HALO (High Altitude Long Operation): A Broadband Wireless Metropolitan Area Network

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Abstract- **The High Altitude Long Operation (HALO) network is a broadband wireless metropolitan area network whose solitary hub is located in the stratosphere above the service area. One of several possible architectures of the HALO network and the corresponding system reference model are presented in this paper. A simulation model was developed for the chosen architecture. Several experiments were performed upon it under various traffic conditions to model the performance of the network.**

I. INTRODUCTION

The markets of broadband, wireless, and multimedia network services are growing rapidly. Those markets are demanding infrastructure that can be quickly and economically deployed. Services must be delivered to businesses and consumers, the end users of the network, at affordable prices. Qualify of Service (QoS) must be guaranteed. And, the information bandwidth must increase dynamically to the needs of the end user with an imperceptible latency following a request for more bandwidth, if not in real time.

Innovative communications networks are being pioneered. The High Altitude Long Operation (HALO) network is a broadband wireless Metropolitan Area Network (MAN) consisting of HALO aircraft operating at high altitude and carrying an airborne communications network hub, with network elements on the ground.

The HALO network combines the advantages of two well-established wireless communication services: satellite networks and terrestrial wireless networks like cellular and personal communication systems. Satellite networks, including those being developed, as well as those proposed, for operating at Low Earth Orbit (LEO), Medium Earth Orbit (MEO), High Elliptic Orbit (HEO), and Geosynchronous Earth Orbit (GEO), have advantages such as free-space-like channels with Ricean fading and high look angles (line of sight). But, their disadvantages include expensive high-power user terminals, long propagation delays, and stagnant performance growth. And, system capacity is practically fixed and can be increased typically only by adding satellites. In contrast, terrestrial wireless networks have advantages such as low-cost low-power user terminals, short propagation delay, and good scalability of system capacity. However, their disadvantages include low look angles, multipath channels with Rayleigh fading, and complex infrastructures. They require many base stations that must be inter-linked over cables or microwave links in order to backhaul aggregated traffic. Cell-splitting, to add system capacity, requires reengineering of the network.

The HALO network will be located in the stratosphere at an altitude between terrestrial wireless and satellite networks. It will provide broadband services to businesses and to small offices/home offices in an area containing a typical large city and its neighboring towns. To each end user, it will offer an unobstructed line of sight and a free-space like channel with short propagation delay, and it will allow the use of low-power low-cost user terminals.

The HALO network infrastructure is simple, having a star topology with a single central hub. Consequently, the deployment of service to the entire metropolitan area can occur on the first day the network is deployed, and the subsequent maintenance cost is expected to be low. The system capacity can be increased by decreasing the size of beam spots on the ground while increasing the number of beams within the signal footprint, or by increasing the signal bandwidth per beam. The HALO network can interface to existing networks. It can operate as a backbone to connect physically separated LANs (Local Area Networks) through frame relay adaptation or directly through LAN bridges and routers. It can also provide videoconference links through standard ISDN or T1 interface hardware.

The remainder of the paper is organized in four additional sections. In Section II, we present a conceptual system architecture of the HALO network and a corresponding reference model is proposed in Section III. We describe the simulation model and results in Section IV and conclude the paper in Section IV.

II. THE SYSTEM ARCHITECTURE OF HALO NETWORK

As shown in Fig. 1, the HALO/Proteus aircraft serves as the hub of the wireless broadband communications network

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[2, 3]. It carries the airborne network elements including an ATM switch, spot beam antennas, multi-beam antennas, as well as transmitting and receiving electronics. The antenna array provides cellular-like coverage of a large metropolitan area. An ATM switch was chosen over an IP switch due to the following attributes: it can be used as backbone and it supports multimedia traffic types with end-to-end QoS expectations. Recently-produced ATM switches have capacities (around 50 Gbps) sufficient to satisfy the traffic volume requirements of the first network deployment and offer margins for growth.

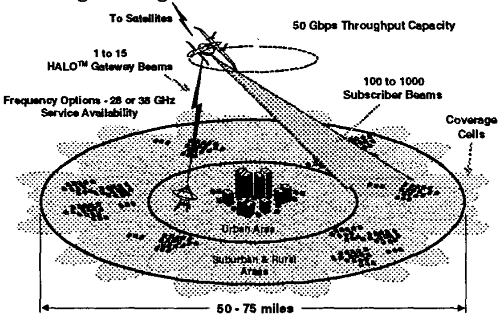

Fig. 1. The system architecture of HALO network

The antenna array produces beams on the ground of two types: 1) The shared beam: It provides services to 100~1000 subscribers. 2) The dedicated beam: It provides connections to gateways serving high bandwidth users and to the network gateway through which a user from a non-HALO network can access the services of HALO network and can deliver information to any end user of the HALO Network.

