Co-channel Interference between High-altitude Platforms and Terrestrial Systems.

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Abstract**—This paper addresses an in-depth analysis of the stratosphere-to-Earth co-channel interference produced by high-altitude platforms (HAPs) and proposes a new methodology for the evaluation of its impact to terrestrial systems in terms of fractional degradation in performance, taking into account parameters such as HAP's mobility, realistic distribution of azimuth and elevation angles of the terrestrial microwave links (TMLs), and gradual high-altitude platform network (HAPN) loading. Simulations performed for different HAPN configurations, prove that the implementation of the methodology proposed, may lead to a more efficient use of the spectrum shared between the two services.**

Index Terms**—high-altitude platform (HAP), co-channel interference, fractional degradation in performance (FDP), terrestrial microwave link (TML), frequency sharing criteria.**

I. INTRODUCTION

Several high-altitude platform (HAP) systems have been recently proposed for the provision of fixed broadband services in the millimeter-wave frequency bands [1-3]. Flying in the stratosphere at altitudes between 15.5 and 30 Km [4] HAPs could operate as a standalone or complementary network to satellite based and terrestrial communication systems, combining advantages of both, such as large coverage area, low propagation delay, broadband capability and clear line-of-sight signal paths offered by high elevation angles. However there are still some critical issues for this new technology, relating to spectrum sharing conditions with other services and HAP station keeping, which are both studied in this paper.

The International Telecommunication Union (ITU) has allocated a pair of 300 MHz spectrum for HAP systems in the 47/48 GHz band shared on a non-harmful, non-protection basis with geostationary satellite and terrestrial services [3]. Up today there are not any applicable frequency sharing criteria concerning the stratosphere-to-Earth interference from high-altitude platforms (HAPs) to the reception of terrestrial microwave links (TMLs). Initial results [5] showed that an impractical separation distance is required for effective operation of HAP and terrestrial systems. ITU results [6], [8] indicate that this scenario dominates and that it will only be possible to deploy terrestrial receivers outside the visible range of the HAP, and that a coordination distance of 772 Km for a HAPS at 21Km is necessary which could make coexistence of the two systems not feasible. This paper proposes a methodology for the evaluation of the impact of co-channel interference from HAP's stratosphere-to-Earth emissions to terrestrial receivers considering the HAP mobility models, realistic distribution of elevation, azimuth angles of typical urban point-to-point stations and gradual loaded high-altitude platform network configurations.

This paper is structured as follows. Section II contains the definitions for the wireless communication network based on HAPs operating in the V-band. The different HAP mobility models are listed and preliminary interference results are presented. Based on these results, the optimum platform in terms of interference levels to the terrestrial receiver is incorporated into the methodology proposed. Section III contains the general methodology for the evaluation of the impact of stratosphere-to-Earth interference into terrestrial systems. To assess the feasibility of sharing in the practical operational environments, a stochastic distribution of typical TMLs and their elevation, and azimuth angles is presented. The evaluation of the methodology and the derivation of initial frequency sharing criteria are considered in Section IV. Finally our conclusions are drawn in Section V.

II. WIRELESS COMMUNICATION NETWORK BASED ON HAPS IN THE V-BAND

The typical parameters of a wireless communication network using high-altitude platforms for the provision of fixed services in the bands 47.2-47.5 GHz and 47.9-48.2 GHz are proposed in [3]. The system considered in our study comprises:

a. a stratospheric platform placed in a fixed position at heights from *15.5 Km to 30 Km*, able to stay aloft for long periods of time (up to 6 months-unmanned aircraft, up to 5 years-airships) [1-3],
b. antenna installed on the bottom of the HAP transmitting *multi-spot beams*, providing broadband channels to ground stations within the HAP's visible range, which for a HAP at 21 Km extends to a radius of:
    - 36 Km away from the HAP's nadir point below the platform, which forms the urban coverage area,
    - 76.5 Km away from HAP's nadir, which forms

the suburban coverage area ,

- 203 Km away from HAP's nadir, which forms the rural coverage area,

c. up to 2100 high-altitude platform user terminals (HAPUTs) arranged symmetrically in HAP's urban, suburban and rural coverage areas ,

d. up to 80 high-altitude platform gateway stations (HAPGWs) in HAP's urban and suburban coverage areas, which provide interconnection with the fixed telecommunication network.

