Soft development of a high altitude platform network for national wireless communication service

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The provision of wireless services to the Egyptian territory is proposed using a network of High Altitude Platforms (HAPs). The platforms are interconnected with optical interplatform links in order to provide all wireless communication system. The connection is directed from the source to the overlaying platform and routed from one platform to the other until that one that is analogous to the destination. Each platform serves a certain area that is divided into cells, with each cell being covered by one beam of the antenna array onboard the platform. The system has the promise to swiftly provide wireless communication service anywhere in the territory at a minimal cost that is cheaper and more robust than the wired counterpart.

في هذا البحث تم تقديم طريقة مبسطة لتصميم شبكات الاتصالات اللاسلكية والتي تعتمد على المناطيد الهوائية عالية الارتفاع المستخدمة في طبقة الإستراتوسفير. وقد تزايد الاهتمام بطبقة الإستراتوسفير نتيجة القفزة الهائلة في استخدام خدمات الوسائط المتعددة على نطاق واسع و كنتيجة أيضا للتقدم المطرد في مجالي تطوير المواد المركبة المستخدمة في مجال التحليق الجوى و الخلايا الشمسية ذات الكفاءة العالية بجانب توافر أشباه الموصلات عالية السرعة. ويمثل استخدام نظام المنطاد الهوائي كبديل لنظم الأقمار الصناعية طفرة في عالم الاتصالات اللاسلكية حيث يجمع هذا النظام بين مزايا الأقمار الصناعية و مزايا نظم الاتصالات اللاسلكية الأرضية كما أنه يتفادى عيوب كلا النظامين.

Keywords: Wireless communication, Aeronautical platform, Smart antenna

1. Introduction

The rapid growth in demand for bandwidth-intensive applications such as high-speed Internet/web access, electronic Commerce, interactive video conferencing, and streaming video has created a demand for wireless multimedia communications [1]. In parallel, the advances in compact, high-speed semiconductor devices, development of high strength, light-weight, UV-resistance composite materials for use in aeronautics, improved efficiency of solar and fuel cells. Advances in the field of telecommunications and information technology were the main incentives for the recently increased interest in exploitation of the stratospheric layer for wireless multimedia communications [2]. Stratospheric Telecommunication Systems (STSs) provide an ideal way of delivering wireless narrowband and broadband telecommunication services as well as broadcasting services. High Altitude Platforms (HAPs) can be considered as a hybrid technology, combining some of the best aspects of terrestrial and satellite-based systems, while avoiding many of their drawbacks. In addition, they have their own benefits [3]. The HAPs can be lighter than air unmanned airships or heavier than air manned/unmanned aircraft [4-6]. They fly in the lower stratosphere (around 17-22 Km altitude) and carry communication payload to serve large metropolitan or regional areas [7]. The STSs is intended to replace the terrestrial Base Stations (BSs) network with a network of BSs in the stratosphere [8].

Recently, there is a great interest in the international community for exploiting smart antennas in wireless communication networks [9]. Smart antennas have intelligent functions such as suppression of interference signals, auto tracking of desired signals, and digital beam forming with adaptive space-time processing algorithms [10]. So, they can be included with BS onboard the platforms to provide higher Quality of Service (*QoS*) all over the cell and to increase the capacity of the system [11]. In addition, smart antennas allow service provisioning where and when desired.

In this paper, we propose an advanced wireless communication system that is based on a network of HAPs using interplatform optical links. The network holds the promise to become an efficient soft infrastructure for providing wireless service to the Egyptian territory. The suggested network is all-wireless with 27 HAPs in the sky of Egypt at about 18 Km altitude.

