The HALO Network™

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ABSTRACT

The High Altitude Long Operation Network™ is a broadband wireless metropolitan area network, with a star topology, whose solitary hub is located in the atmosphere above the service area at an altitude higher than commercial airline traffic. The HALO/Proteus airplane is the central node of this network. It will fly at altitudes higher than 51,000 ft. The signal footprint of the network, its "Cone of Commerce," will have a diameter on the scale of 100 km. The initial capacity of the network will be on the scale of 10 Gb/s, with growth beyond 100 Gb/s. The network will serve the communications needs of each subscriber with bit rates in the multimegabit per second range. A variety of spectrum bands licensed by the FCC for commercial wireless services could provide the needed millimeter wavelength carrier bandwidth. An attractive choice for the subscriber links is the LMDS band. The airplane's fuselage can house switching circuitry and fast digital network functions. An MMW antenna array and its related components will be located in a pod suspended below the aircraft fuselage. The antenna array will produce many beams, typically more than 100. Adjacent beams will be separated in frequency. Electronic beamforming techniques can be used to stabilize the beams on the ground, as the airplane flies within its station keeping volume. For the alternative of aircraft-fixed beams, the beams will traverse over a user location, while the airplane maintains station overhead, and the virtual path will be changed to accomplish the beam-to-beam handoff. For each isolated city to be served, a fleet of three aircraft will be operated in shifts to achieve around-the-clock service. In deployments where multiple cities will be served from a common primary flight base, the fleet will be sized for allocating, on average, two aircraft per city to be served. Flight operational tactics will be steadily evolved and refined to achieve continuous presence of the node above each city. Many services will be provided, including but not limited to T1 access, ISDN access, Web browsing, high-resolution videoconferencing, large file transfers, and Ethernet LAN bridging.

INTRODUCTION

The markets of broadband, wireless, and multimedia network services are growing rapidly, as evidenced by NASDAQ minting millionaires on a daily basis. Those markets are demanding infrastructure that can be deployed quickly and economically. Services must be delivered to businesses and consumers, the end users of the network, at affordable prices. Quality of service (QoS) must be guaranteed. Also, the information bandwidth must respond dynamically to the needs of the end user with an imperceptible latency following a request for more bandwidth.

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 and 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 to be deployed at low earth orbit (LEO), medium earth orbit (MEO), high elliptic orbit (HEO), and geosynchronous earth orbit (GEO) will offer quasi free-space channels with, at worst, Ricean fading, due to clear line-of-sight signal paths offered by high look angles. However, their disadvantages include expensive high-power user terminals, long propagation delays, and stagnant performance growth. Also, system capacity will be practically fixed and can be increased incrementally only by adding satellites. In contrast, terrestrial wireless networks have advantages such as low-cost, low-power user terminals, short propagation delays, 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 interlinked over cables or microwave links in order to backhaul aggregated traffic. They often require significant reengineering to increase capacity when using cell-splitting techniques.

The HALO network will be located in the atmosphere, at an altitude miles above terrestrial wireless, but hundreds to thousands of miles