A. HAP mobility models

One critical aspect in HAP operation is its station keeping when flying in the stratosphere. There are three types of platforms considered in the literature as potential HAPs, which are described below.

1) Unmanned Airships:

Unmanned airships are semi-rigid or non rigid structures, helium filled, deriving power from solar cells on their upper surface, which is used for propulsion and payload operations [3]. These platforms appear to be very large up to 200 m in length and more effective in maintaining station keeping. The ITU considers such a structure which uses a differential GPS sensor for closed loop control of its spatial location to a 400 m radius circle and a vertical dimension to ± 700 m (nominal height 21 – 25 Km) at altitude.

2) Solar-powered Unmanned Aircraft

Unmanned solar-powered aircraft are best represented by HELIPLAT [1] and HELIOS [4]. They are expected to maintain their stability within a position cylinder that is sized depending on the service availability. The target figures for this category are based on HELINET results [1]**,** which indicated ± 4 km laterally and ± 1500 m altitude for 99·9% of the time and ± 2.5 km laterally and ± 500 m altitude for 99%. Along with airships, unmanned aircraft appear to grapple with high altitudes of 21 Km.

3) Circling Manned Aircraft

Circling aircraft are best represented by HALO platform [2]. They keep a quasi-stationary position above the Earth by flying in a toroidal volume of airspace with a diameter of about 9.3 Km to 14.8 Km and heights between 15.5 Km and 18.3 Km.

B. Evaluation of HAP Mobility Models

The evaluation of the statistical behavior of interference variations due to platform's movement was based on a Monte-Carlo approach, in which every trial corresponds to a different random position of the HAP inside the edge area of each mobility model described in the previous subsections. The cumulative distribution functions (CDFs) of interference density are generated corresponding to the probability that a certain amount of interference may be experienced. The analysis was performed with a HAP serving 50 user terminals in the rural area coverage. The rural area is the worst frequency sharing area for this interference propagation path [5]. In the first case studied (Fig. 1), the terrestrial receiver was deployed 60 Km away from the nadir point underneath the HAP, while in the second case (Fig. 2), the receiver was deployed 135 Km away from the border of HAP coverage area. Simulation results (Figs 1, 2) show that the co-channel interference levels depend on the HAP mobility model used. In both cases HALO model appear to have the strongest effect on the interference levels, with the HELINET an ITU models subsequent. ITU model proves to be the optimum model in frequency sharing criteria and thus it will be the one to be used in the analysis presented in Section IV.

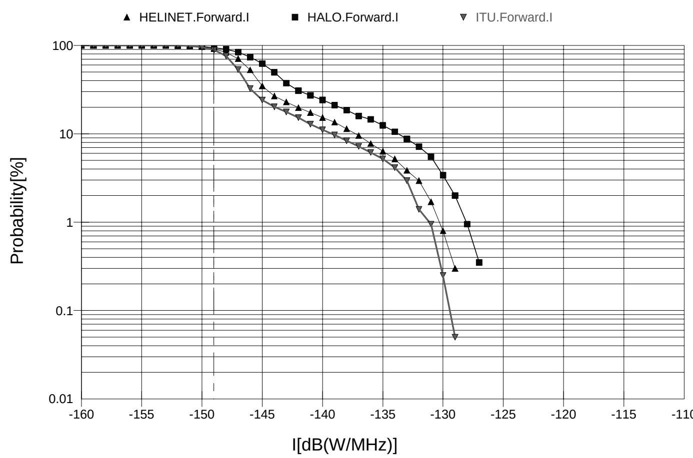


Fig. 1. CDFs of Interference density – Terrestrial receiver 60 Km away from the HAP's nadir.