2. Stratospheric wireless communications

There are three general telecommunications architectures, which can be used to deliver wireless services. These are space-based satellites, terrestrial-rooftop cellular-like millimeter wave repeaters and stratospheric relay platforms [3]. Compared to terrestrial systems, HAPs can achieve better Line-of-Sight (LoS) coverage, providing a relatively benign propagation path. Also, they require less ground-based communications infrastructure, where they can deliver multimedia services for larger-area coverage [7]. In addition, their shorter slant path results in less rain attenuation. On the other hand, cellular architecture can be employed to allow for highly efficient channel reuse (smaller cells) schemes, while providing LoS links without the excessive path loss and delay associated with satellite-based systems. The HAPs have much closer range than satellites that results in lower power requirements and smaller size of antennas and user terminals. Besides, they require lower launch costs than satellites and there is no need to rocket launching. They are environmentally friendly, through the use of solar and non-polluting fuel cells. The stratospheric system is to be deployed on a population-based manner instead of the orbital dynamics-based spacing as applied in satellites. The HAPs do not present the risk of uncontrolled downfall as the low orbit satellites do. In case of failure it can be generally possible to remotely pilot the platform descent. Unlike satellites they can be brought down relatively readily for maintenance or upgrading of the payload. Redundant platforms are deployed to provide coverage during these periods. Although stationary when on operation they can easily be moved in compliance with changing communication demands to cover different regions, thus providing network flexibility and reconfigurability [12]. As platform systems require few hours for launching, they are well suited for the instantaneous or gradual deployment of the network, e.g. in emergency situations, when the usual telecommunication infrastructure is suddenly unavailable. Therefore, in comparison with satellites, HAPs seem safer and more suited for a large class of applications, including: pollution monitoring, remote sensing, meteorological measurement, real time monitoring of seismic or coastal regions and terrestrial structure, agriculture support, localization services, video-surveillance, and telecommunication services [8,13].

3. Stratospheric network configuration

The stratospheric platform communication system consists of a quasi-stationary platform in the stratosphere (including airship that carries a station-` keeping system, integrated solar arrays and fuel cells, and communication payload), user terminals, several gateways, and the ground facilities for Telemetry, Tracking, and Command (TT&C) [2,14]. A single platform can provide instant telecommunication infrastructure for an entire region and does not require the deployment of additional, or a constellation of, stations to provide service. Therefore, each HAP constitutes a stand-alone regional system that provides access for the users in the coverage area to the central ground station and can be individually deployed [2].

3.1. Interplatform links

High altitude platforms are interconnected to form a network of platforms. As depicted in fig. 1, the platforms can be linked to one another via Ground Stations (GSs) or via InterPlatform Links (IPLs), and can also be linked indirectly via satellites or the PSTN [15]. When connecting HAPs via GSs, the HAP operation is enabled only above the area where the GS is placed. So, the system coverage depends on ground facilities. When connecting HAPs via IPLs, GSs are used mainly as gateways to other public and/or private networks. The choice between optical and Radio Frequency (RF) interplatform links technologies depends on the link budget analysis [15]. The technology of RF links is well established for satellites. The technology of optical links can be thought of as an optical communications system that transmits laser beams point-to-point through the space, instead of along a fiber optics cable. In this technology the information is superimposed onto a carrier signal with an operating frequency that lies in the optical region. This signal is generated by either a Light Emitting Diode (LED) or a laser diode (onboard one platform) and is propagated outward into the space. A receiver (onboard adjacent platform) intercepts the optical signal some distance away allowing the information to be extracted [16]. For optical systems, unlike radio systems, no spectrum licensing is required and interference from other equipment is not a concern. In addition, data rates comparable to fiber transmission can be carried with very low bit error rates. The effect of signal attenuation encountered in the troposphere layer limits the maximum acceptable distance between platforms to 450-500 km [15]. In comparison with IPLs, Platform to Satellite Links (PSL) are heavier terminals with higher power consumption due to longer communication paths resulting in higher attenuation. However, they can be used as a possible way of integration between STSs and terrestrial or satellite networks. A network of 27 platforms is suggested to cover the Arab Republic of Egypt (ARE), as shown in fig. 2. The coverage area size of each platform depends on the minimum elevation angle, platform height, population density, province area, percentage of business and residential users as well as terrain features.

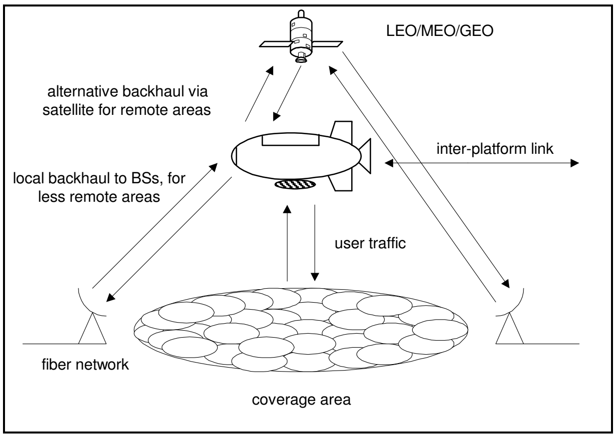

Fig. 1. Different platform links.

