White Paper

Broadband Wireless Network Overcomes Line-Of-Sight (LOS) Constraints and Lowers Deployment Cost

In April 2006, EION Wireless acquired several major product lines and expert staff from Calgary based Wi-LAN Inc. Among the products acquired by EION were the VIP 110-24, Ultima 3 and Libra MX.

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Abstract: *A variety of technologies are being developed to address the fixed broadband wireless market. These networks are typically configured in a cell based point-to-multipoint topology. The deployment of these networks requires a high initial up-front investment to pay for base stations and backbone network. Additionally, a significant number of potential subscribers may not be reached due to Line-Of-Sight (LOS) constraints. The Wi-LAN VINE network solution provides an alternative approach that overcomes the LOS limitations and minimizes initial up -front costs.*

1 Introduction

It has been widely recognized that fixed broadband wireless is a viable alternative to overcome the "last-mile" distribution problem of bringing High-Speed data connections to the end user. In areas where the wired infrastructure is inadequate or does not yet exist, fixed wireless solutions can be deployed much faster and at a fraction of the cost when compared to wired networks.

There are currently several solutions being deployed or proposed to address this emerging fixed broadband wireless market. These solutions can be categorized based on various parameters including frequency band, range, bandwidth capacity, licensing requirements etc. The table below summarizes the major fixed broadband wireless technologies:

	Frequency Band	Bandwidth	Range
LMDS	> 28 GHz	1.2 GHz	< 3 miles
MMDS	2.5 GHz	200 MHz	< 30 miles
Unlicensed	2.4 GHz	83 MHz	< 30 miles
Unlicensed	5.8 GHz	200 MHz	< 12 miles

LMDS (Local Multipoint Distribution Service) has extremely high bandwidth; however, due to its short range and elevated hub cost it is only economical in high density urban areas. MMDS (Multichannel Multipoint Distribution Service), with its longer range is a better match to cover medium density are8as.

In the United States both LMDS and MMDS operate under license. The unlicensed spectrum allows less costly and immediate deployment of networks. It is attractive to the independent ISPs which do not have access to the license spectrum and have limited financial resources.

In all these bands, a major deployment requirement is that the transmit and receive antennas for every link be within Line-Of-Sight (LOS) of each other. There is a current debate over different modulation techniques that "overcome" the LOS limitation in the lower frequency bands (2.4 GHz). However, these techniques aim at improving signal reception when the signal path is partly obstructed by leaves or thin walls. None of those techniques can overcome the LOS issues imposed by mountainous terrain topography.

2 Cell-Based Wireless Networks

In order to cover a large geographic area, most systems today use a cell-based deployment. In this strategy a central base station at the center of each cell has the capability of handling communications with a plurality of subscriber stations. These "point-to-multipoint" systems use various medium access mechanisms to coordinate how the subscribers can all be serviced by a single base station. These include Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), and Code Division Multiple Access (CDMA). The base station having direct access to all the subscribers provides centralized control to perform bandwidth sharing and allocation between the subscribers.

The geographic coverage of a single point-to multipoint cell is limited to the range of the radio equipment and LOS limitations. When the required geographic coverage exceeds the RF range of the equipment, such systems require multiple neighboring base stations, each at the center of a cell. Within each cell, subscriber stations communicate with the base station that is nearest to them. The cells are ideally distributed on a honeycomb grid with a different base station at the center of each hexagon. Those base stations are then interconnected to a point of presence with high bandwidth backbone transmission facilities.

Deployments of cell based systems have the following difficulties:

1. Traffic gets concentrated at the various base stations but still needs to be carried to a single central point through the additional backbone network. This backbone needs to be deployed with the maximum capacity envisioned, even though, at the early stages of deployment, it will be greatly underutilized. This represents an up-front expense before the service comes online.

2. Topographical features will shadow areas where coverage becomes unavailable. Studies have shown that in a cell-based system, up to 30% of the potential subscribers may not be reachable due to LOS limitations. This coverage shortfall can be reduced by using mini-cells to cover some dark areas. However, this adds cost for the additional base stations and the associated backbone connections.