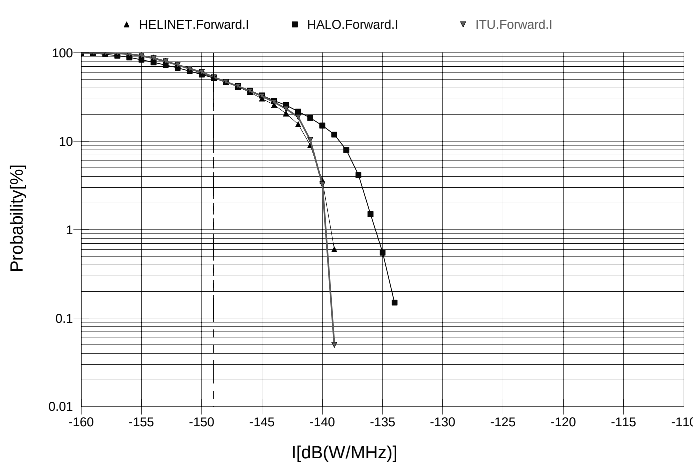


Fig. 2. CDFs of Interference density – Terrestrial receiver 135 Km away from the border of HAPN RAC

III. Methodology for Evaluation of the Impact of Co-Channel Interference from High-altitude Platforms to Terrestrial Microwave Links

The methodology described in this section provides a model for the evaluation of the impact of co-channel interference from the downlink (stratosphere-to-Earth) emissions of HAPs to the reception of terrestrial point-to-point (P-P) systems. Spectrum sharing between high-altitude platform networks and terrestrial systems involves *time-varying phenomena* such as HAP's movement, interference geometry, propagation conditions, HAPN traffic allocation during day and night.

In such cases it is appropriate to model the effects of interference in terms of *fractional degradation in performance* (FDP) [2]. The outage probability of a digital system can be written in the following form:

$$P_0 = C\left[10^{-DFM/10} + 10^{-TFM/10} + 10^{-(C/I-CNC)/10}\right] \quad (1)$$

where C is a constant depending on climate, terrain and link parameters, DFM is the dispersive fade margin in dB, TFM is the thermal fade margin in dB, C/I is the ratio of unfaded signal power to the noise-equivalent value of interference power in dB, and CNC the value of carrier-to-noise ratio at which the performance criterion is just met in dB.

Considering that:

a) modern digital systems usually have dispersive fade margins larger than their thermal fade margins, the first term in equation (1) can be ignored for interference,

b) since the difference in decibels between the unfaded carrier-to-noise ratio and the critical carrier-to-noise ratio (CNC) is the thermal noise fade margin (TFM), the fractional increase in P_0, the probability of exceeding the performance objective, is equal to the ratio of the interference power I to the noise power N_T,

we conclude that the fractional increase is equal to I/N_T, for a constant interference power I. Such an increase in P_0 will be designated as a fractional degradation in performance (FDP). If an interferer caused an interference power I_i for a fraction of reference period f_i, and was absent for the remainder of the period, the incremental FDP due to this interference is given by:

$$\Delta P_{O,i} = \frac{I_i f_i}{N_T} \quad (2)$$

The FDP due to a set of events, where the i_{th} event consists of the fraction of time that the interference had a power I_i is given as:

$$FDP = \sum \Delta P_{0,i} = \sum \frac{I_i f_i}{N_T} \quad (3)$$

where the summation is taken over all interference events.

Considering the interference geometry, depicted in Fig. 3, where θ is the discrimination angle between the direction of the main beam of HAP towards the HAPUT and the direction of the interfered terrestrial station, ϕ is the discrimination angle between the azimuth of the TML (T1-T2) and the direction towards the HAP,

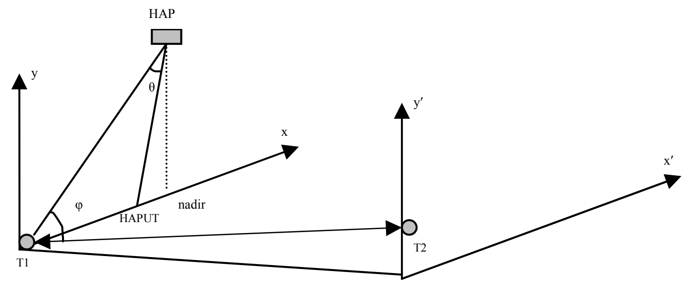


Fig. 3. Geometry of interference between HAP and TML

the interference power from the HAP to the terrestrial receiver is obtained by:

$$I_{(\mathrm{H-T})} = P_{H-T} + G_H(\theta) + G_T(\phi) - FSL_{(H-T)} - L_{feeder} - L_{Atmospheric} \quad (4)$$

where $P_{(H-T)}$ is the transmission power density from HAP to the ground station in dB(W/MHz), $G_H(\theta)$ is the transmitting antenna gain of HAP at the angle θ in dBi, $G_T(\phi)$ is the receiving antenna gain of terrestrial station at the angle ϕ in dBi. $FLS_{(H-T)}$ are the free space losses in the channel between the HAP and the terrestrial station, L_{feeder} are the feeder losses of the HAP and the terrestrial station in dB.