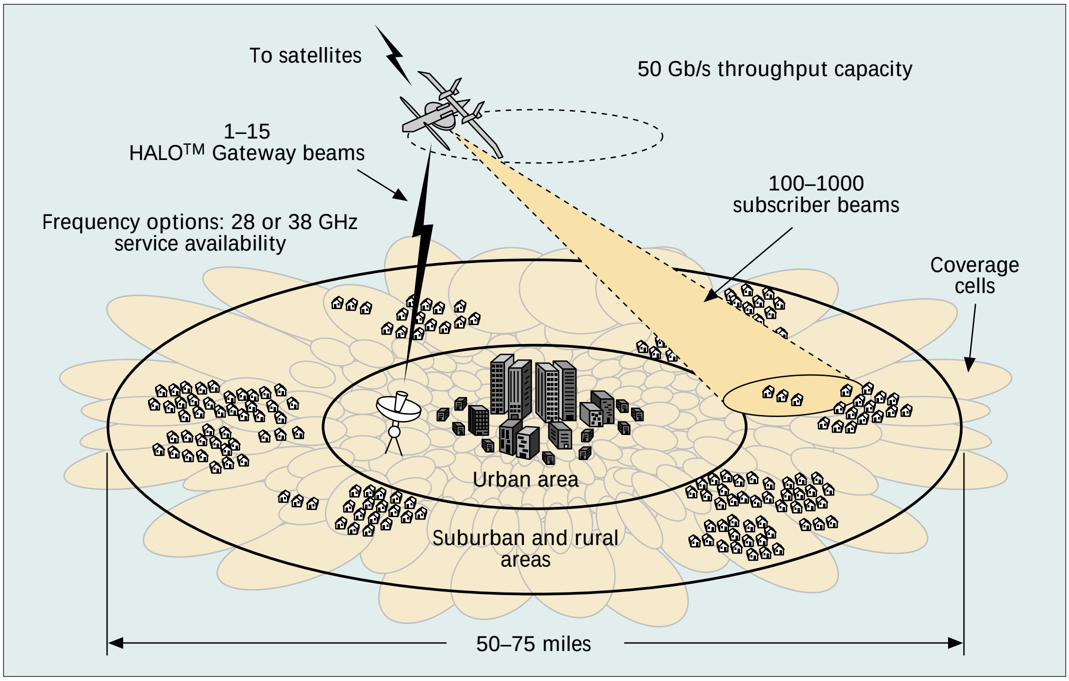

Figure 1. *The system architecture of the HALO network.*

below satellite networks. It will provide broadband services to businesses and 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 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 this article is organized in four sections. We present a conceptual system architecture. A corresponding reference model is proposed. We discuss the services provided by HALO networks. The user terminals are described. The advantages of HALO networks are compared with terrestrial wireless and satellite networks, followed by concluding remarks.

The System Architecture of the HALO Network

As shown in Fig. 1, the HALO/Proteus aircraft serves as the hub of the wireless broadband communications network [1–4]. It carries the airborne network elements including an ATM switch, spot beam antennas, and multibeam antennas, as well as transmitting and receiving electronics. The antenna array provides cellular-like coverage of a large metropolitan area. Asynchronous transfer mode (ATM) switches, now available, have capacities sufficient to satisfy the traffic volume requirements of the first network deployment and margins for growth.

The HALO/Proteus airplane shown in Fig. 2 has been specially designed to carry the hub of the HALO Network. The airplane can carry a weight of approximately 2000 lb (900 kg) to its station keeping volume. The airplane is essentially an equipment bus from which commercial wireless services will be offered. A fleet of three aircraft will be cycled in shifts to achieve continuous service above an isolated city. In a multicity deployment, an average of two aircraft will be allocated to each city, and the fleet operations will be conducted from a common primary flight base as a “hub and spokes” operation to achieve

