Next-Generation Head-of-Train and End-of-Train Communications

Solving the Challenges to Enable Safe Operation of Longer Trains, Positive Train Location, Moving Block, and More

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The adoption of End-of-Train (EOT) and Head-of-Train (HOT) devices is one of the most important advancements in railroad history. Through the incorporation of various telemetry and positioning technologies, EOTs have delivered proven operational and safety benefits to the railroads for decades. The widespread use of HOT and EOT devices could not have been possible without the deployment of a highly reliable and dedicated communications link currently operated on the AAR's 450 MHz channels. However, a handful of new initiatives have been introduced by the railroads over the last few years which have revealed increasing challenges with the radio technology utilized on this legacy 450 MHz network. Fortunately, the adoption of 802.16t radio technology can address these challenges, delivering a host of new operational safety and business objectives.

Before diving into how 802.16t technology addresses the needs for next-generation HOT and EOT (NGHE), let's first discuss these challenges associated with legacy NGHE operation.

Longer Trains Further Complicate an Already Challenging Communications Link

Even before the operation of longer trains, legacy HOT – EOT communications links operated in a highly challenging environment. Unless a train is on a curve, no direct line of sight exists between the HOT and EOT antenna due to the obstruction of the EOT installation on the last train car. Therefore, propagation relies mostly on reflections from static wayside objects. As a result, this radio link exhibits characteristics typical of mobile channels including doppler, multipath, and fast path loss variations. These characteristics will be discussed later in this document.

While testing legacy EOT operation, a 2018 FRA report noted that the frequency of RF signal fading increases as the speed of the train increases. This indicates the dominant propagation mechanism involves reflections from wayside objects which may introduce RF signal fades of up to 20 dB on the HOT-EOT communications link. Unfortunately, the current radio technology utilized in legacy

HOT – EOT communications cannot offset these deep types of fades. The result is a loss of communication of safety data such as brake pressure as well as train telemetry data with the locomotive.

Several high-profile derailments and the potential impacts of daily blocked crossings on communities have also raised concerns about the operation of longer trains. Yet railroad companies have been operating increasingly longer trains in order to reduce the number of crews, locomotives, and total number of trains required. Communication failures associated with deep RF fading will only increase with longer train lengths (between locomotive and the EOT). The limitations of the legacy HOT – EOT radio – including power limits, antiquated modulation schemes, and lack of modern RF signal recovery technologies – reveal the need for next-generation radio technology to enable railroads to operate longer trains safely.

Enabling Safety and Operational Improvements Through Highly Accurate Positioning for PTC

Legacy HOT-EOT systems incorporate GPS technology which cannot reliably determine the exact location of the end of a train (and therefore, the exact length of a train). Over the past several years the FRA has tested Positive Train Location (PTL) technologies which can reliably determine and communicate the precise location of a train's rear end EOT devices.

PTL systems are designed to provide accurate and timely HOT and EOT positions to the Positive Train Control (PTC) system on the locomotive. With the information provided by PTL, precise train lengths can also be computed. These PTL systems can deliver a host of safety and operational benefits to the railroads, including:

- Safe train separation in PTC mode while trains are operating under restricted speed in a permissive block
- Automatic truncation and release of train authorities in dark territory
- Automatic determination of train clearing a grade crossing or power-operated switch
- Moving block operations
- Automatic determination of train integrity
- Vital PTC

However, the benefits of PTL cannot be fully realized without a highly reliable and available communications link capable of addressing the unique challenges associated with longer trains and the desire for higher data capacity over the legacy 450 MHz network. PTL also requires a high level of security to prevent spoofing and unwarranted attacks – security which cannot be implemented on legacy HOT-EOT radios. Only 802.16t technology can solve these problems.