$L_{Atmospheric}$ are the losses due to atmospheric absorption. In the path between a HAP and terrestrial terminals, atmospheric gases including water vapour cause attenuation, which depends on the distribution along the path of meteorological parameters such as temperature, pressure and humidity, and thus varies with the geographic location of the site, the month of the year, the height of a ground terminal above sea level, the elevation angle of the slant path and the operating frequency [8]

The thermal noise of the terrestrial station is obtained by $N_T = 10\log(kTB) + NF \ (dB)$ where k is the Boltzmann's constant ($1.38 \times 10^{-23} (J/K)$), T is the temperature (K), B the bandwidth (Hz), and NF the noise figure of the terrestrial receiver (dB).

A. Terrestrial Microwave Links

The technical characteristics of typical terrestrial systems in the 47-50.2 GHz band are specified in [9]. We have selected to perform our simulations based on the characteristics of the most sensitive to interference system. In this way the results and the conclusions of this study can be a guide for all the terrestrial systems proposed in the recommendation.

The position of terrestrial stations was obtained from databases that provide specifications of the existing links in the geographic region of Attiki (Greece). The terrestrial microwave links in our analysis are deployed in a typical urban environment covering an area of 11300 Km^2 with the centre of the area having the following coordinates: Latitude N 38:8′, Longitude E 23:40′

In most studies up today the worst case regarding the elevation angle of the terrestrial stations was considered. In this paper we propose a realistic stochastic distribution of terrestrial station antenna elevation angle derived from the database, which can be useful for frequency sharing studies in this kind of environment (Graph 1). As can been from the graph 49.51% of the elevation angles are in the range of 0-1 degrees, 37.87% are in the range of 2-4 degrees while the rest are in the range of 5-23 degrees.

IV. Derivation of Separation Distance between the two Service Areas for the Efficient Use of the Spectrum

Initial simulations were performed between a high-altitude platform network and terrestrial microwave links with the scope of evaluating the fractional degradation in the performance of all the terrestrial links using the model introduced in Section III. First we characterized the effect of the orientation of a possible HAPN deployment towards the TMLs area. After that we studied gradually loaded HAPN configurations at different geographical separation distances from the TMLs area as specified in the preceding section. All simulations have been performed based on the following assumptions:

- HAP is placed at 21 Km,
- HAP follows the ITU mobility model

Preliminary results indicated that the coexistence of the two services in the same geographical areas is not feasible. Therefore we have focused our analysis on deriving a geographical separation distance d_{sep} between HAP coverage area and TMLs deployment area taking into consideration that a HAPN will be gradually deployed. For this reason we introduce the following different *HAPN configurations* shown in Table 2.

In our analysis we assume the required protection level of 10%. Reference [9] states that, in principle, the interference level relative to receiver thermal noise should not exceed –10 dB (or –6 dB). In the case of digital terrestrial systems, these values correspond to an FDP value of 10% (or 25%), respectively.