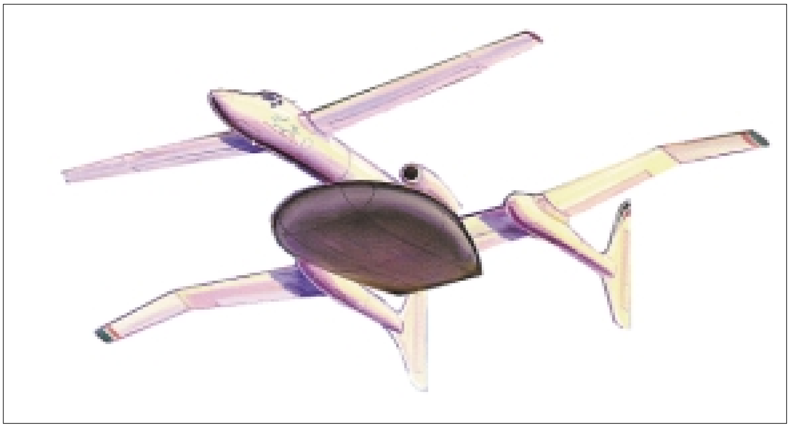

Figure 2. *A HALO/Proteus airplane.*

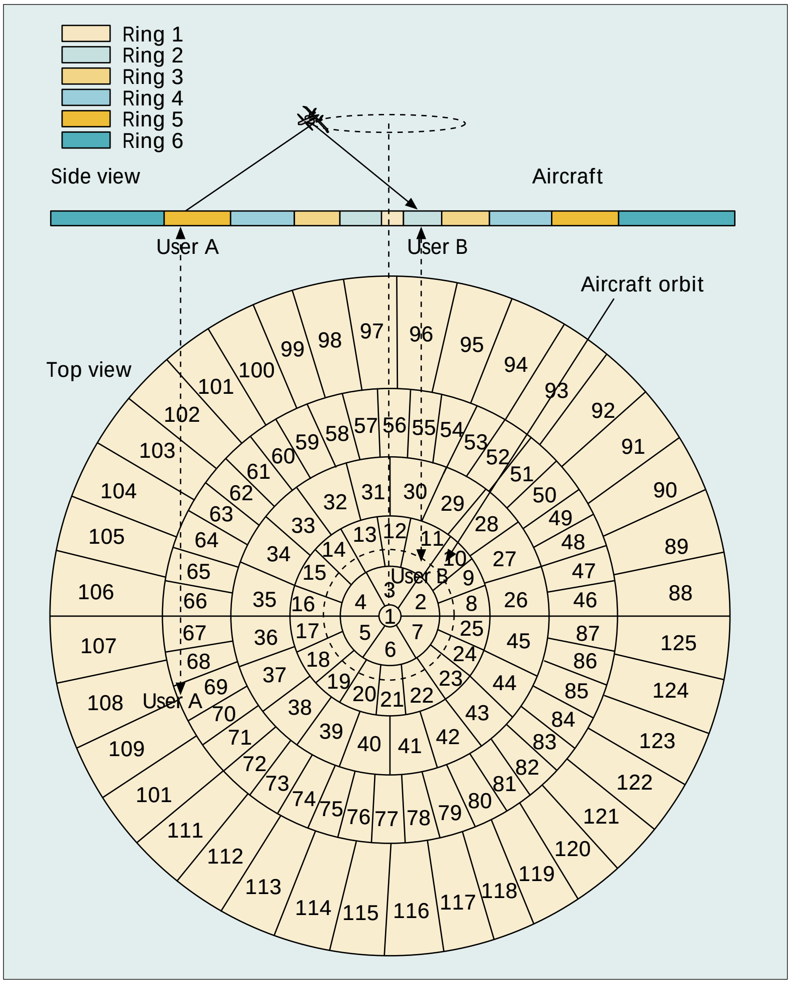

Figure 3. *The footprint of shared beam cells.*

continuous service. Each shift on station will have an average duration of approximately 8 hr.

The HALO/Proteus airplane will maintain station at an altitude of 51,000–60,000 ft by flying in a toroidal volume of airspace with a diameter of about 5 to 8 nautical mi. The look angle, defined to be the angle subtended between the local horizon and the airplane with the user terminal at the vertex, will be greater than a minimum value of 20 degrees. The minimum look angle (MLA) for a given user terminal along the perimeter of the service footprint is defined to occur whenever the airplane achieves the longest slant range from that terminal while flying within its designated airspace. Under these assumptions, the signal footprint will cover an area of approximately 2000–3000 mi^2, large enough to encompass a typical city and its neighboring communities. Such a high value for the MLA was chosen to ensure a line-of-sight connection to nearly every rooftop in the signal footprint, and high availability during heavy rainfall for most of the major cities in North America, especially for broadband data rates propagated in the K/Ka bands (above 20 GHz).

By selecting millimeter wavelength (MMW) frequencies, a broadband network of high capacity can be realized, since carrier frequency bandwidths on the scale of 100–1000 MHz have been licensed and may be made available through partnerships. Small antenna apertures on the scale of 1 ft will provide beams with narrow beamwidths; thus, user terminals can be compact but offer high gain. Also, a multi-aperture antenna array can fit in an airborne pod with dimensions practical to an aerodynamicist.

A variety of spectrum allocations 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 on the following two spectrum allocations as examples for creating a high-capacity HALO network offering wireless broadband services:

- Local multimegabit data service (LMDS) at 28 GHz
- The microwave point-to-point allocation at 38 GHz

The antenna array produces beams on the ground of two types:

- The shared beam provides services to 100–1000 subscribers.
- The dedicated beam provides a connection to a gateway serving high-bandwidth users, or to the network gateway through which a user from a non-HALO network can access the services of, and exchange information with, any end user of the HALO Network.

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 subbands. The pattern has a periodic nature and each subband in the set so chosen (i.e., each subband of the frequency reuse plan) is used multiple times within the service area. Through frequency reuse, about 2800 mi^2 of area can be covered. The total capacity achieved by only one platform can be in the range of 10–100 Gb/s.

