Cambium Networks™

REFERENCE ARCHITECTURE FOR

Smart Highways

The goal of this System Architecture Document is to educate readers about Cambium Networks' diverse and proven wireless solutions that enable design and support of the numerous communications needs associated with Smart Highway and Intelligent Transportation Systems (ITS) industry projects. It accompanies the solutions use cases outlined in our Smart Highways White Paper, providing more robust product details, and offering compatibility and compliance information to ensure adherence of wireless system components to industry-wide standards and direction defined by the local ITS ministries or agencies. The value propositions for leveraging wireless technology in order to satisfy these use-cases are more thoroughly covered in the Smart Highways White Paper, but will be summarized within this Architecture Document.

WHAT IS A SMART HIGHWAY (ITS)

OVERVIEW

The IP communications network(s) that support the life cycle of a National Smart Highway System are often complex and demanding, supporting critical information transmissions from a myriad of specialized use cases, spread out across extensive coverage areas with varying terrain and climate attributes. Each use case often has its own unique needs and IP data transmission patterns – some with constant heavy demands (e.g. Video media distribution), and some with lesser load due to more sporadic and/or transactional transmissions (e.g. Electronic Toll collection).

The Smart Highway System Architecture Visualization diagram below offers a macroscopic view of a typical Smart Highway system's numerous IP communications needs, providing context for several possible use cases supported by Cambium Networks' diverse wireless solutions portfolio (hardware and software platforms).

