacecraft. Prior to commencement of HAP design process, calculations do not include any enhancement capabilities. Estimation of power requirement of HAP are made in accordance with Eq.1 [7]. Total 123.13 W of power estimated for a 30dBm payload power.

$$P_t = 1.13 \cdot P_{pl} + 122 \text{ (Watts)} \quad (1)$$

A margin of 90% of computed power is made to be refined as the design and estimation of power consumption mature. A power of 234 W is used after making adjustments of said margin.

$$P_T = 234 \text{ Watts} \quad (2)$$

A system within the range of power budget is proposed based on power and energy criterion of a solar-based system as illustrated Figure 5 [7]. All the power required by spacecraft is assumed to capture by solar arrays during the daylight time period. Power requirement can be calculated by energy balance equation (Eq. 3). The energy from solar arrays used to perform daytime process and charge batteries including power-system losses. Detailed parameters of power required from solar arrays are shown in Table 2 [7].

$$E_{sa} = E_n + E_d \quad (3)$$

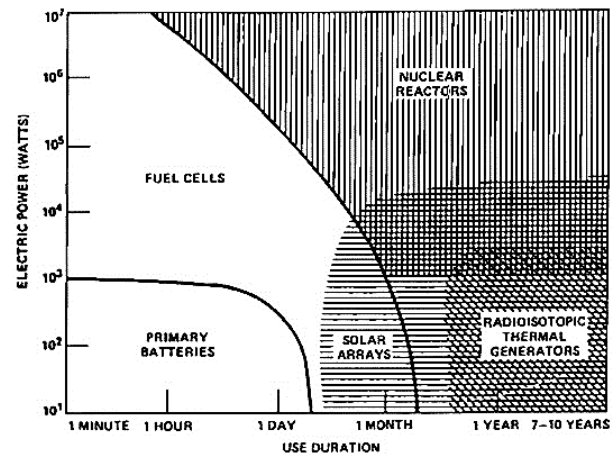


Figure 5. Operating Order of Spacecraft Power Source [8]

TABLE 2. POWER BUDGET

Power Required without losses	$P_{sa} \cdot T_d = P_n \cdot T_n + P_d \cdot T_d$	561.6 Watts
Power Required with losses	$P_{sa} = \frac{P_n \cdot T_n}{X_{a-b} \cdot X_{b-l} \cdot T_d} + \frac{P_d}{X_{a-l}}$	1345.47 Watts
Battery Capacity For One Night Duration	$C = \frac{P_n \cdot T_n}{X_{b-l} \cdot DOD \cdot V_d}$	472.21 AH
Power Produce per Cell	P_c	0.0592 W/Cell
Area Of Solar Array	$A_{SA} = N_c / D_c$	20.62 m ²

$$P_c = P_L \cdot (\eta_{rad} \cdot \eta_{uv} \cdot \eta_s \cdot \eta_{cy} \cdot H_l \cdot \eta_m \cdot \eta_l \cdot \eta_{con} \cdot \eta_t \cdot L_p) \quad (4)$$

HAPs operate in the stratosphere, therefore the duration of day and night will be the same as on the ground. Ten hours daylight time and fourteen hours of eclipse time periods are assumed. Cables, charger and battery efficiencies are assumed

to be 85% at an operating voltage of 12V. The depth of battery discharge is considered to be 80%. Pointing loss is presumed by taking the angle of incidence (α) equal to 5° [7]. Silicon solar cells of (2 x 4) cm with an efficiency of 14.9% are considered for calculating power production as expressed by Eq. 4 [7]. Solar flux power is inversely proportional to distance from earth, hence it decreases with an increase in distance and its value varies from 1310 to 1399 W/m². Solar flux is considered to be 1371 W/m² in lower atmosphere of earth [7]. No solar adjustments are to be made as the altitude of HAP is associated close to earth, thus adjustment for solar intensity at orbit position (H_i) is considered to be 1. Packaging density of silicon cells is 88% which gives cell density (D_c) = 1100 cells/m². Lithium Ion cells are compact in size and weight for 472.21 AH requirement [9].

V. RESULTS AND DISCUSSION

In this section, results are discussed for BER vs. Eb/No on different code rates using QPSK as a modulation scheme for proposed DVB-S2 and WiMAX 802.16e standards. MATLAB is used for simulation and parameters used for DVB-S2 simulation are shown in Table 3.

TABLE 3. SIMULATION PARAMETERS FOR DVB-S2

Modulation type	QPSK
Number of bits per packet	1504
Frame Size	64800
LDPC Encoder Input Type	Bits
LDPC Decoder output Type	Information Part
LDPC Decoder Number Of Iterations	50
Modulator Input Type	Bit
Demodulator Output Type	Bit
Channel Noise Factor	SNR
Bits/Symbol	2

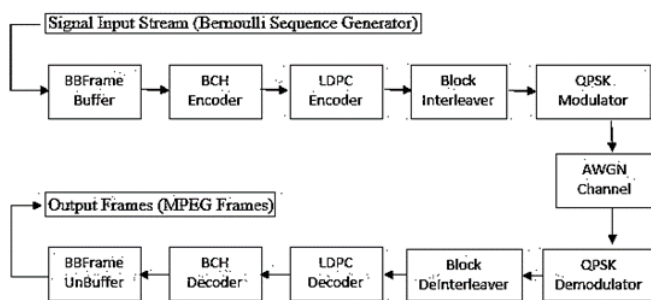


Figure 6. DVB-S2 Block Diagram [10].

Block diagram of DVB-S2 is shown in Fig. 6. BER for varying code rate using QPSK is shown in Figure 7. It is evident that signal power requirement is increased with increasing code rate to make signal detectable at receiver end and reduce interference. QPSK with $1/4$ code rate shows the best performance as BER approaches order of 10^{-5} with minimum power required.