The aircraft maintains station at an altitude of 52 to 60 thousands feet by flying in a circle with a diameter of about 5 to 8 nautical miles. A continuous presence is established overhead, 24 hours per day, by operating a small fleet of aircraft in shifts. Since the look angle is of 20 degrees or higher, the aircraft can have a clear line-of-sight to every rooftop in the signal footprint with a high probability.

There are a variety of spectrum allocations that could be utilized by a HALO network. The choice of which spectrum to use will be driven by pragmatic technical and business factors including, but not limited to, practical link margins, licensed bandwidth, maturity and affordability of the user terminals, teaming agreements, spectrum access and regulatory law. Prior publications [2, 3] have commented upon the following two spectrum allocations as examples for creating a high-capacity HALO network offering wireless broadband services: 1) The Local Multipoint Distribution Services (LMDS) at 28 GHz; 2) The microwave point-to-point allocation at 38 GHz.

The HALO network utilizes multiple beams on the ground arranged in a typical cellular pattern. Each beam spot in the pattern functions as a single cell. Each cell covers more than several square miles of area. Adjacent cells have different frequency sub-bands. The pattern has a periodic nature and each sub-band in the set so chosen (i.e., each sub-band of the Frequency Re-use Plan) is used multiple times within the service area. Through frequency reuse, about 2800 squares miles of area can be covered. The total capacity achieved by only one platform can be greater than 40 Gbps.

In Fig. 2 we provide a map of the shared beam cells that, for the purpose of modeling, we assumed would be produced by the antenna array carried by the HALO aircraft we assumed that there would be 6 rings of cells composed of 125 beams. The cells created by the antenna array would be fixed on the ground and there would be no overlapping area between adjacent cells. The cellular pattern would cover a metropolitan-scale area. The altitude of aircraft would be 16 kilometers. It would have an orbit diameter of 14.8 kilometers (ring 3 level). By assuming a constant ground speed, the orbit would have a period of approximately 6 minutes.

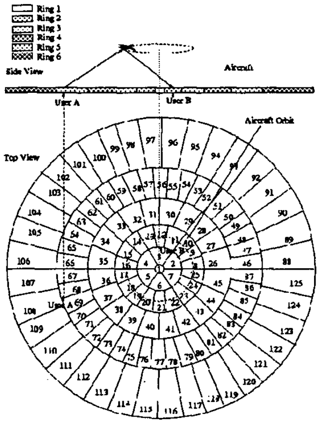

Fig. 2. The footprint of shared beam cells.

Each cell on the ground is covered by one spot beam. However, the spot beam that covers a particular cell changes due to the motion of the aircraft. A given beam covers a given cell on the ground for a duration of time called *dwell time*. Once the duration is exceeded, the beam must ratchet over by one or more beams to cover a new cell on the ground. The ratcheting action requires a burst modem in the user terminal and the use of electronically stabilized beams aboard the airplane. A beam-to-beam handover event may arise [1]. Suppose users A and B are connected by antennas 106 and 26 at time t. When ratcheting is completed at time $t+T$, they both are connected by two new antennas: 108 and 27 respectively. The beam-to-cell correspondence matrix is dynamic. The handover event beckons an innovative and pragmatic solution and our future work will focus on developing proprietary methods.

III. THE SYSTEM REFERENCE MODEL OF HALO NETWORK

Shown in Fig 3 are the major elements of the conceptual HALO network including the airborne communications hub carried by the HALO/Proteus airplane, the premise equipment or user terminals, the network control station, HALO Gateway (HG) and the various interfaces. The reference architecture shows the topology of the interconnected network elements.