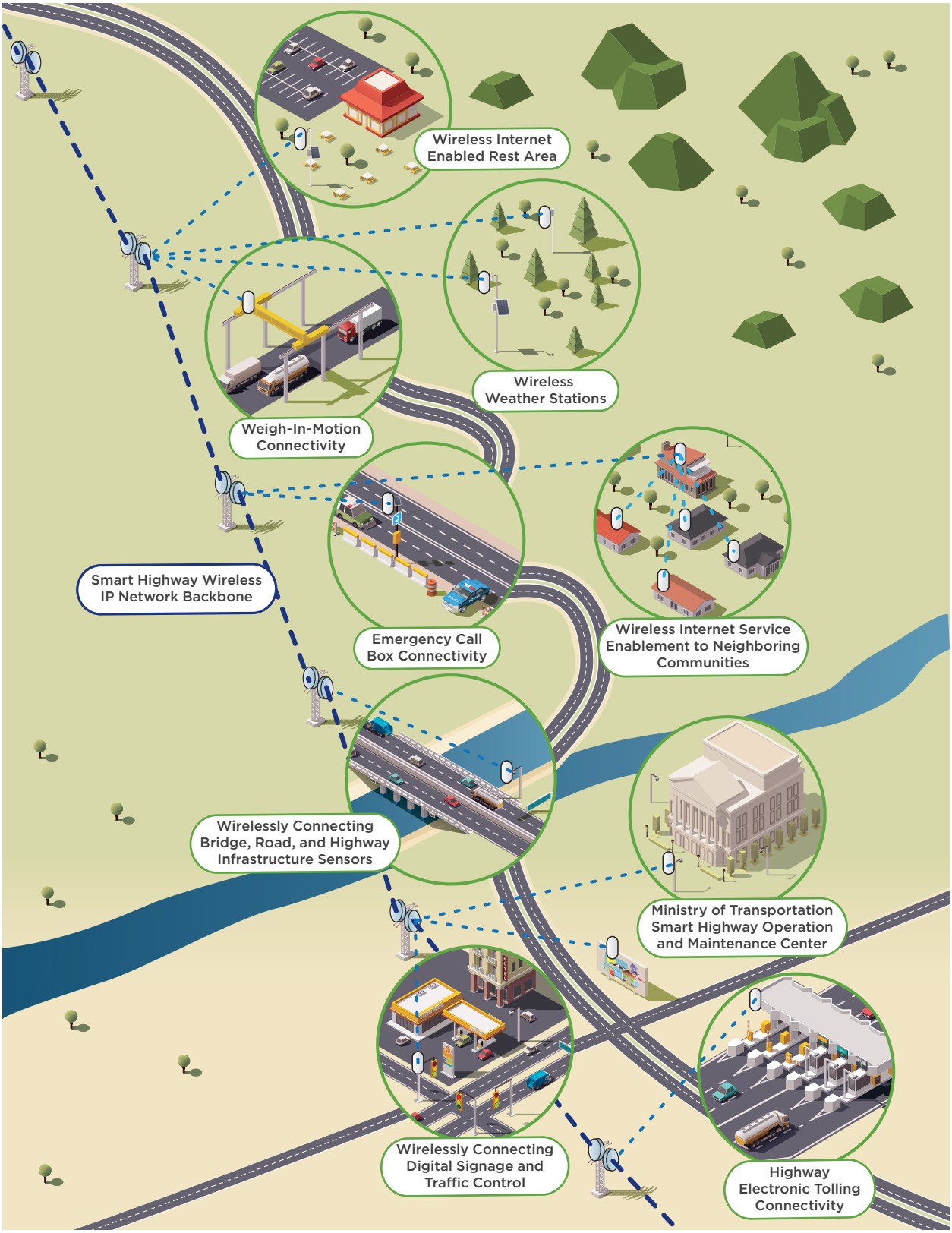


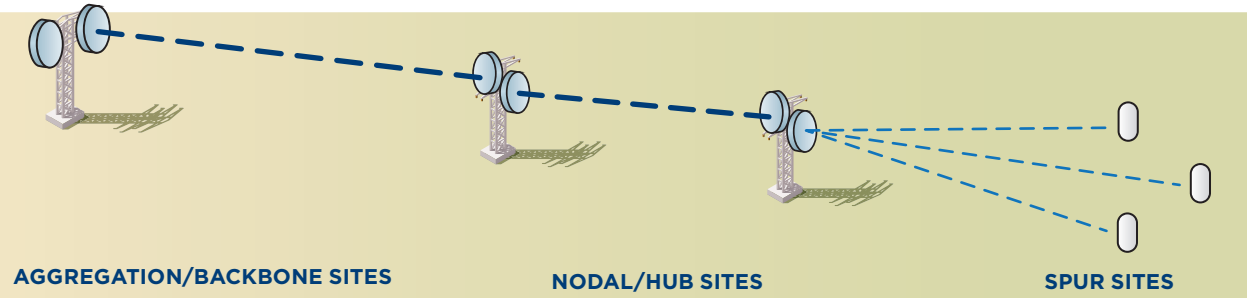
Figure 1: Smart Highway System Architecture Visualization

Each of the many potential wireless communication needs identified in the architecture diagram above commonly occur in multiple instances along the buildout of a National Highway system, all aggregating into one or more regional or national Network Operations Centers for data processing and Command and Control decision making as needed. Read on for technical explanations of the use cases depicted, and subsequent analysis of the Cambium Networks solutions that feature the ideal characteristics to satisfy each use case's requirements.

COMMUNICATIONS NETWORK USE CASES DEFINED

The individual Smart Highway use cases to be discussed in more detail follow below:

WIRELESS IP NETWORK BACKBONE THROUGHOUT HIGHWAY SYSTEM



As with most large-scale wireless communications networks, the construction of a Smart Highway system typically begins with implementation of a solid wireless network backbone design, often utilizing multiple Point-to-Point (PTP) radio links paralleling the highway system itself.

The wireless network backbone provides the attachment point for all other wireless use cases deployed throughout the Smart Highway communications network, and therefore are often configured for low latency and the capacity to support hundreds of Mbps (if not Gigabit in some locations), ensuring adherence to any latency sensitive applications that may be required across the network (e.g. Emergency Roadside VoIP Call Boxes).

As such, availability, resiliency, and redundancy are all critical attributes that must be considered when selecting the ideal backhaul solution. PTP solutions offer 1+1, 2+0, split-mount, and/or spatial diversity – "must have" feature sets that achieve these outcomes where needed. Additionally, with numerous traffic sources traversing up and down the wireless backhaul network with varying degrees of priority, strong QoS and/or traffic shaping/ policing capabilities is essential.

Leveraging PTP wireless technology has been proven to succeed with respect to factors that influence total cost of ownership (TCO) for a Smart Highway infrastructure buildout – avoiding the prohibitive trenching costs and deployment time associated with fiber. Wireless backhaul solutions also prevent physical threats to fiber such as vandalism and thievery along remote stretches of highway, or accidental damage caused by construction crews during roadway maintenance or expansions. PTP solutions are often installed at manned or other secured locations along the highways, further mitigating the aforementioned risks.