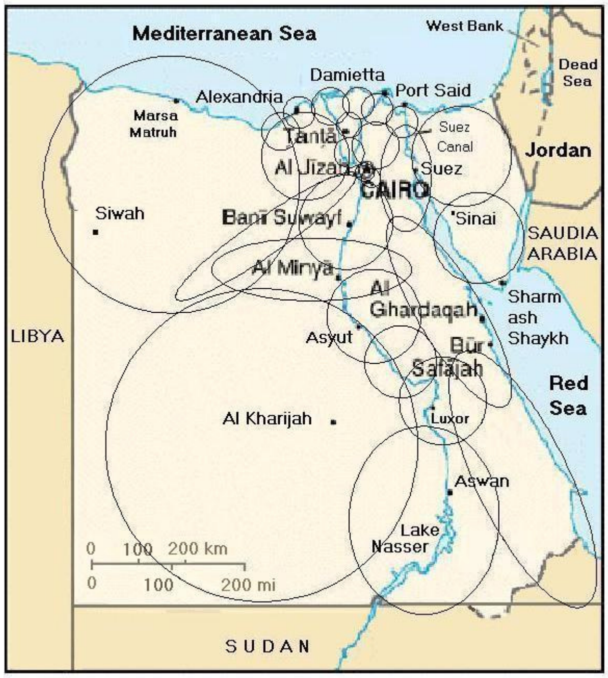

Fig. 2. The footprint of the platforms over ARE.

3.2. Smart antennas onboard the platforms

Smart antennas are able to increase the capacity and reduce the interference of the cellular system by employing Space Division Multiple Access (SDMA) and Spatial Filtering for Interference Reduction (SFIR) approaches [17]. The first approach allows users in the same cell to use the same physical communication channel. In the second approach frequencies can be more closely reused. The smart antenna is equipped with hardware and software combination in order to automatically modify and adapt its own radiation pattern over the time according to the operational scenario while the antenna is in operation [9]. They can be implemented in two categories; these are Switched-Beam (SB) and Adaptive Array (AA) antennas [10]. The first category is the easiest to implement, as it comprises only a basic switching function between separate directive antennas or predefined beam of an array. However, it gives a limited improvement. The second category utilize sophisticated signal-processing algorithms, such as Direction Of Arrival (DOA) and dynamic adaptive beam former (DAB) algorithms, to continuously distinguish between desired signals, multipath and interference signals [18]. Despite their complexity, the ability of AA arrays to track users smoothly with main lobes and interferers with null ensures that the link budget is constantly maximized. The antenna array onboard the platform is designed so that the generated beams are tailored for providing wireless coverage to the pre-defined regions.

4. Design approach

The area to be covered by a HAP is divided into sub areas called cells and frequencies are reused. The challenge in the provision of wireless service by a HAP is the capability to provide service to the smallest cell as this determines the number of elements in the antenna array. Let r denotes the radius of the central cell at the nadir of the platform. The number of antenna elements N of a two-dimensional array of N*x*N elements is given by,

$$N = \frac{0.886}{\sin\left(\tan^{-1}\left(\frac{r}{h}\right)\right)}. \quad (1)$$

Where h is the platform altitude and the spacing between elements equals half the wavelength. The cell area is determined according to the number of available channels and the required grade of service [12]. The grade of service is dependent on the offered traffic by the potential users that is in accordance a function of the population density and the telephone request rate. If the number of channels being assigned to a cell is C and the offered traffic is A Erlang, the grade of service is specified in terms of the call blocking probability using Erlang B formula as

$$P_B = \frac{A^C / C!}{\sum_{i=0}^{C} A^i / i!}. \quad (2)$$

A number of 5 platforms is suggested to cover provinces of Delta, as shown in fig. 3, and the design parameters are declared in table 1. For Al-Gharbia and Kafr El-Sheikh provinces, consider the number of channels per cell C is 1000 and the tolerable blocking probability is 2%. This corresponds to an offered traffic A of 991.9 Erlang. The radius r

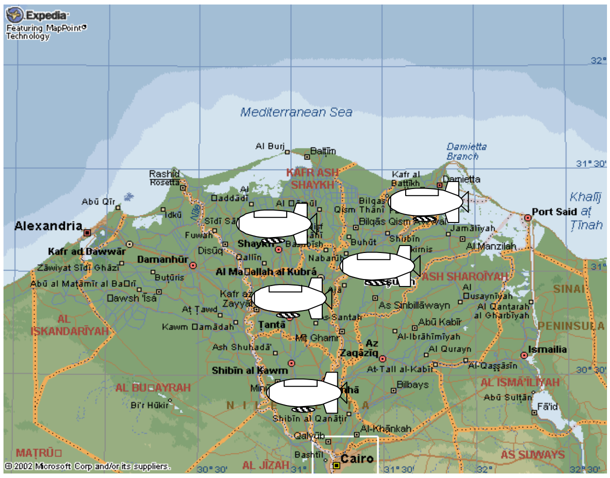

Fig. 3. The platforms over provinces of Delta.