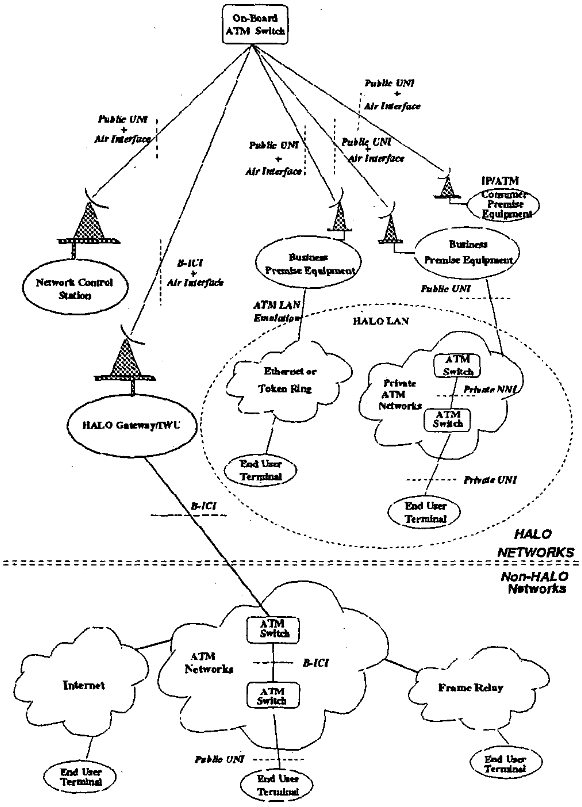

Fig. 3. The system reference model of HALO network.

The HALO network can be connected to non-HALO networks, e.g., ATM networks, Internet, and Frame Relay via HALO Gateway/InterWorking Unit (IWU).

Within the HALO network, four types of network elements can directly be connected to the on-board ATM switch:

1) *Consumer premise equipment (low-rate user terminals):* Since these terminals are equipped with the necessary interfaces to the HALO wireless channels, they have direct access to HALO networks. The terminals can support either ATM or IP end users. If it is an IP user, IP over ATM needs to be implemented in the terminals.

2) *Business premise equipment (high-rate user Terminals):* This type of premise equipment is provided for a user group such as a company, university, factory, or another type of user group. Normally there are local networks available within a user group. For example, a company may have a private ATM network and its employees will have access to that network. If the private network has a HALO network compatible BPE, to serve as a bridge between the corporate network and the HALO network, then all of the users within the company will be able to gain access to the HALO network.

3) *HALO gateway/IWU:* This equipment provides the interface between HALO and non-HALO networks. As shown in Fig. 3., only public ATM networks have direct connection to the HALO Gateway/IWU because other networks are not compatible to the HALO Gateway/IWU. Therefore, the Internet and Frame Relay have to be connected to the public ATM networks before they are connected to the HALO Gateway/IWU.

4) *Network control station:* It is responsible for the maintenance, operation, and administration of HALO networks. Also, the Connection Admission Control (CAC), processing of time slot reservation or request generated by the Medium Access Control (MAC) protocol, handover processing, and location management of mobile users are all managed in this control center.

There are four types of signaling interfaces between ATM networks and the HALO network. The public UNI interfaces are located between the on-board ATM switch and the consumer premise equipment. The signaling interface between HALO Gateway/IWU and the on-board switch is B-ICI. If there exists a private ATM network within the local networks of the HALO, both private NNI and private UNI will exist as shown in Fig. 3.

IV SIMULATION MODEL AND RESULTS

We developed a simulation model to assess the performance of the HALO network concept [1]. In this model, the network components from source to sink are module 1, uplink propagation delay, module 2, ATM switch, module 3, downlink propagation delay, and module 4. Modules 1, 2, 3, and 4 are shown in Fig. 4. The stages from source to sink in the model are as follows:

- *Source traffic generation:* Only data type traffic has been evaluated in the first version of the simulation model. Connection requests and the duration of connections in all beams are generated according to exponential inter-arrival time. Note that connections in different beams may be generated at the same time. We assume the mean arrival rate of connection request is independent of the number of active connections. During the signaling phase, each connection is allocated some time slots per demand if the time slots are available. Otherwise, the connection is blocked. The procedure is carried out by the connection admission control. After a connection is established, it is assigned a channel ID and a beginning time slot number. Furthermore, the ATM cell arrival time or IP packet arrival time is initialized. At this stage, we assume the number of time slots requested by a connection is uniformly distributed in a time interval.

- *Segmenting IP packets into ATM cells (optional. native ATM connections can also be supported):* For the case of IP over ATM, the IP packet is segmented into ATM cells. The IP packet interarrival time and the IP packet length are generated according to the exponential distribution. Since buffering is necessary to carry out segmentation, we allocate a buffer having an appropriate size. However, buffering will cause cell losses and cell delays. We have recorded those variables and have collected statistics of cell loss ratios and average delays. For a pure ATM user-to-user connection, ATM cells will arrive with a constant arrival rate proportional to the number of the assigned time slots.