WIRELESS INTERNET ACCESS SERVICES AT HIGHWAY REST AREAS

Wi-Fi Internet access at roadside rest areas is increasingly common around the world. Visitors benefit from the convenience of free or paid internet services that offer quick access to emails or map directions, but perhaps more importantly is the incentive Wi-Fi access provides to drivers to take a break during long road trips. Driver fatigue on long trips is increasingly found to be a cause of accidents, so any added amenity at rest areas that can help compel drivers to pull over and take a break can literally save lives.

Wi-Fi Access Point (AP) solutions that seamlessly and reliably serve both indoor and outdoor public areas at highway rest stops facilitate integration with smart highway communications networks. Wi-Fi product solution characteristics common to this use-case are:

- Environment friendly esthetics (Blending in with environment)
- Low power consumption (Some remote rest areas may require solar powered solutions)
- Basic meshing capabilities (easily extending indoor to outdoor Wi-Fi coverage)
- Support for both indoor and outdoor rated product variants
- Selectable antenna coverage area (Omni or directional as needed)
- Customizable login splash pages that are centrally and easily managed remotely throughout the highway system(s)

The Wi-Fi network capacity requirements can vary greatly between different rest areas depending on multiple factors such as location, weather, holidays/vacation season, and more. Smaller or remote areas might average 5-10 Mbps of daily demand, whereas large or urban areas could average a Gigabit or more of traffic capacity daily.

WIRELESS CONNECTIVITY FOR HIGHWAY SECURITY AND TRAFFIC CAMERAS

IP video cameras can be found in almost every use case supported by Smart Highway systems. Needs range from daily traffic control aspects, to security of infrastructure and highway assets, License Plate Recognition (LPR) data capture, monitoring of roadway construction crews and equipment, mobile (nomadic) incident scene command and control needs, and beyond.

IP traffic backhaul demands also vary widely depending on the type of camera, the codec compression techniques employed, and camera's specific usage. High Definition (HD) and 360 degree panoramic camera solutions can demand upwards of 10-20 Mbps on a wireless backhaul network, whereas lower resolution or fixed still picture image cameras typically demand much less bandwidth, in 1-5 Mbps range. Note that cameras are typically configured to push this heavy video traffic up to a core video server or monitoring center somewhere in the IT network, and generally receive very little traffic being sent down. Video transport's bursty nature can tax many wireless solution ingress buffers beyond their capabilities, so selecting radio solutions with the ability to circumvent this challenge is critical. Wireless products that provide Auxiliary PoE-Out facilities to directly connect IP cameras and facilitate installation requirements are also a big plus for large highway deployments.

WIRELESS CONNECTIVITY FOR DIGITAL SIGNAGE

The primary purpose of Digital Messaging Signs (DMS) is to alert drivers to incidents and unexpected conditions. They may give general information, such as "congestion ahead," or specific details as to the location of an accident or predicted travel time to a particular destination. When operators are alerted to a problem (either by police, a caller from the roadway or from CCTV images), they program the DMS units with the relevant display.

Contemporary DMS are remotely controlled via wireless Ethernet communications and updated with new message information often in real time from a central traffic operations center. On a wireless backhaul solution, these DMS have minimal traffic demands, with message board transactions typically only requiring a few hundred kilobits at a time. The DMS do require occasional remotely applied software updates and/or maintenance data exchanges, which may slightly increase transport needs.

WIRELESS HIGHWAY TOLL COLLECTION INFRASTRUCTURE

Electronic Toll Collection (ETC) reduces delay on toll roads, HOV lanes, toll bridges, and toll tunnels by collecting cashless tolls from cars in motion. Electronic toll booths may operate alongside cash lanes so that drivers without transponders can pay manually. Open road tolling is a popular form of cashless tolling without toll booths; cars pass electronic readers even at highway speeds without the safety hazard and traffic bottlenecks created by having to slow down to go through an automated toll booth lane.

As cars pass, ETC systems perform small, but very fast real-time transactional queries to a regional or national user database (transponder user account status) such that visual feedback (typically in the form of a red, green or yellow status light) can be provided to the driver before they fully exit the toll collection area. This necessitates a very low latency wireless IP network backbone connecting the various smart highway ETC collection entities to the appropriate backend core server facility. The IP data frames must be prioritized over most other best effort marked IP data traversing the wireless system, again requiring robust QoS features to be part of the wireless product solution.