In Fig. 3 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 have assumed that there would be six 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 km. It would have an orbit diameter of 14.8 km (ring 3 level). By assuming a constant ground speed, the orbit would have a period of approximately 6 min.

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 air-

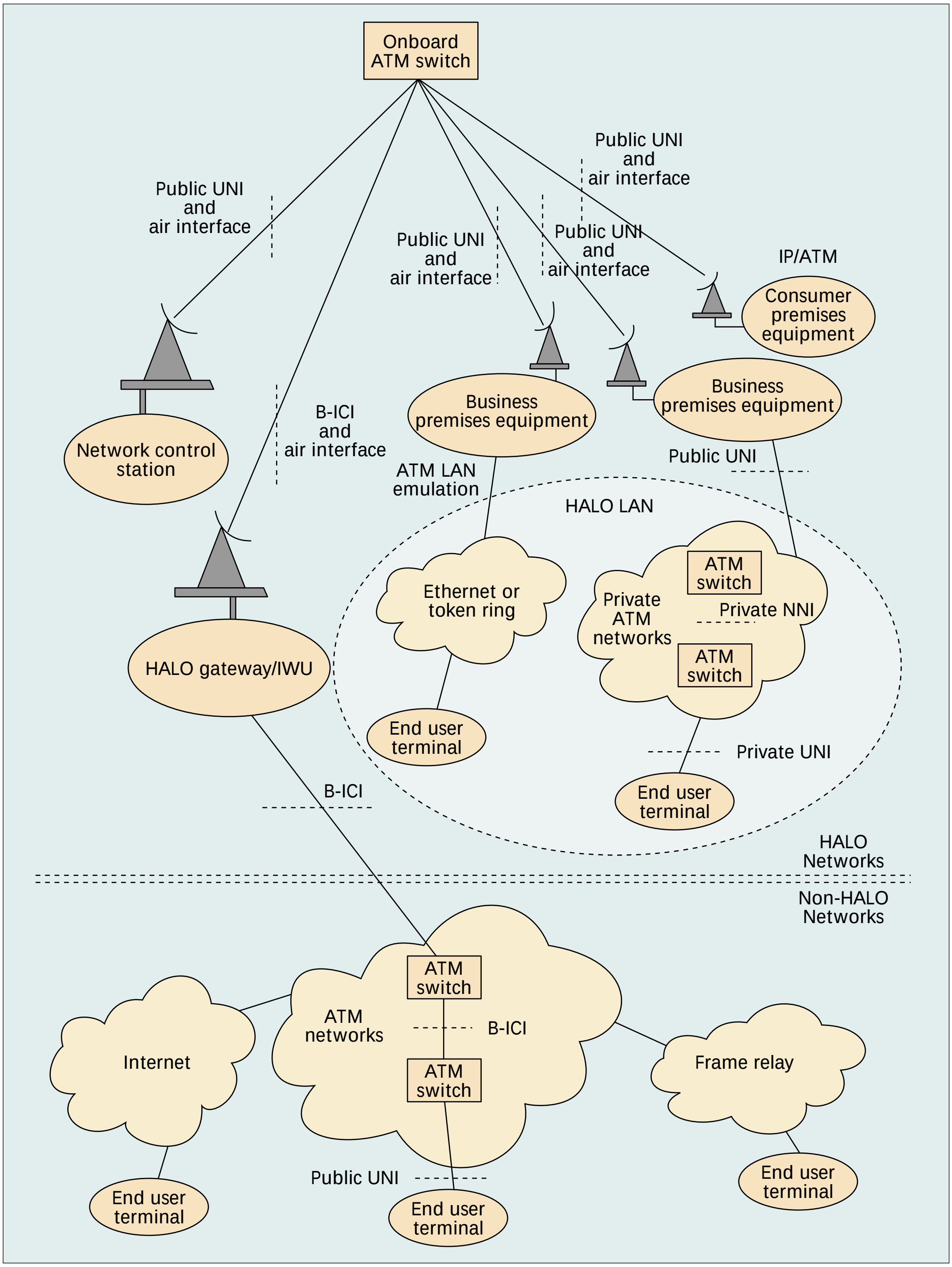

Figure 4. *The system reference model of the HALO Network.*

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plane. A beam-to-beam handover event may arise [1]. Suppose users A and are connected by antennas 106 and 26 at time t. When ratcheting is completed at time $t + T$, they will both be connected by two new antennas: 108 and 27, respectively.