"NGHE" - A Desire to "Do More" with Head-of-Train and End-of-Train

In June of 2023, the "Generation 4 HOT / EOT System" was presented by the AAR's Railway Electronics Standards Committee in order to focus suppliers on the development of a next-generation HOT – EOT system capable of supporting a variety of new capabilities and efficiencies including:

- Automated HOT – EOT repeating and relaying of messages
- Elimination of wayside repeaters
- Single person arming and testing of HOT and EOT devices
- Support for the industry's new EOT ID scheme
- Remote HOT and EOT asset management
- Health and status information to back office
- Positive Train Location (noted above)

Supporting an antiquated modulation scheme developed in the 1950s and a maximum bit rate of 1,200 bps, the legacy HOT – EOT radios will not be able to support the additional traffic demands necessary to deploy these "NGHE" applications. Using 802.16t technology, railroads will be able to not only dramatically increase the amount of throughput on existing HOT – EOT 450 MHz spectrum but will also be able to do so without allocating new spectrum.

Understanding the Challenges

After researching various industry studies and test results, Ondas Networks developed a sophisticated RF channel model associated with HOT – EOT communications. This model enabled us to simulate the impact of the 802.16t protocol on HOT – EOT links against various train speeds and lengths. We developed our own field test tool – known as "Curiosity" – which enables us to perform passive in-line monitoring of the HOT-EOT while testing NGHE radios in the field environment. We also developed the Ondas Magellan tool which allows us to emulate a variety of RF protocols for field testing (such as legacy HOT-EOT and 802.16t) through software-defined radio technology. These tools allowed us to perform a three-stage test of our radio technology:

1.) Establish a baseline of the real RF environment associated with existing (legacy) HOT and EOT radios.
2.) Quantify improvements to the HOT – EOT communications link when using Ondas radios with enhancements to the legacy protocol. These improvements can be measured against the actual baseline with legacy radios.
3.) Measure the improvements to the HOT-EOT communications link when using Ondas 802.16t radios operating in Direct Peer-to-Peer (DPP) mode.

One of the critical aspects of our testing is that we subjected our testing to the *exact* constraints faced by legacy radios. This means that our radio testing was subjected to the same power and space constraints as well as antenna and cable infrastructure. We needed to be able to demonstrate to the railroad industry that migration to 802.16t technology is possible while using the existing HOT and EOT form factors and connectors.

Our real-world testing has demonstrated not only that 802.16t DPP is the best technology suited to address the challenges associated with Generation 4 HOT – EOT deployment, but that Ondas software-defined radios provide unique differentiators that other vendors have not been able to match. ***Just as important, we can demonstrate that the transition to 802.16t technology for the HOT – EOT is the least disruptive option for the railroads as it can be utilized on the existing pair of 450 MHz channels and incorporated with any vendors' HOT and EOT offerings.*** Let's now discuss these specific features and how they apply.

IEEEE 802.16t and DPP

For over five years, the AAR Wireless Communications Committee, suppliers, and technologists have been working within the IEEE to develop a new interoperable and open standard developed for the specific needs of railroads and other industries which operate in narrowband channels. This new IEEE 802.16t standard is the latest amendment to the IEEE 802.16-2017 wireless standard due to be fully released this year. Known also as "dot16," the 802.16t standard was developed for "Fixed and Mobile Wireless Access in Narrowband Channels" with channel bandwidths ranging from 5 kHz 100 kHz.

IEEE 802.16t incorporates numerous enhancements designed for high-demand industrial applications. The standard is frequency agnostic which enables it to be deployed in any AAR-owned spectrum. It standard also includes contiguous and non-contiguous channel aggregation, allowing railroads to aggregate "picket fences" of channels to support high throughput applications. A wide array of higher order modulations is supported to pack more data onto existing channels. IEEE 802.16t networks also incorporate Direct Peer-to-Peer (DPP) mode which allows for communication between radios with the need for intermediate base stations.