WIRELESS CONNECTIVITY FOR EMERGENCY ROADSIDE VOIP CALL BOXES

An emergency call box system is an end-to-end solution for roadside assistance in case of emergency, comprised of telephone boxes installed at strategic locations along the smart highway and connected to a control center for swift response.

Given that many recent call boxes now use VoIP technology to for phone communications, the supporting wireless IP connectivity solutions require very low latency and low jitter specifications. The bandwidth requirements for VoIP are very low (less than 1 Mbps per VoIP call), but due to the small packet size of these calls, the backhaul solution's Packets Per Second (PPS) support should be adequately spec'd to handle the expected peak VoIP calls for the network. The supporting wireless solution should also allow low power operation, to enable these emergency call boxes for solar power when deployed in remote areas.

WIRELESS CONNECTIVITY FOR COMMERCIAL TRUCK WEIGHING SENSORS ON HIGHWAY

Smart highway systems frequently incorporate Weigh-In-Motion (WIM) systems as part of their overall ITS planning, often strategically placed approaching weight sensitive highway infrastructure (e.g. bridges or viaducts). In this situation, the WIM station is installed in the roadway at some distance before the actual bridge, giving highway or bridge authorities time to halt a vehicle that has triggered an overweight alarm. WIM devices are designed with sensors that capture and record truck axle weights and gross vehicle weights when driven over.

The WIM road sensors typically interface into a collocated controller that converts the measured data to IP Ethernet packets, which are then wirelessly connected to data collection and monitoring servers at a nearby Highway Operations Center. The IP data streams generated from these WIM controller boxes are generally small in size, and usually pretty constant with occasional bursts during peak traffic hours.

WIRELESS CONNECTIVITY FOR ATMOSPHERIC AND ROAD CONDITION SENSORS

Road Weather Information Systems (RWIS) are widely deployed throughout smart highway systems to continuously monitor and report on important atmospheric and road related conditions. A RWIS is comprised of Environmental Sensor Stations (ESS) in the field (example ESS shown in the Wireless Network diagram below), a communication system for data transfer, and a central server to collect field data from numerous sensor stations. ESS typically measure local atmospheric (e.g. temperature, wind, humidity, air quality, etc.) and pavement (e.g. water / ice / salt / snow, etc.) levels and conditions. They also include a local data logger that connects directly to all of the environmental sensors as well as any Intelligent Road Sensors (IRS) installed in the nearby road. The data logger encapsulates all of this raw sensor data into IP packets to be transported wirelessly to the closest integration point into the highway's wireless network backbone.

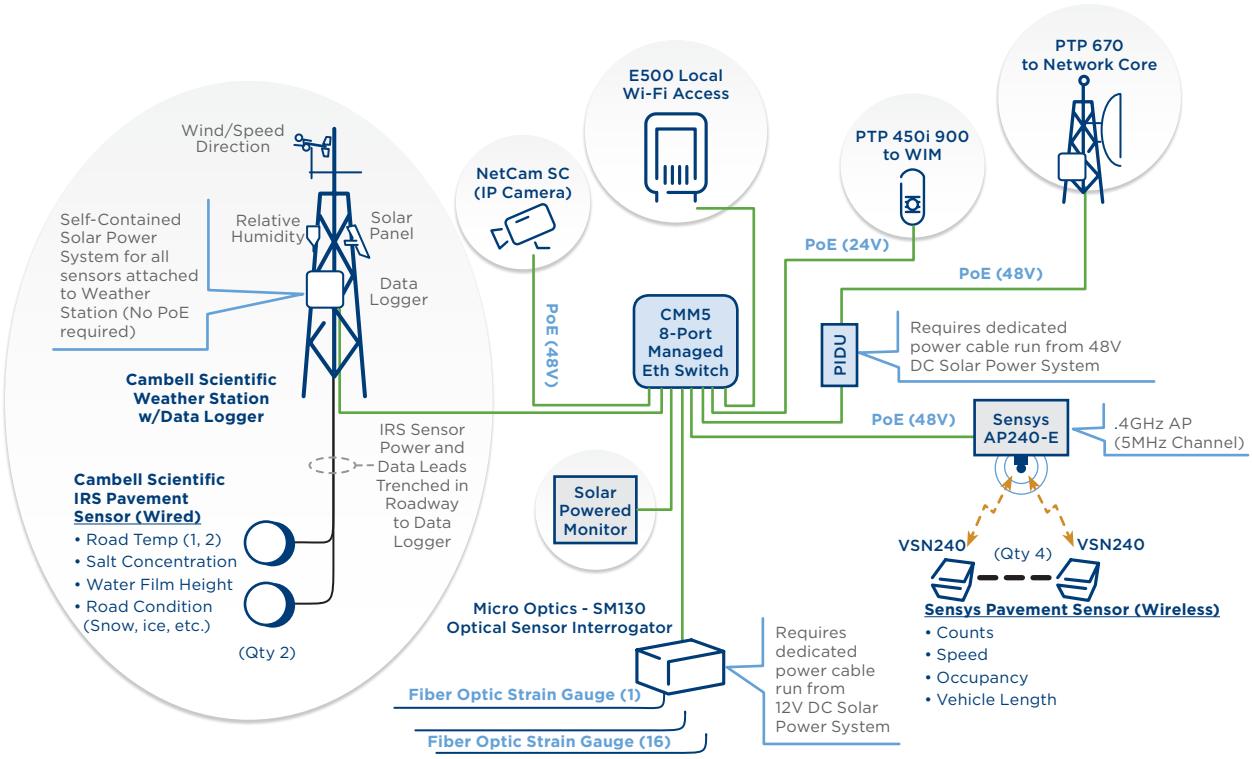
Central RWIS servers are used to process observations from ESS to develop forecasts and display or disseminate road weather information, and the RWIS data are used by Smart Highway operators to support decision-making.