3 Multipoint-to-Multipoint Networks

In order to overcome a need for a backbone network and get around the LOS issues, a "mesh" network topology has also been proposed. In this topology each station is equipped with an omni-directional antenna and must be within RF reach of other stations in the network. The radios transmit and receive from any of its direct neighbors and forward packets to their various destinations using any of many possible routes. This approach does not require a backbone and can easily reach hidden locations through multiple hops. This type of approach, however, has the following drawbacks:

1. To establish connectivity to more than one neighbor, the radio antenna will typically be an omni-directional or sector antenna (as opposed to the directional antenna used by the subscriber stations in a point-to-multipoint system). This reduces the link distance that can be achieved between any two points and exposes the receiver to noise and interference from all directions.

2. Each radio may have a good number of neighbors that can be reached with one-hop. This is indeed the advantage of the mesh network - provide multiple alternate routes between any two points. However, the transmissions from any given radio will reach not only the intended receiver but all of its other neighbors. The number of possible simultaneous transmissions by neighboring radios is greatly reduced in order to avoid collisions.

3. Due to the possibility of collisions referred above, all radios need to coordinate their transmission times with neighboring radios without the help of a central site. This must be done with over the air messages, which further reduce the air time utilized for actual data transmissions.

These last two reasons make mesh networks significantly less efficient than point-to-multipoint topologies.

4 Wi-LAN VINE Network

The Wi-LAN VINE solution is a hybrid between point-to-multipoint and the mesh topologies that keeps the advantages of both and avoids the disadvantages of either. VINE consists of a network topology and Medium Access Control (MAC) protocol that facilitates the deployment of a fixed wireless network with the following characteristics:

1. The network can be deployed a node at a time with no need for base stations.

2. For a new node to become part of an existing network, all that is needed is for it to be within RF reach of any other node already in the network.

3. Once part of the network, the new node can become the attaching point for other new nodes.

4. Only two independent communication channels are required.

5. Medium access method self synchronizes all nodes in the network with no overhead or dedicated transmissions for synchronization.

6. Frequency and directional diversity are combined, allowing multiple nodes to transmit simultaneously in the same geographical area without collisions.

7. No backbone is needed initially. All traffic can be forwarded by the deployed radios, through

multiple hops if necessary, to reach its destination.

8. Backbone point-to-point links can be added at a later time to scale up the network. These are only needed once the total offered load starts exceeding the available bandwidth.
9. The radio equipment deployed at each subscriber is identical for all locations. There is no expensive hub or base station equipment.

The transceiver platform necessary to implement VINE contains at least three ports: one port for interfacing with the subscriber equipment (typically Ethernet), and two RF ports, designated as A and B, available for connection to two distinct antennas. The RF ports are switched under software control, so that the receiver or transmitter circuitry is connected to one of the antennas at a time. Over RF the transceiver operates in half duplex mode, i.e., at any given time it may either be transmitting or receiving.

4.1 Network Topology and Deployment

The initial installation may consist of as few as two transceivers, one at a central site and the other at a subscriber site (nodes 1 and 2 in figure 1). In this initial installation, the transceiver at the central site (location 1) is installed with a wide-focus antenna (omni-directional or sectorized) connected to port B. At the subscriber site (location 2), the transceiver is equipped with a directional antenna, connected to port A, pointing at the central site.

When more subscribers need to be added to the network, if they are within LOS of the central site (location 3 and 4 in figure 1), they are installed in a similar fashion as the subscriber at location 2, i.e., using a directional antenna connected to port A pointing at the central site. At this point, the network configuration (nodes 1 through 4) is no different than a cell based network with a single cell.

However, when a subscriber needs to be added that is not within LOS of the central site (location 5, figure 2), a cell-based network would require a new base station at the center of a new cell, and a backbone connection between the two base stations. In the VINE topology, any node already in the network can be used as a relay point to reach the central site. If location 5 is within LOS of location 2 for example, node 2 will start functioning as a "repeater" by simply installing a wide focus antenna connected to its port B. At the new subscriber site (location 5) a transceiver is installed with a directional antenna pointing at location 2.

As the network grows any node can be promoted to become a repeater by simply attaching a wide focus antenna to its port B. The only requirement for a new node to get attached is to have RF connectivity to any node already in the network (figure 3). We call this deployment strategy "Anypoint-to-Multipoint" since any node already in the network can become the center of a point-to-multipoint branch. As more nodes are deployed, the geographic coverage and range of the network grows. Hard to reach locations in valleys, or otherwise obstructed, can easily be reached once the "VINE" spreads into that neighborhood.