- *Uplink buffering and framing of ATM cells:* Since each ATM cell must be transmitted on the assigned wireless channel and time slot, we consider the framing process for each ATM cell. When an ATM cell arrives and occupies a time slot in the current available frame, then it is put in that time slot and transmitted. Otherwise, it must wait for the next available time slot within the next available frame. No cell losses will occur in this stage. The delay in this stage is called framing delay. We assume 16 uplink channels per beam. In this stage the buffer sizes of uplink framing for each user are infinite and the queue size of uplink buffering is assumed to be 1000 ATM cells.

- *Propagation delay in the uplink:* In this stage the framed ATM cells are transmitted on the available fixed time slots of the uplink channel to the aircraft. Since the distance from the ground to the aircraft changes dynamically, the propagation delay is assumed to be variable.

- *Constant delay in Rx electronics:* This part is used to consider the delay resulting from Rx Electronics. This delay is assumed to be constant.

- *Queueing and deframing in each beam in the uplink:* Queueing process in this stage is used to simulate the Mux/Formatter in module 2. The output capacity of this queue is determined by 4 OC-1's. Deframing is also considered in this stage since time slots must be deframed into ATM cells before they enter the ATM switch. We assume the deframing time to be constant.

- *Constant delay in the ATM switch:* Since a non-blocking ATM switch will be used on the aircraft, the delay resulting from ATM switch will be constant and assumed to be 10 microseconds.

- *Demultiplexing and framing ATM cells coming from ATM switch:* The outcoming cells from the ATM switch will be routed to the desired beam and channel by appropriate VP/VC translation as well as demultiplexing. These ATM cells will then be framed as the wireless packet and will be assigned into their allocated time slot. In this stage the demultiplexing time is assumed to be constant and the buffer sizes of downlink framing for each user are assumed to be infinite.

- *Constant delay in the Tx Electronics:* After the downlink formatter in module 3, the data traffic will get through the Tx Electronics. This process results in constant delay for each wireless packet.

- *Propagation delay in the downlink:* The distance from the aircraft to the ground results in the downlink propagation delay for each wireless packet. This delay is also variable since the location of the aircraft changes continuously.

- *ATM cells received by the destination on the ground:* In this stage the wireless packets are stripped off of their control information and ATM cells will be obtained.

- *(IP over ATM/reassembly of IP packets from ATM cells):* For IP connections, the ATM cells will be reassembled to create IP packets.

- *Sink at destination:* Delivery of IP packets to their correct destinations.

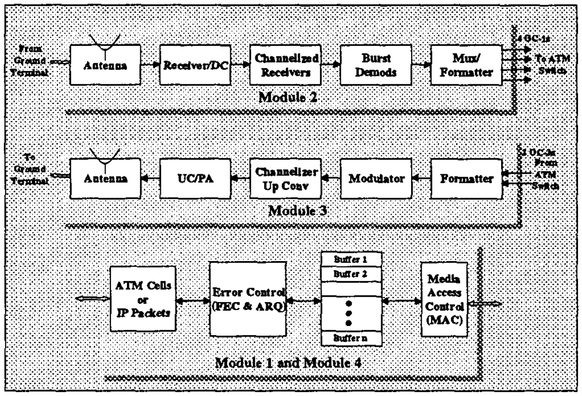

Fig. 4. Modules 1, 2, 3 and 4.

From the simulation model, we computed the end-to-end delay versus cell arrival rate. We assumed the connection request rate in the system to be 0.5 connections/s/beam and the number of time slots requested by a connection is uniformly distributed in the time interval [1,21] where we assume between 1 and 21 time slots can be requested by each user with equal probability. We varied the connection request rates from 0.5 to 5 connections/s/beam.

In Fig. 5 we show the average end-to-end delay for different ATM cell arrival rates with respect to two different connection request rates. Note that the term "NOTS" denotes the number of time slots assigned to the users of a particular connection. The cell arrival rate is in the unit of "NO_TS cells/ms" instead of "cells/ms". The reason is because we used Generalized TDMA (G-TDMA) as the bandwidth allocation scheme. In this scheme, the allocation of bandwidth to a connection is proportional to the amount of traffic generated in the connection. Due to the proportional bandwidth allocation, the unit of cell rate is "NO_TS cells/ms". Also note that the average end-to-end delay in this experiment is defined as the average end-to-end delay of all connections divided by the number of connections.