WIRELESS CONNECTIVITY FOR HIGHWAY BRIDGE INFRASTRUCTURE SENSORS

Another crucial part of a smart highway design is the monitoring of highway bridges and viaducts' structural integrity. Fiber-optic strain gauges mounted on bridge structures provide for high-performance strain measurements, evaluating the expansion and contraction of material due to mechanical stress or thermal effect.

The strain gauges are designed around a Fabry-Perot interferometer (FPI). When bonded to a specimen, the strain transferred to the gauge is converted into engineering units by the readout.

The deployed Fiber strain gauges are monitored by a local Optical Sensing Interrogator (example shown in the diagram below), resulting in a single system that can measure both dynamic and static phenomena for large complex structures.



Bridge and Road Senor Wireless Network Segment

WIRELESS CONNECTIVITY IN SUPPORT OF WISP OPERATIONS OFFERED TO CITIES / VILLAGES ALONGSIDE HIGHWAYS

It's not all that unusual to find small and remote communities still struggling to find an economically feasible way to gain access to basic internet services for their residents. This puts highway ministries in the uniquely positive position to strategically and advantageously operate as a wireless internet service Provider (WISP) in these remote areas, offering cost effective services to underserved communities. By leveraging excess capacity available on nearby Smart Highway infrastructure, affordable wireless point-to-multipoint radio solutions can easily be added to reach these communities, helping to bridge the digital divide, positively impacting area residents and businesses.

Typical services provided by WISPs include basic internet, VoIP, and possibly OTT media services such as Netflix, Hulu, DirectTV Now, etc. Depending on the size of the community being served, the bandwidth and latency demands on the IP backbone network could range from a few tens of Megabits to several Gigabits of Internet service demand (or more) per day.

WIRELESS PRODUCTS FOR SMART HIGHWAYS AND ITS NETWORKS

SYNOPSIS OF USE CASE REQUIREMENTS FOR SMART HIGHWAYS / ITS

As can be surmised from the various highway communication use cases described above, product and network design requirements such as availability, capacity, latency, prioritization, and power draw are all key attributes that must be scrutinized when selecting the wireless products required to support the implementation of each of these use cases. Cambium Networks is uniquely positioned to to offer a full complement of globally field-tested PTP, PMP, Wi-Fi, and IIoT solutions that integrate easily, meeting all of the necessary criteria and more. Additionally, offering the capability to manage all product solutions with cnMaestro™, Cambium's unified life-cycle network and Wi-Fi controller solution, this high-valued differentiator makes any wireless deployment and ongoing maintenance a breeze.

CAMBIUM NETWORKS PRODUCT SOLUTIONS FOR DEFINED USE CASE

POINT TO POINT SOLUTIONS (LICENSED & UNLICENSED) FOR WIRELESS NETWORK BACKBONES

Cambium Networks' licensed point-to-point microwave radio solutions (PTP 820) are predominately utilized in this space, as they offer high capacity, low latency, and carrier class redundancy features, with the added protection of using licensed frequencies for each link.

