White Paper:
SkyPilot SyncMesh™ Architecture

The SkyPilot SyncMesh™ Architecture
Purpose-built for Mesh Networking

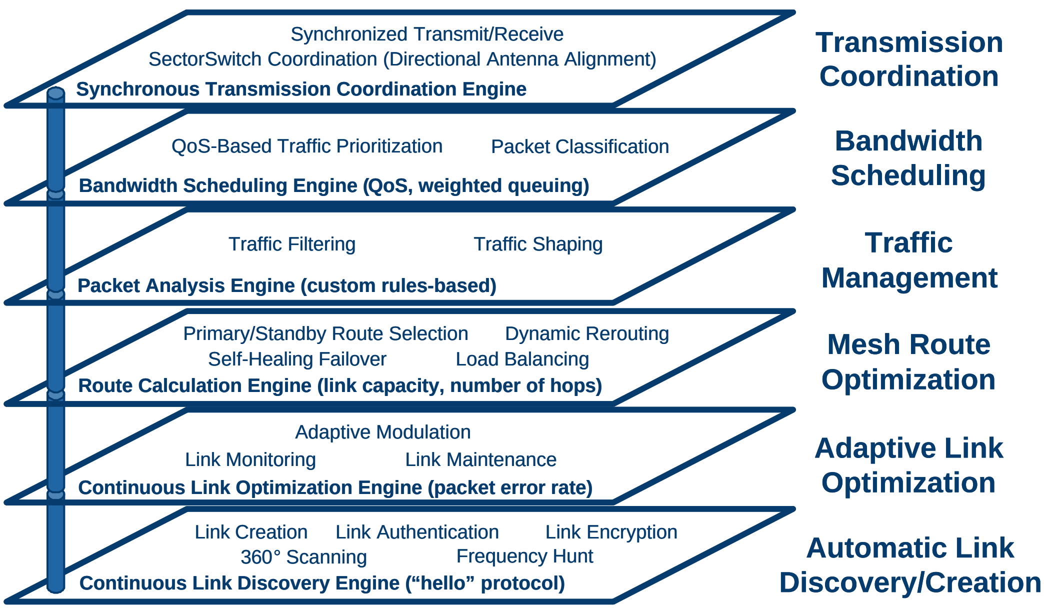
Introduction

Mesh networks are remarkably resilient and scalable, which is why a mesh topology is utilized in both the Internet and the Public Switched Telephone Network. But many wireless mesh networking solutions suffer from a fundamental flaw that can severely degrade performance and, ultimately, limits scalability.

The inherent flaw is rooted in the very nature of wireless communications. As with any shared medium protocol, including Ethernet, all nodes within range of one another must “listen” before transmitting, and only one can transmit at a time. Without this process, “collisions” regularly occur and halt all transmissions until the affected nodes are able to recover. As might be expected, this multi-access protocol is terribly inefficient. With wired Ethernet, the problem can be mitigated using brute force bandwidth. But in an RF environment, where bandwidth is not as copious, the use of asynchronous IEEE 802.11 protocols with omnidirectional antennas results in crippling limitations.

To overcome the limitations inherent in “shared air” wireless communications, SkyPilot Networks created a system architecture purpose-built for the mesh topology. The design objectives required maximizing packet throughput, enabling Quality of Service (QoS) and improving scalability, while preserving the many advantages of mesh networking and wireless communications.

The resulting SkyPilot system uses a combination of high-gain, sectorized antennas with a synchronous protocol that coordinates directional links throughout the mesh topology. The software that manages this system is SyncMesh™ (depicted in the diagram below), which takes a system-oriented approach to organizing the initiation and operation of a wireless mesh network into six distinct layers. The layers are comparable to those of a protocol stack that begins with basic communication capabilities, adds functionality through each successive layer, and culminates in a comprehensive, end-to-end suite.



This document describes the role of all six layers, including how each builds on those preceding it. The discussion is at a high level, making the content suitable for both business and technical professionals. Additional technical detail can be found in the SkyPilot *Protocol and Architecture Guide*, which is available by contacting SkyPilot at sales@skypilot.com.

While such a detailed architecture contains numerous capabilities, two are particularly noteworthy: directional antennas and traffic synchronization. As the discussion will show, it is impossible to create a robust mesh topology without the spatial and spectral reuse afforded by these capabilities. The many other functions of the SyncMesh Architecture further optimize the network to create a carrier-class infrastructure capable of competing on a price/performance basis with digital subscriber line (DSL) and cable access technologies.

Automatic Link Discovery & Creation

The *Continuous Link Discovery Engine* leverages the capabilities of the eight-way antenna array to locate all neighboring nodes. The sectorized array consists of eight antenna elements, each with a 45° spread that together provide a full 360° of coverage. While an antenna array could be made to radiate in an omnidirectional pattern at times, the futility of doing so will soon become apparent.