This deployment builds a natural "tree" topology as shown in figure 4 for the expanded network represented in figure 3. In general, each node in the network, with exception of the root, has one and only one "parent". Antenna port A in each transceiver is assigned for communications with that node's parent. That antenna is always a high gain directional antenna pointing at the location of its parent.

Antenna port B is assigned for communications with the node's "children". This antenna must provide coverage to all of the node's children. Depending on the geographic location of those children the antenna connected to port B may be an omni-directional, sector, or directional antenna. Nodes that have no children do not require an antenna connected to port B.

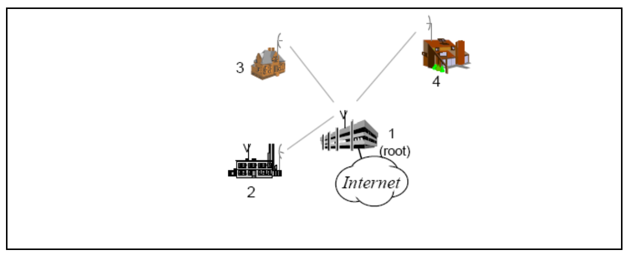

Figure 1. Initial Deployment – All subscribers within LOS of ISP

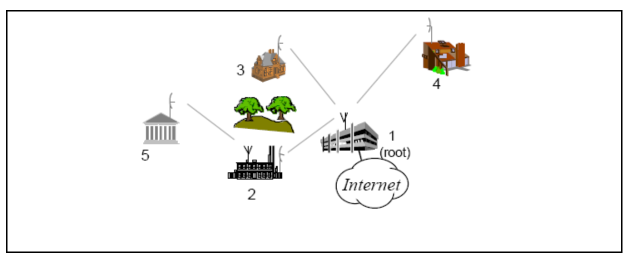

Figure 2. New subscriber with no LOS – Use radio 2 as repeater

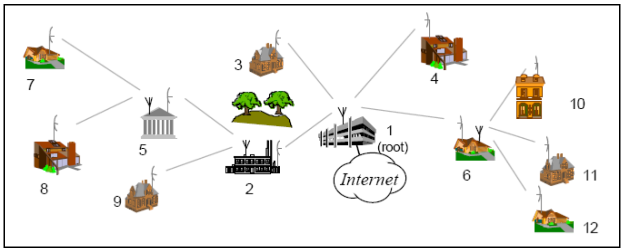

Figure 3. Expanded VINE Network covering large area with no backbone

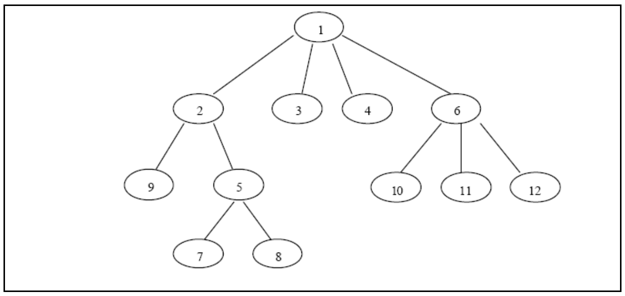

Figure 4. Expanded Network graph representation

4.2 Frequency and Time Diversity

RF Transmissions consist of variable length packets. "Outbound" packets flow "downstream" or away from the root node. "Inbound" packets flow "upstream" or towards the root. Outbound and inbound transmissions are assigned to two non-overlapping frequency channels.

With this topology, a transmission within any given "branch" (defined as a parent transceiver together with its one-hop children) does not interfere with simultaneous transmissions in any other branches. Any two simultaneous outbound transmissions will be received by the intended nodes due to the high gain antenna in the receivers. Similarly, any two simultaneous inbound transmissions will be received by the intended upstream nodes due to the high gain antenna in the transmitters. This scheme is further optimized by having all transceivers control their output power to achieve no more than the adequate link margin for that particular transmission.