PTP 820 - Microwave PTP Backhaul Solutions

Licensed Ethernet microwave for multi-service networks

PTP 820 is a point-to-point licensed microwave backhaul platform that integrates leading networking functionality with the industry's most advanced microwave technologies, creating a superior transport solution.

Cambium Networks' PTP 820 radios offer the ability to easily design and deploy high reliability ring networks where needed, and can be readily augmented to accommodate future growth in either or both capacity or expansion of infrastructure.

When NLOS or nLOS link performance is required, Cambium Networks' PTP 670 based solutions are used to fill this need with quick deploy unlicensed solutions.

POINT TO MULTIPOINT SOLUTIONS SUPPORTING SMART HIGHWAY APPLICATIONS

Cambium Networks extensive suite of PMP 450 and ePMP™ point-to-multipoint wireless broadband solutions can be found serving highway sensor networks, ETC services, security camera video backhaul, operation center connectivity, and traditional WISP service offerings worldwide. Our industry-leading PMP 450m with cnMedusa™ technology remains the most powerful solution, with uplink and downlink beamforming, coupled with exceptional spectral efficiency enabled by its Multi-User MIMO capabilities.

All of our PMP solutions offer the low latency, traffic prioritization, ease of use, and manageability attributes noted in the Smart Highway use case requirements presented earlier.

PMP 450m

One AP device changes everything

PMP 450m with cnMedusa™ Massive MU-MIMO technology delivers ground breaking spectral efficiency in a highly integrated package while being managed from a single pane of glass in the Cloud.

INDOOR AND OUTDOOR WI-FI SOLUTIONS

Reliable and affordable cnPilot™ Wi-Fi solutions from Cambium Networks, which support both indoor and outdoor smart highway use cases, provide MOT/DOT entities a "perfect fit" product solution, with a full connectivity experience that can be shared by smart highway users.

Designed for the Indoors and Outdoors

- 802.11ac with dual Gigabit ports
- UV rated IP-67 enclosure
- Operating temp: -300C ~ +600C
- Electrical heater for cold start
- Rugged electrical surge & ESD protection circuitry
- Flexible wall mount or pole mount bracket design
- Special LTE coexistence filter for enhanced interference rejection
- Light weight - 881g

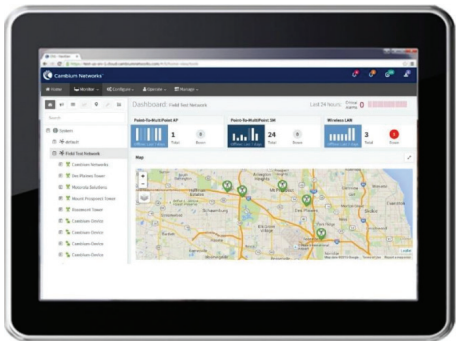
Cambium Networks cnPilot portfolio offers a wide selection of Wi-Fi products that can address every need within a Smart Highway design and deployment, with the ability to provide superior connectivity for any size coverage area or user density. Configuring and maintaining the network is easy with our cnMaestro management system that simplifies installation and provides a complete view of network performance.

INDUSTRIAL INTERNET OF THINGS (IIOT) SOLUTIONS

Cambium Networks cnReach™ N500 radio product solutions support critical outdoor infrastructure operations found throughout smart highway networks, transporting process monitoring and control data from remote sensors (bridges, roadways, ESS, etc.) back to the operations hub, supporting real-time automated decision making and on-going analytics. cnReach delivers reliable, secure connectivity to the transportation industries, regardless of large geographic areas, hard to reach terrain, and challenging spectrum environments. cnReach also supports upgrades for legacy infrastructure, facilitating the migration to modern networks by combining existing serial and analog/digital I/O with TCP/IP and Ethernet connectivity. Fully integrated into cnMaestro's 'single pane-of-glass' management platform, cnReach helps bridge the IT/OT sides of complex organizations. Combining cnReach's licensed and unlicensed narrow-band radios with Cambium Networks' broadband technologies, industrial organizations maximize the benefits of end-to-end Industrial Internet of Things (IIoT) solutions.