In Fig. 5 we also illustrate the average end-to-end delay for higher connection request rates is higher than for lower connection request rates. Furthermore, the average end-to-end delay for both scenarios increases with ATM cells arrival rate. From Fig. 5, we conclude that the average end-to-end delay for the HALO network is around 5~7 ms, which is much smaller than in LEO systems and comparable to terrestrial wireless networks.

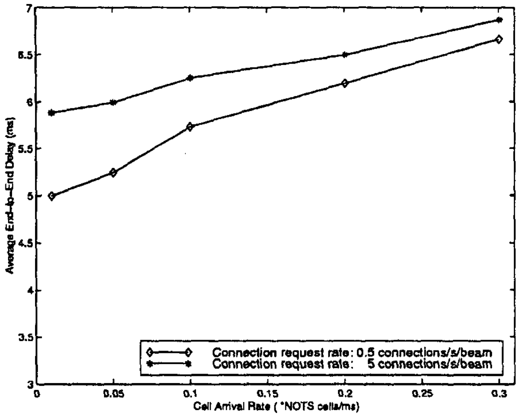

Fig. 5. Average end-to-end delay versus cell arrival rate.

In Fig. 5 we see that the average end-to-end delay increases gradually depending on the ATM cell arrival rates. However, the delay increases very abruptly, when the cell arrival rate reaches a particular value as shown in Fig. 6. The particular value is the maximum cell arrival rate in the unit of "NO_TS cells/ms" for each user. The existence of this maximum cell arrival rate results from the upper bound of the cell arrival rate which is approached at NOTS×1/3 cells/ms. We justify this upper bound as follows.

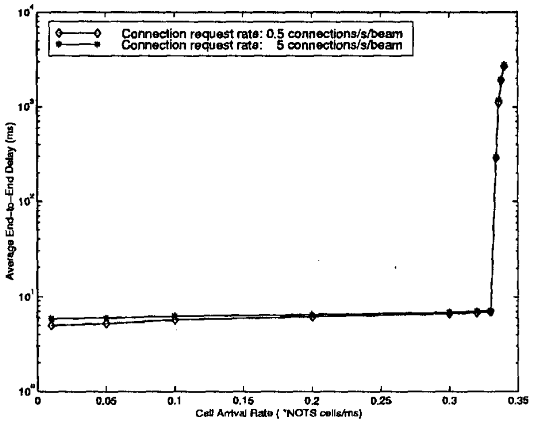

Fig. 6. Average end-to-end delay versus cell arrival rate.

The incoming link capacity for each antenna beam of the ATM switch is 4 OC-1's, i.e., 4×49.536 Mbps [1]. If the frame length is 6 ms and there are 16 channels in each uplink beam with 2 ATM cells in each time slot, then the number of time slots for transmitting ATM cells should be 2×4×49.536/(2×53×8×16/0.006) = 87.6, or 88 time slots. Therefore, for a frame length of 6 ms and 88 time slots per channel, each time slot can only transmit 2 ATM cells. Therefore, the upper bound of the ATM cell arrival rate for each time slot is 2/6 cells/ms = 1/3 cells/ms. If the arrival rate is equal to or higher than this value, more and more ATM cells would wait in the queues. Thus, the average end-to-end delay will increase abruptly. Therefore, our experimental results are consistent with the theoretical analysis.

V CONCLUSIONS

The HALO network is a stratospheric communications layer for offering broadband wireless services to a metropolitan area through a single airborne communications hub [4]. The HALO network has the advantages of low end-to-end delay, good line of sight, good tradeoffs of spectrum reuse versus propagation delay, low power affordable user terminals, a simple topology, and a low handover overhead. It is a promising network option to provide broadband wireless network services at an affordable price to many types of end users.

In this paper, we described one possible system architecture concept of the HALO network. We also presented a corresponding system reference model. Several experiments were completed based on a simulation model. Performance such as end-to-end delay has been computed and reported.

In the future, we plan to report on a variety of system architectures appropriate to deploying HALO network. For each choice, we intend to investigate variations and their impacts upon system performance: e.g., the altitude of the aircraft as related to propagation delay, end user terminal power, degree of look angle, and spectrum reuse factor. In the first set of experiments reported herein we assumed only data traffic. However, since the objective of the HALO network is to support multimedia traffic, our future experiments will attempt to capture the effect of integrated traffic types. Finally, we are developing efficient traffic control algorithms and dynamic channel allocation schemes that aim to provide satisfactory QoS expectations for the end users.

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