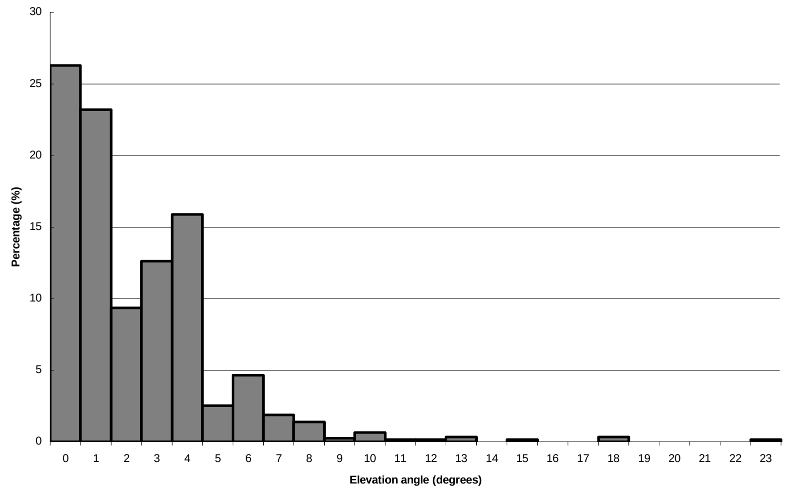
The first step of our analysis was to identify the worst possible orientation of the HAPN coverage area with respect to the deployment area of the terrestrial stations. We considered a 10% loaded HAPN, providing services westwards to the TMLs area and another one northwards to the TMLs area, based on the possible deployment strategies defined by the specific geographic environment around the area of *Attiki (Greece).* The HAPN and the TMLs areas are adjacent (d_{sep}=0 Km). By comparing the statistics presented in Fig. 4, we focus our analysis on the westwards placed HAPN which appear to produce the worst FDP levels in the TMLs with an average value of 9.6% and a deviation of around 24%. In addition one of the two directions of the links, return direction, is selected for our study for the reason that it appears to be more degraded than forward links. Adjacent operation of the two services seems difficult even for a low loaded HAPN. However it should be mentioned that the average values of FDP (presented in Table 3) are below the criterion of 10% (3.19 % for the north HAPN, 9.62% for the west HAPN).

Figure 5 show the results of the analysis concerning a 10% loaded HAPN and a 25% loaded HAPN with their coverage areas limits being 130 Km away from the limit of the TMLs area. Figure 6 show the results of a 50% loaded HAPN and a 75% loaded HAPN with their coverage areas borders being 130 Km away from the limit of the TMLs area. A d_{sep} of 130 Km proves to be adequate for a 10% loaded HAPN but appears to be insufficient for the other three configurations. However the average values of FDP for the 25%, 50%, 75% loaded HAPN are very low (<2 %) and far below the criterion. Last, we compare the contribution of HAP links to user terminals and gateway stations, to the fractional degradation in the performance of the TMLs.

Fig 7. shows that there is an apparent difference in the degradation due to the user terminal links and the degradation due to gateway station links. Average values of FDP are in the range of 0.91%, 1.29% and 0.15%, 0.24% accordingly.

Table 1. HAPN configurations

HAPN	*HAPUTs in UAC/SAC/RAC*	*HAPGWs in UAC*	*HAPGWs in SAC*
10% loaded	210	4	4
25% loaded	525	10	10
50% loaded	1050	20	20
75% loaded	1575	30	30
100% loaded	2100	40	40



Graph 1. Antennas' elevation angle distribution of terrestrial point-to-point stations in typical urban environment [Mean=4.17, standard error=1.56, Median=0.29, standard deviation=7.65]

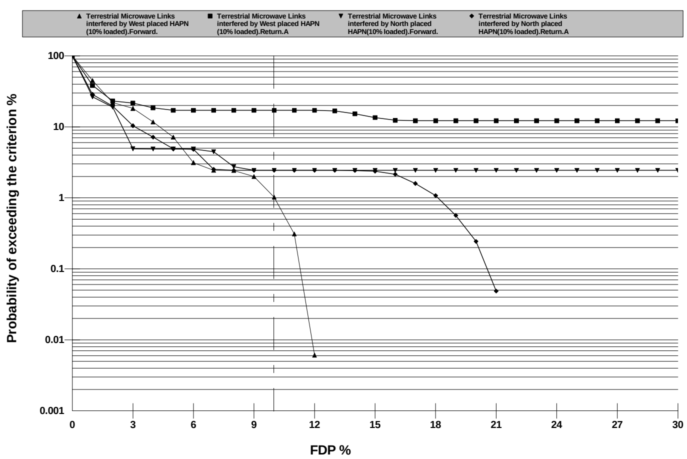


Fig. 4. FDP statistics for a 10% loaded HAPN (North and West oriented) adjacent to the TMLs area