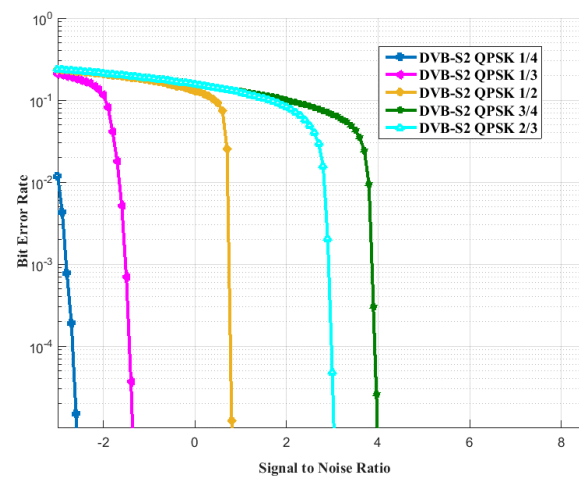


Figure 7. BER Analysis for Different Code Rates Using QPSK

Simulation parameters used for WiMAX 802.16e are shown in Table 4. Figure 8 demonstrates block diagram of WiMAX 802.16e. BER for different modulation schemes and code rates is shown in Figure 9. It is observed that increasing code rate is improving BER but increasing signal energy requirement to be detected at the receiver end. However, different modulation schemes show difference in spectral efficiency characteristics, hence, application- dependent selection can be made.

TABLE 4. SIMULATION PARAMETERS FOR WiMAX 802.16e

No. of Subcarriers	200
FFT Size	256
Ratio of Guard time to G useful symbol time	1/4

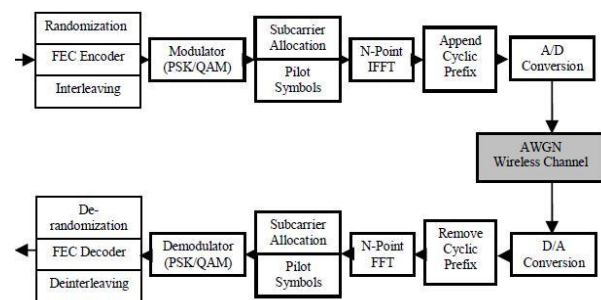


Figure 8. WiMAX 802.16e Block Diagram [11]

DVB-S2 and WiMAX 802.16e for various code rates of QPSK are compared in Fig. 10. It is observed that QPSK with minimum code rate shows the encouraging outcomes in using DVB-S2 compared with WiMAX 802.16e. Satellite communication systems are already using DVB-S2 as broadcasting communication protocol. In lieu of results shown above, proposed link budget in the present study depicts optimum results for single carrier-based LOS scenario which used the minimum required power of 3.8 dBm in clear weather.

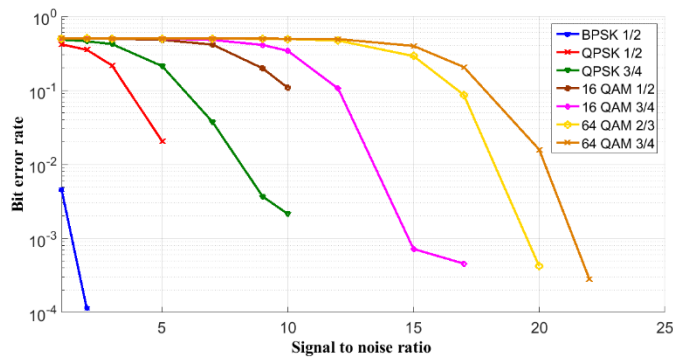


Figure 9. BER Analysis for Different Modulation Schemes and Code Rates

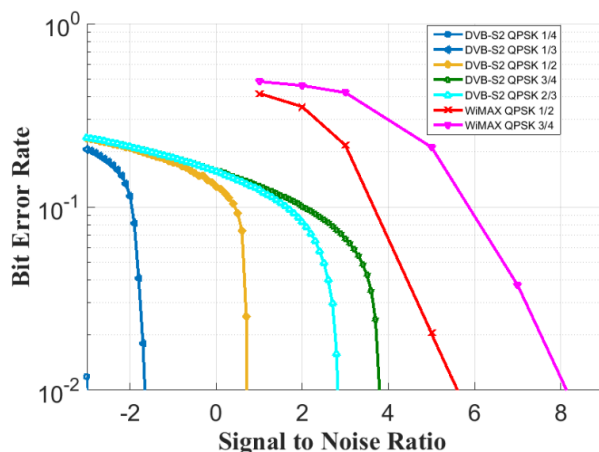


Figure 10. BER Comparison of DVB-S2 and WiMAX

There are several effects which are needed to be incorporated in a more comprehensive study. These aspects include atmospheric losses and power requirements for varying weather conditions and eclipse times.

VI. CONCLUSION

In the present study, a link budget is proposed for simplex communication systems using high altitude platform for the provision of backhaul communication. DVB-S2 for QPSK mode, and IEEE 802.16e in OFDM mode using QPSK as modulation scheme is simulated to perform a BER analysis. DVB-S2 and WiMAX communication protocols are analysed for usage in HAPs for application dependent requirement. Solar power source and lithium ion cells-based energy storage devices are proposed in power budgeting to ensure smooth and uninterrupted operation.

Results illustrates that DVB-S2 at various code rates shows encouraging BER at low SNR (E_b/N_0) as compared with WiMAX 802.16e, which refines the power consumption of overall system for backhaul communication provision.

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