The System Reference Model of the HALO Network

As shown in Fig. 4, the major elements of the conceptual HALO network are the airborne communications hub carried by the HALO/Proteus airplane, the premises equipment or user terminals, the network control station, the HALO gateway (HG), and the various interfaces. The reference architecture shows the topology of the interconnected network elements.

The HALO network can be connected to non-HALO networks, such as ATM networks, Internet, and frame relay via an HG/interworking unit (IWU).

Within the HALO network, four types of network elements can be connected directly to the onboard switch:

- *Customer premises equipment (CPE, low-rate*

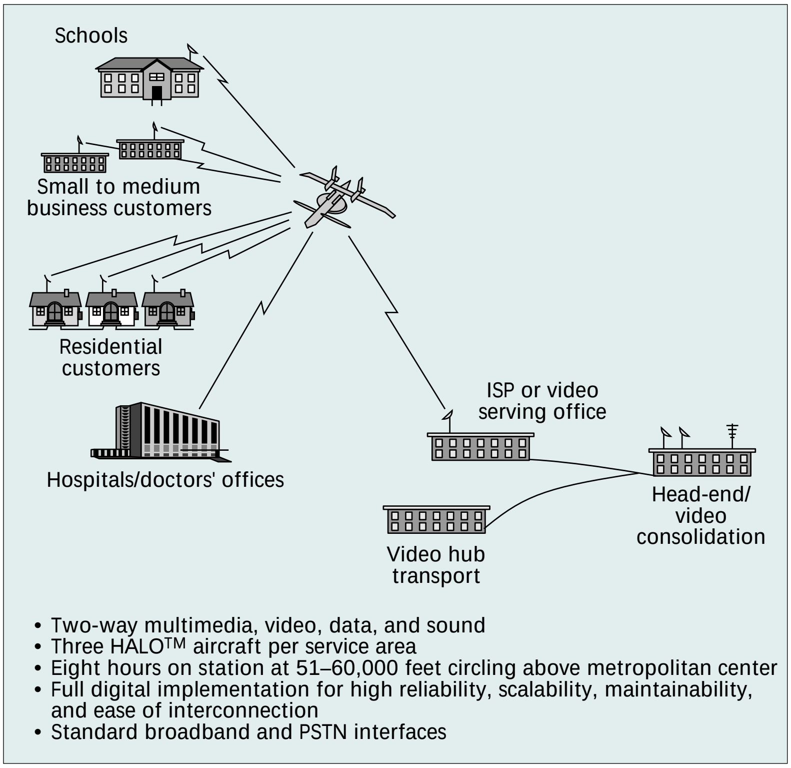

Figure 5. *HALO Network services.*

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 will be implemented in the terminals.

- *Business premises equipment (BPE, high-rate user terminals)*: This type of premises 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 HALO Network compatible BPE to serve as a bridge between the corporate network and the HALO network, all of the users within the company will be able to gain access to the HALO network.
- *HG/IWU*: This equipment provides the portal and interfaces between HALO and non-HALO networks. As shown in Fig. 4, only public ATM networks have direct connection to the HALO Gateway/IWU because other networks are not compatible with the HG/IWU. Therefore, Internet and frame relay services have to be connected to the public ATM networks before they are connected to the HG/IWU.
- *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.

According to Fig. 4, there are four types of signaling interfaces between ATM networks and the HALO network. The public user–network interfaces (UNIs) are located between the onboard ATM switch and the CPE. The signaling interface between the HG/IWU and the onboard switch is B-ICI. If there exists a private ATM network within the local networks of the HALO network, both the private network node interface (NNI) and private UNI will exist, as shown in Fig. 4.