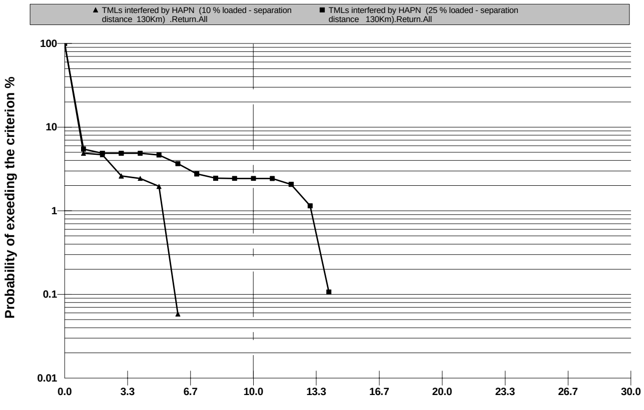


Fig. 5. FDP statistics for a 10% loaded HAPN and a 25% loaded HAPN 130 Km away from the TMLs area

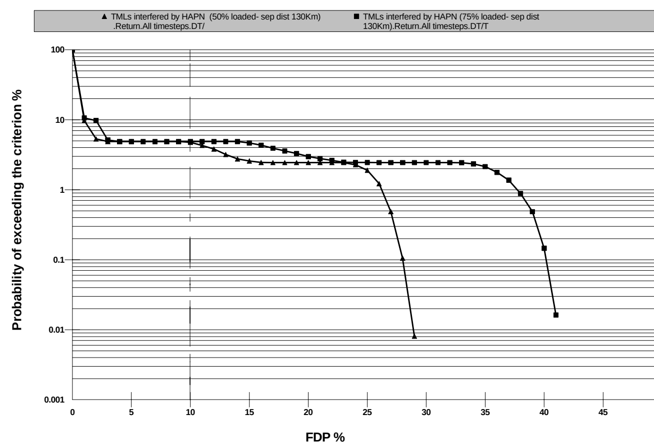


Fig. 6. FDP statistics for a 50% loaded HAPN and a 75% loaded HAPN 130 Km away from the TMLs area

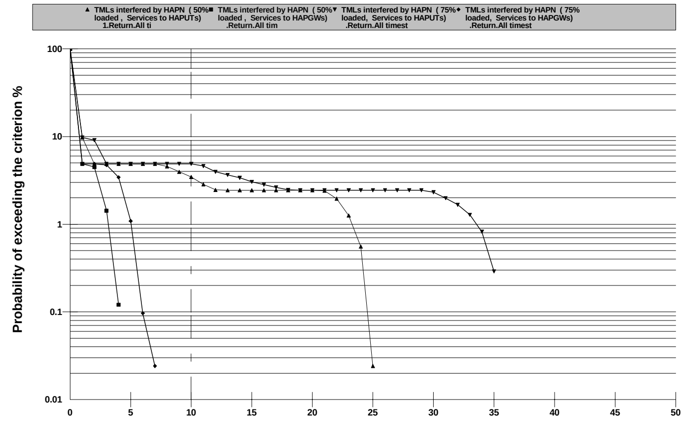


Fig. 7. FDP statistics showing the contribution of HAP links to user terminals and gateway stations

I. Conclusions

This paper has described a methodology for estimating the impact of stratosphere-to-Earth co-channel interference from high-altitude platforms to terrestrial systems. This methodology is based on the evaluation of fractional degradation in performance of terrestrial systems considering parameters such as high-altitude platform's movement, different high-altitude platform network configurations and realistic allocation of azimuth and elevation angles of the terrestrial microwave links. New concepts which could be used in spectrum sharing studies between HAP and terrestrial systems operating in adjacent geographical areas in the millimeter-wave bands were presented. Recapitulating these are:

1. Evaluation of the co-channel interference levels produced by HAPs downlink (stratosphere-to-Earth) emissions considering the platform's instability. Comparison of existing mobility models (ITU, HELINET, HALO) showed that ITU model behaves better in terms of interference levels produced to the direction of terrestrial receivers.
2. Derivation of a $d_{sep,}$ (separation distance), should be based on calculations of fractional degradation in the performance of multiple terrestrial links in their deployment area, taking into account aggregate interference from HAPs.
3. High-altitude platform systems will be gradually deployed and different loaded network configurations should be considered in frequency sharing studies

Initial simulations were performed and the results indicate that the application of the methodology leads to the determination of applicable frequency sharing criteria between the two services. The comparison with the coordination distances proposed by ITU shows that by using the proposed methodology a more efficient use of the spectrum in the V-band is obtained. The proposed methodology can constitute the basis for the development of realistic coordination distances around areas with terrestrial stations.

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