This frequency and directional diversity allow simultaneous transmissions of many different radios in the same geographical area without collisions. Within any given "parent/children" group, the parent radio services its children using an Adaptive Time Division Multiple Access scheme. In each group the total bandwidth is shared among the active nodes. The VINE Medium Access Control (MAC) layer performs these functions and also synchronizes the repeater radios to switch between being a parent or a child at the appropriate times.

4.3 Packet Switching

Packets can enter the VINE network at any node through the user interface port (Ethernet). Each radio maintains a map of the complete network and routes the packet, through multiple hops if necessary, to its required destination. The destination may be any station connected to one of the radios in the VINE. In a typical Internet Access application the destination for inbound packets is always the ISP location. However, VINE can also be used in private network applications where this is not the case.

Radios are not allocated fixed bandwidths in either upstream or downstream directions. The total network bandwidth is shared, on demand, between only the nodes that are active at any given time.

4.4 Quality Of Service

Even though the total bandwidth can be shared fairly between all the active radios, the VINE protocol also supports different levels of Quality Of Service (QOS) assigned to individual radios. The network manager may assign a different Committed Information Rate (CIR) and Maximum Data Rates for each radio, separately for the inbound and outbound directions. This allows an ISP to provide different service plans charged at different rates.

When a radio has a CIR, it will always be guaranteed access to the committed data rate. However, if the radio is not active, the committed bandwidth is not wasted; it is shared among all the other active radios.

4.5 Network Scalability

As the number of subscribers grows, the traffic in the network may grow to a point where the quality of service is no longer acceptable. This point depends on the throughput of the actual radios, customer utilization patterns, and total committed information rates allocated. A VINE network can be scaled up in one of two ways:

1. Use multiple radios at the root location, each feeding a separate sector antenna. Each of these radios becomes the root of a separate VINE with full capacity.
2. Break a link between the root and one of its children and reconfigure that child as the root of a new VINE ("prune" the VINE). The two separate roots must then be connected with a dedicated wired or wireless link. This link constitutes the beginning of a "backbone". Compared to a cell-based network, however, this backbone link is only required once enough

3. subscribers are on-line instead of when the network is first deployed.

4.6 Other VINE features

The VINE protocol supports a number of other features listed below:

1. Self Configuration: In order to deploy a new node all that is needed is to point its antenna A to a parent and turn the power ON. The new node will listen to its environment to identify the parent and then responds to a "new node discovery" poll transmitted by the parent on a regular basis. The new node learns about the network from its parent with no need for manual configuration. Even pointing the directional antenna is made easy with an audio tone, output by the transceiver, which has a pitch proportional to signal strength.
2. Adaptive RF Data Rate and Power Adjustments: When a node gets attached, the new node and the parent negotiate the modulation and transmit power parameters for optimum performance. This overcomes partial obstructions, or achieves longer range, by using more robust modulation schemes at the expense of throughput. The VINE MAC protocol also supports changing this parameter dynamically once the node is attached.
3. Node Authentication: Before the node is allowed to transact any data in the network it must be authenticated in order to reject radios that are not supposed to be part of this VINE. The protocol includes an authentication handshake at the time a node is attached to the network.
4. Network Management: The MAC layer monitors and records all packet losses, bit errors, actual flow rates, and traffic congestion patterns. These, and other noteworthy events, can be monitored remotely from a single node. Configurable parameters give the network manager considerable flexibility in adapting the network to different applications.
5. Limited Mobility: Within a framework of a fixed radio network, VINE supports a number of mobile units that can attach themselves to any of the fixed nodes. As these mobile nodes move, they break the connection to their parent and reestablish it to the nearest fixed node.

5 Conclusions

The Wi-LAN "Anypoint-to-Multipoint" VINE network topology combines the strengths of the cell based point-to-multipoint networks (subscribers with directional antennas, central station providing master control), with the advantages of the generic multipoint-to-multipoint approach (no backbone, hop-by-hop routing). The use of frequency and directional diversity results in a Medium Access Control protocol that is extremely efficient, leaving the radio bandwidth available for actual data traffic.

A VINE network can be deployed a node at a time with very little up-front cost. Coverage increases as more subscribers come on-line. These features make the VINE network a dominant solution in medium to low density subscriber areas where an up-front cost of an infrastructure can not be quickly amortized.