Table 1
Provinces of delta design parameters

Province	Al-Gharbia	Kafr El-Sheikh	Al-Dakahlia	Dumyat	Al-Kalubia, Al-Menoufia
Area (km^2)	1942.21	3437.12	3470.9	58.17	2533.139
Pop. density (Citizen/km^2)	1750.58	640.07	1210.06	15532.53	3296.67
PF height (km)	18	18	18	18	18
Blocking probability (%)	2	2	2	2	2
Channels/beam	1000	1000	1000	1100	1100
Offered traffic (erlang)	991.9	991.9	991.9	1093	1093
Radius of central cell (km)	2	3.35	2.44	1.55	1.55
Minimum elevation angle (degree)	40	28	29	55	35
Dimension of AA array	8 x 8	5 x 5	7 x 7	10 x 10	10 x 10

of the central cell of each province is found by implementing the algorithm shown in [12]. The central cell radii of both Al-Gharbia and Kafr El-Sheikh provinces is achieved to be 2 Km and 3.35 Km, respectively. From (1), the AA array dimensions required to form these cells is 8x8 and 5x5, respectively, for the proposed altitude of 18 Km. The suggested cellular structure for deploying wireless communications for users roaming in Al-Gharbia is shown in fig. 4. The corresponding structure of Kafr El-Sheikh province is shown in fig. 5. Considering the fact that Kafr El-Sheikh province has wider area and lower population density than Al-Gharbia province, the cellular structure of Kafr El-Sheikh province will have wider cells. Comparison of fig. 4 and fig. 5, clarifies such result.

5. Conclusions

The rapid development of a cost effective communication service can be satisfied through the usage of HAP network with IPLs. Exploiting the flexibility of the smart antenna arrays allows provisioning of wireless communication anywhere in the Egyptian territory. The design approach was explained and the network layout was proposed in this paper. The presented results will help designer of such network to implement their network based on sound concepts.

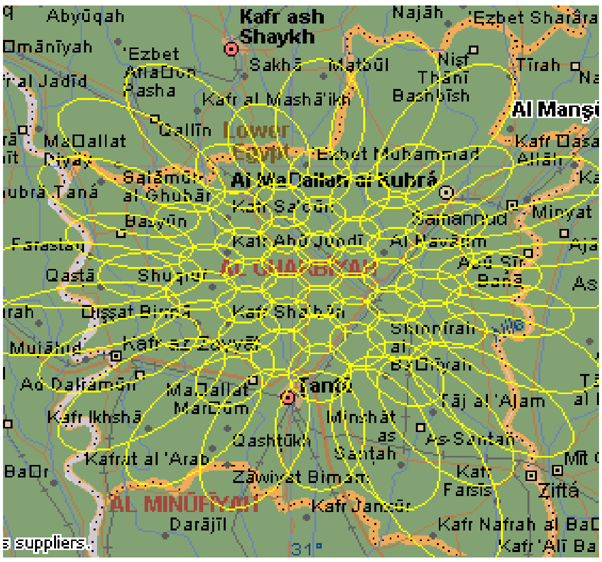

Fig. 4. The projection of spot beams over Al-Gharbia province.

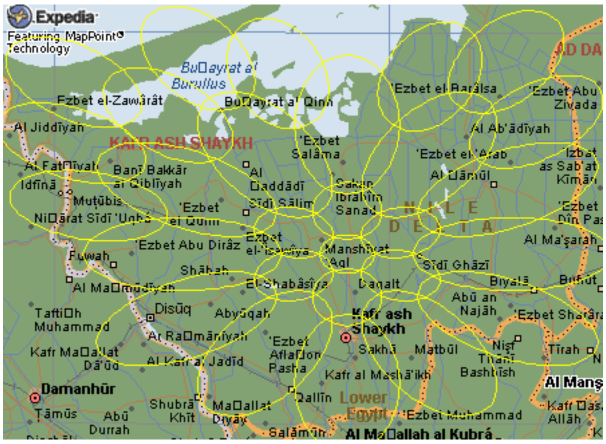

Fig. 5. The projection of spot beams over Kafr El-Sheikh province.

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