The engine employs an efficient "Hello" protocol to transmit packets at various frequencies (*Frequency Hunt*) on all eight sectors (*360° Scanning*). The frequencies used can be specified by the operator (as being required or preferred) or selected automatically from any available.

When a neighboring node within radio range receives and replies to a "Hello" message, its legitimacy is verified through certificate matching (*Link Authentication*) before an actual directional link is established between nodes (*Link Creation*).

Link Encryption builds on Link Authentication by adding an important layer of security that ensures the privacy and integrity of all traffic. To make this critical form of protection as tamper-proof as possible, SkyPilot employs strong 128-bit encryption based on the Advanced Encryption Standard (AES).

Adaptive Link Optimization

The advantages of using directional antennas begin to become obvious with the *Continuous Link Optimization Engine*. Regulations restrict the transmission power of omnidirectional antennas to minimize interference. Point-to-point links, such as those established by individual sectors on the SkyPilot eight-way antenna array, are permitted to operate at significantly higher power levels. Higher power levels provide a number of advantages, including lower error rates based on an improved signal-to-noise ratio, better penetration through obstructions that attenuate signals, and a much longer range—up to 10 miles / 16 kilometers between nodes. Together these advantages help lower the total cost of ownership by enabling a fairly sparse mesh to deliver sufficient levels of performance and resiliency.

The *Link Monitoring* and *Link Maintenance* processes continuously and automatically modulate each link at its optimal performance based on the error rate at progressively higher throughput levels. Specifically, the highest modulation rate with less than a 0.5% packet error rate is selected for each directional link, and links throughout the mesh can operate at different modulation rates to optimize throughput. In an operating network, of course, the Transmission Control Protocol (TCP) corrects all errors that might occur in the actual traffic flow. The resulting *Adaptive Modulation* process is, therefore, able to adjust for variable conditions, such as intermittent noise or signal attenuation, while maintaining a low error rate to maximize overall throughput.

Mesh Route Optimization

The *Route Calculation Engine* is a distributed vector-based algorithm that assigns a cost to each link based on the directional link's modulation and the cost of subsequent links along the path to the mesh egress node. The lowest cost path is, by definition, the optimal route, which is designated as the Primary path; one or more other paths are designated as available Standby path(s).

With SkyPilot's adaptive link optimization, link costs can change over time. To accommodate changing RF environments, SkyPilot uses *Dynamic Rerouting* to automatically select the current optimal path when link costs change, whether Primary or Standby. Therefore, if a Primary link experiences degraded throughput, the *Route Selection* process immediately actives the best available Standby link by making it the new Primary link—all without dropping any packets. The same process automatically promotes a Standby link into the Primary role when it experiences an improvement that reduces its cost below that of the current Primary path.

If a link ever experiences a complete outage, a *Self-Healing Failover* process immediately and automatically routes around the failure. Normally, the *Dynamic Rerouting* process will have already routed around a link that is degrading or failing. Which is why the *Self-Healing Failover* process is needed only in the event of a sudden, unexpected outage.

Because the route calculation and selection processes operate automatically in real-time from end-to-end through the mesh, the network affords inherent *Load Balancing* capabilities, complete with automatic failover. The load is balanced at every node, including all ingress/egress points (SkyPilot Gateways and Extender MultiBand access points), as well as all intermediate hops (SkyPilot Extenders and Extender MultiBands).

Traffic Management

The bottom three layers of the SyncMesh Architecture optimize the mesh topology itself; the top three layers serve to optimize the flow of traffic throughout the mesh. The key function at Traffic Management Layer is the *Packet Analysis Engine*, which employs a set of customizable rules to both filter and shape traffic.

Traffic Filtering goes beyond basic user authentication and access control lists to screen traffic based on Ethernet Type (Layer 2), IP Address (source, destination and/or source ARP), TCP or UDP Port, and Protocol (Layers 3-4). Filtering can be used, for example, to provide support for customer-defined Virtual LANs (VLANs) and Voice over IP (VoIP), or to help thwart certain abuses or forms of attack. The level of granularity gives network operators total control over what applications are permitted, and forms the foundation for how the mesh can best accommodate the aggregate traffic from all permitted applications.

Traffic Shaping classifies traffic entering the mesh network on a per-user basis to facilitate the fairness of traffic management in a shared, multi-user environment. Traffic can be shaped in a symmetric fashion or asymmetrically as needed to accommodate different data rates in the upstream and downstream directions, and traffic shaping is maintained across all hops throughout the mesh. The use of profiles in template form simplifies the process of applying different classes of traffic shaping to different classes of users (e.g. standard and premium, or residential and business).