HALO Network Services

The HALO Network accommodates the following design objectives:

- Seamless ubiquitous multimedia services
- Adaptation to end user environments
- Rapidly deployable to sites of opportunity
- Bandwidth on demand for efficient use of available spectrum

As shown in Fig. 5, many types of organizations — schools, hospitals, doctors' offices, and small to medium-sized businesses — around the world will benefit from the low pricing of broadband services provided by the HALO Network. Moreover, HALO can be used as a wireless local loop (WLL) for mobile telephone services, two-way paging, one-way broadcasting, low-data-rate acquisition, and as satellite concentrator. Standard broadband protocols such as ATM and synchronous optical network (SONET) will be adopted to interface the HALO Network as seamlessly as possible. The gateway to the HALO Network will provide access to the public switched telephone network (PSTN) and to the Internet backbone for such services as the Web and e-commerce. The gateway will provide to information content providers networkwide access to a large population of subscribers.

Various classes of service can be provided to subscribers sharing the bandwidth of a given beam, for example, 1 to 10 Mb/s peak data rates to small businesses, and 10 to 25 Mb/s peak data rates to business users with larger bandwidth appetites. Since each link can be serviced according to "bandwidth on demand," the bandwidth available in a beam can be shared between sessions concurrently active within that beam. While the average data rate may be low for a given user, the instantaneous rate can be grown to a specified upper bound according to demand. A dedicated beam service can also be provided to those subscribers requiring 25–155 Mb/s.

Subscriber Units (User Terminals)

As shown in Fig. 6, the user terminal entails three major subgroups of hardware: the RF unit (RU) which contains the MMW antenna and MMW transceiver; the network interface unit (NIU) and the application terminals, such as PCs, telephones, video servers, and video terminals. The RU consists of a small dual-feed

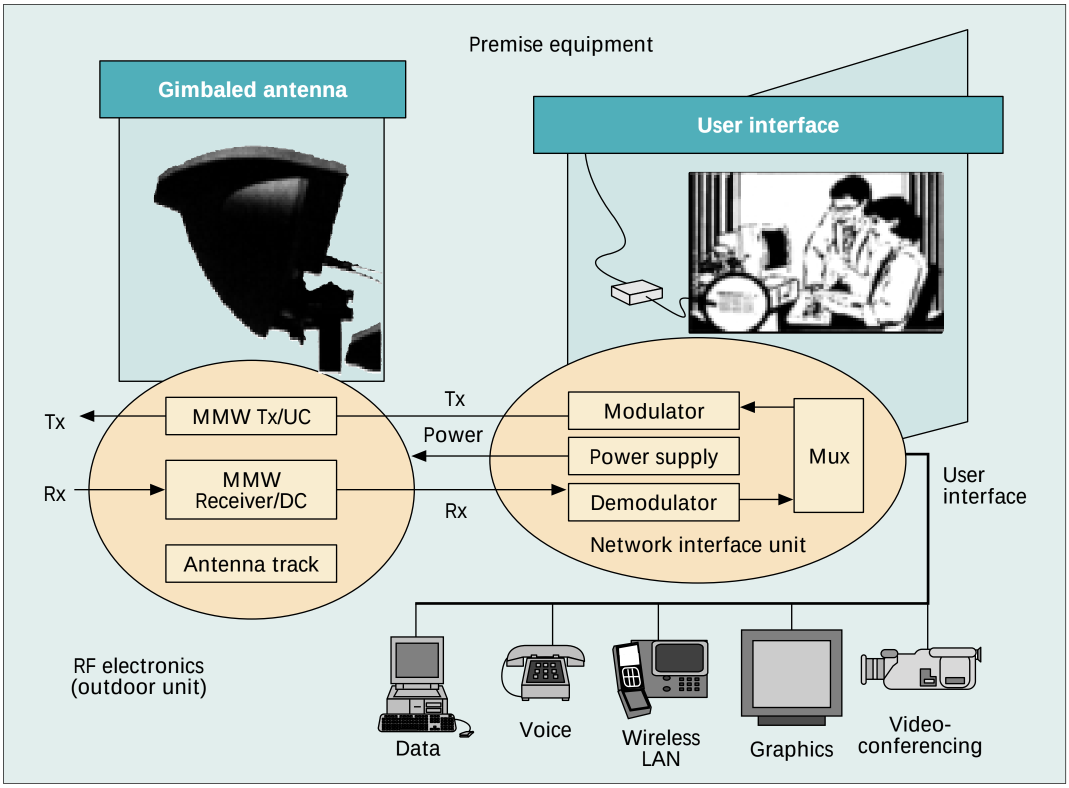

Figure 6. *User terminal architectures.*

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antenna and MMW transmitter and receiver mounted to the antenna. An antenna tracking unit uses a pilot tone transmitted from the HALO aircraft to point its antenna at the airplane. The antenna tracks the airplane with a mount possessing low-rate two-axis gimbals. Other schemes for performing the auto tracking function are feasible and appear to be competitive in cost. The high-gain antenna is protected beneath a radome from wind loading and the weather.