- Licensed and unlicensed 900 MHz (cnReach is also available in 700 MHz licensed)
- Secure communications with AES 128/256-bit encryption with password authentication
- Highly reliable communications with access point synchronization and adaptive modulation
- Single and dual radio configurations for advanced back-to-back relay and store-and-forward applications.
- Extensive I/O capabilities easing the transition from serial to all-IP networks with multiple serial ports, Ethernet ports and analog/digital I/O built-in.
- Sophisticated network planning with LINKPlanner, a no-charge planning tool enabling network designers to predict both capacity and availability of networks crossing all of Cambium Networks technologies.
- Supported by cnMaestro software for monitoring the status of entire networks carrying traffic across sensors

CLOUD BASED NETWORK MANAGEMENT AND LIFECYCLE SOLUTION



MOT and DOT agencies need a streamlined management system that facilitates efficient operation and growth of their Smart Highway wireless networks. Cambium Networks' cnMaestro management platform is available in the cloud or on premises, purpose-built for secure, end-to-end network lifecycle management, inventory control, onboarding of devices, daily operations, and maintenance. Managing it all with full visibility and vast scalability, cnMaestro has a full set of features targeted to simplify management of Cambium Networks Devices:

Full Visibility Across the Network

- Single pane of glass to manage an entire network, including backhaul point-to-point links, point-to-multipoint access and Wi-Fi
- Dedicated dashboards for each device, with common and centralized upgrade and device configuration workflows to minimize the learning curve for network managers

Client End-to-End Wireless Troubleshooting

- One-click functionality reveals the entire chain of network nodes under management related to the problem area, displaying the results of performance and latency tests, as well as sub-system level health checks on a single screen
- Managers will see network elements on Google maps that may be causing issues and determine timely solution

Wi-Fi Controller

- Deploy enterprise grade hotspots with built-in personalized branding capabilities
- Use vouchers to provide authenticated access to wireless clients, with multiple tiers of service
- Use social login to provide wireless access and business analytics on wireless users

Frictionless Deployment

- Pre-configure devices; settings will automatically apply at the time of installation
- Ensure large networks are kept up to date by streamlining software upgrades and configuration changes

Power of Secure Cloud

- Access cnMaestro quickly from any location with secure HTTPS. No need for VPN connections
- The cloud management system always has the latest updates, keeping the latest software at your fingertips
- Easily scalable, saving up-front hardware expense with cnMaestro cloud, and no need to deal with the complexities of server management and deployment

Designed for Wireless

- Many ways to view your wireless network data including maps, tables and historical charts to quickly assess a single device or an entire group
- Wireless parameters and statistics are automatically available, enabling operators to focus on designing and growing their network – not their management system

cnMaestro's robust features will continue to be enhanced and extended over upcoming releases. The functionality in cnMaestro includes the following:

SUMMARY AND CONCLUSION

Wireless solutions from Cambium Networks provide end-to-end connectivity for indoor and outdoor deployment at a fraction of the time and cost of wired or fiber solutions. Whether connecting a city square, an event venue, or a conference, people can get online quickly and enjoy a consistent, reliable experience.

PROVEN SOLUTIONS

- Long range point-to-point wireless backhaul
- Licensed microwave and unlicensed backhaul
- Wide-Area point-to-multipoint wireless access
- Licensed and unlicensed Wide Area Networks (WAN)
- Enterprise-class 802.11ac Wave 2 Wi-Fi Access

LAYER NETWORKS

- Indoor Wi-Fi networks
- Outdoor hotspot and Wi-Fi networks
- Single pane of glass network management
- Bird's eye view of Field Area Network (FAN)
- Rapid on-boarding and provisioning of new nodes
- End-to-end performance and fault management
- Centralized firmware and software management

THE CAMBIUM NETWORKS DIFFERENCE

- **Scalability** – Connect up to thousands of individual locations with a synchronized network that enables RF frequencies to be re-used throughout the network, providing the highest level of connectivity in the least total amount of spectrum.
- **Reliability** – Deploy wireless broadband with confidence that it will work right the first time and continue to work 24/7, with a long life.
- **Affordable Quality** – Minimize the total cost of network ownership with one IP-based wireless network comprised of licensed and unlicensed components that can be rapidly deployed and perform reliably with minimum maintenance cost.
- **Sustainability** – Solutions designed to operate for years from a supplier with a proven track record of stability and sustainable product evolution.
- **Spectral Efficiency** – Provide the highest amount of information transfer in the least amount of scarce spectrum with industry award winning throughput.

Cambium Networks™

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