Bandwidth Scheduling

The *Bandwidth Scheduling Engine* is responsible for applying *Packet Classification* rules to prioritize traffic at each node based on conventional fairness criteria, and enforced using a rate control mechanism. The objective of bandwidth scheduling is robust Quality of Service (QoS), which is achieved through *QoS-Based Traffic Prioritization*. In addition to maximizing throughput, the scheduling algorithms have been designed to deliver carrier-class QoS for VoIP traffic that requires minimizing packet loss, latency (delay) and jitter (variations in latency).

Each user's traffic is prioritized and weighted based on the QoS profile applied at the Traffic Management Layer. When available capacity is consumed by traffic from all current users, bandwidth becomes allocated and gets queued on a proportional basis. The algorithm employed ensures that high priority traffic takes precedence in the queue, but that no single user's high priority traffic ever takes bandwidth allocated (proportionally) to another user's traffic.

Transmission Coordination

The various functions performed in the first five layers all come together to enable mesh-wide management of all traffic at the Transmission Coordination Layer. The *Synchronous Transmission Coordination Engine* employs the Time-Division Duplex (TDD) protocol to synchronize all transmissions in a way that maximizes throughput by minimizing self-interference caused by localized collisions and other protocol inefficiencies that result from sharing the air. TDD is a bi-directional extension to the time-tested Time Division Multiple Access (TDMA) protocol employed in cellular phone networks, including Global System for Mobile (GSM).

Successful synchronization requires a common timing source, which is provided by a Global Positioning System (GPS) receiver built into every SkyPilot infrastructure node. The accurate, common clock allows the *Synchronized Transmit/Receive* process to coordinate simultaneous transmissions on multiple links throughout the mesh (all being out of directional range of one another, of course) with great precision.

SectorSwitch Coordination provides the *Directional Antenna Alignment* for the eight-way antenna array. During a node's synchronized transmission interval, one and only one antenna sector is activated. The SectorSwitch operates quite rapidly, activating sectors within 10 milliseconds, to minimize end-to-end latency as traffic is relayed node-to-node in a collision-less fashion from source to destination through the mesh.

An analogy useful for understanding synchronized directional-antenna mesh operation is the "bucket brigade" where buckets (packets) of water (payload) are handed (transmitted and received) person-to-person (node-to-node along directional paths) from the water supply (source) to the fire (destination). Synchronization is what assures that every single time a firefighter in line turns around, there is another firefighter there ready with, or ready to grab, the next bucket.

It is important to note that mesh-wide coordination also makes a synchronized mesh deterministic; that is, the total throughput and latency become predictable because the traffic flow is no longer subject to variable conditions that cause congestion and collisions in other wireless mesh networks. The deterministic nature of the SyncMesh Architecture makes it suitable for even the most demanding applications that require real-time voice and video communications.

Conclusion

The diagram below summarizes how the SyncMesh Architecture manages all four critical elements of a wireless mesh network: the radio antennas, the radio frequency spectrum, the mesh topology itself and the traffic flows throughout the mesh. With so many advancements in the state-of-the-art for wireless mesh networking, SkyPilot believes the SyncMesh Architectures sets a new standard for the industry: a true third generation in mesh technology.

SyncMesh™		
RF Management	**Mesh Management**	**Traffic Management**
Industry-Best Spectral Reuse Industry-Best Self-Interference Mitigation NLOS Coverage Adaptive Modulation	Automatic Discovery Self-Optimized Best-Path Routing with Dynamic Rerouting Load Balancing Self-Healing Failover Scalable Capacity	End-to-End Synchronization Deterministic QoS Traffic Shaping Traffic Filtering Traffic Prioritization
SectorSwitch™ Antenna Management Real-Time Switching of 8-Way Sectorized Antenna Array (360° Coverage with Spectral Efficiency) High Output Power Radio to Directional Antenna Sectors (Increased Link Budget for Extended Range and Higher Modulation)		

But this innovative architecture may well raise as many questions as it answers. Why don't other mesh solutions employ directional synchronization? A good question, whose answer is found in how extraordinarily difficult it is to synchronize antenna switching up to 10,000 times a second throughout an entire large-scale mesh. How severe are the problems caused by using omnidirectional antennas that lack traffic synchronization? It depends on the application, of course, but the problems are very real—and inevitable. Is there anything missing from the SyncMesh Architecture? SkyPilot believes the answer is a definitive "No" because the various functions are both necessary (individually) and sufficient (collectively) to make wireless mesh networking carrier-class in every respect.

For more information on how your organization can benefit today from wireless mesh networking based on the third generation SyncMesh Architecture, visit SkyPilot on the Web at www.skypilot.com, or call +1-408-764-8000 (or 866 SKYPILOT in the U.S.) to speak with a representative about your application.

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