The MMW transmitter accepts an L-band IF input signal from the NIU, translates it to MMW frequencies, amplifies the signal using a power amplifier to a transmit-power level of 100–500 mW, and feeds the antenna. The MMW receiver couples the received signal from the antenna to a low noise amplifier (LNA), downconverts the signal to an L-band IF, and provides subsequent amplification and processing before outputting the signal to the NIU. The MMW transceiver will process a single channel at any one time, perhaps as narrow as 40 MHz. The particular channel and frequency are determined by the NIU.

The NIU interfaces to the RU via a coax pair which transmit the L-band TX and RX signals between the NIU and the RU. The NIU comprises an L-band tuner and downconverter, a high-speed demodulator, a high-speed modulator, multiplexers and demultiplexers, and data, telephony, and video interface electronics. Each user terminal can provide access to data at rates up to 51.84 Mb/s each way. In some applications, some of this bandwidth may be used to incorporate spread spectrum coding to improve performance against interference (if so, the user rate would be reduced).

The NIU equipment can be identical to that already developed for LMDS and other broadband services. This reduces the cost of HALO Network services to the consumer since there is minimal cost to adapt LMDS equipment to this application, and we could take advantage of the high volume expected in the other services. Also, the HALO RU can be very close in functionality to the RU in other services (like LMDS) since the primary difference is the need for a tracking function for the antenna. The electronics for the RF data signal will be identical if the same frequency band is utilized.

Advantages Relative to Satellite and Terrestrial Networks

The HALO network has several advantages over terrestrial wireless networks. The latter have complex geometries involving many base stations interlinked by cabling or microwaves. The communication paths have low look angles with multipath Rayleigh fading. Moreover, each time cell splitting is used to increase system capacity, the network can demand significant reengineering. On the other hand, satellite networks require more expensive terminals with high power to achieve the same data rates possible through the HALO Network. Also, the longer propagation delays demand more complex algorithms to achieve interactivity. The capacity of a satellite network can be increased, but at higher expense than the HALO Network, typically only by adding more satellites. And, like terrestrial networks, reengineering of the

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entire satellite network may be required. The HALO Network has striking advantages over proposed large LEO constellations, including ease of repair and rapidly evolving performance [5].

CONCLUSIONS

The HALO network will provide wireless broadband communication services. The feasibility of this network is assured due to a convergence of technological advancements. The key enabling technologies at hand include GaAs RF modules operating at MMW frequencies, ATM/SONET technology, digital signal processing of wideband signals, video compression, ultra-dense memory modules, lightweight aircraft technology including composite airframes, and small fanjets capable of operating reliably at low Mach and low Reynolds numbers. These technologies are available, to a great extent, from vendors targeting commercial markets. The HALO Network is predicated on the successful integration of these technologies to offer communications services of high quality and utility to small and medium-sized businesses at reasonable prices. The regulatory climates of the FAA and FCC are favorable. While a variety of broadband access modalities are promising for the U.S. markets, the HALO Network may be a winner for "green field" deployment, especially in regions where the existing infrastructure is not amenable to an upgrade or retrofit.

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BIOGRAPHIES

NICHOLAS J. COLELLA (Ncolella@AngelHALO.com) is chief technology officer of Angel Technologies Corporation. In prior years he held senior technical positions at Lawrence Livermore National Laboratory. He invented the RAPTOR/TALON theater ballistic missile defense concept and served as the Department of Defense's executing agent for pioneering low-cost, high-altitude, long-endurance unmanned aircraft, high mass fraction kinetic kill interceptors, electro-optics, and communications systems. He co-created Brilliant Pebbles, led LLNL's spacecraft design and survivability projects, and developed one-steradian wide field of view (WFOV) cameras employing spherically concentric refractive optics for tracking satellites and space objects. He is a founding partner of a multichip module company and the National Robotics Engineering Consortium at Carnegie Mellon.

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