As with all IEEE standards, the 802.16t standard is open to any vendor to incorporate into their HOT – EOT products. While "dot16" technology enables a wide range of capabilities across railways, the specific features that make it the idea choice for HOT – EOT communications include:

- **Advanced time diversity mechanism to mitigate deep fades associated with longer, fast moving trains:** With dot16t time diversity, an Ondas radio utilizes repetition - combining to accumulate the power of multiple, unusable repetitions of signal to combine them into a usable signal. By recovering messages which would have previously been lost by legacy HOT-EOT radios, a dot16 radio maintains communications even when the link suffers from severe fading. Through this repetition-combining technique, an Ondas 802.16t radio dramatically improves the received signal performance without any increases of HOT – EOT power beyond current limits.

- **Higher order modulations to pack more data onto the existing 450 MHz network:** The Generation 4 HOT – EOT requires more data traffic to be supported on the existing pair of 450 MHz channels. An 802.16t radio can dynamically select from a variety of modulation schemes (up to 64 QAM) depending on the RF environment, allowing more data to be packed on the existing channels. While this allows the railroads to perform more HOT-EOT maintenance-related tasks over the link, the higher data throughput allows for more repetitions of HOT – EOT data messages which further mitigates the impact of deep RF fades.

- **A Direct Peer-to-Peer mode specifically designed for the HOT-EOT environment:** HOT or EOT radios communicate directly with each other while operating in Direct Peer-to-Peer (DPP) mode. However, a radio operating in DPP Relay mode can be used to further extend the range by relaying messages. This means that a radio installed in the middle of a train consist (such as a distributed power locomotive) can also be used to relay messages between HOTs and EOTs. The 802.16t DPP mode's CSMA / CA channel access mechanism is also specifically optimized to leverage the deterministic behavior of HOT and EOT traffic. As a result, high utilization of the existing 450 MHz channels is feasible with no packet collisions. This allows more HOT – EOT systems to operate in close proximity to each other.

- **Operation of more HOT – EOT-equipped trains in range of each other:** A legacy HOT – EOT radio utilizes 2 x 12.5 kHz wide channels, each dedicated to communication in one direction. A dot16 radio supports frequency diversity in order to operate simultaneously on both channels in each direction. By utilizing a distinct channel in each direction and coupled with the packet collision-avoidance capabilities of DPP mode noted above, more equipped trains can be operated in range of each other and HOT-EOT message collisions can be eliminated (currently specified as a worst-case scenario of up to 24 trains in range of each other).

- **User-defined prioritization of train management data traffic -with customizable Quality of Service (QoS):** The dot16 standard enables network administrators to create varied QoS levels, prioritizing different types of data traffic and tailoring uplink / downlink (UL/DL) ratios to specific use cases. This enables the prioritization of higher priority traffic – such as brake pipe pressure on the EOT – to take precedence over less critical traffic (such as log retrieval).

- **Enhanced reliability and security:** The Generation 4 HOT and EOT devices must incorporate a range of new security requirements to prevent spoofing and unauthorized access. The dot16 standard builds on current standards by integrating advanced security protocols and reliability features - vital for mission critical communications. The dot16 technology allows for security enhancements as encryption and other cybersecurity tools evolves.

- **Interoperability and scalability between vendors:** Compliance with IEEE standards ensures that devices from various HOT and EOT manufacturers can interoperate, reducing vendor dependency and enabling scalable network architectures.

Where to Learn More

Ondas Networks is proud to contribute to the industry's effort to solve the communications issues posed by longer trains and address the needs of the Generation 4 HOT – EOT project. Delivering a next-generation, highly reliable HOT – EOT communications network is the key to enable the potential of technologies such as Moving Block and Positive Train Location. Ondas Networks plans to make the results from our most recent rounds of testing of 802.16t radios in the HOT-EOT application available in 2025. We invite railroads, suppliers, local and community officials, and regulatory officials to learn more about how this important technology can help railroads run safer and more efficiently, increasing the level of safety to the public. To learn more, please contact:

Kevin Nichter
Vice President of Product Marketing
Ondas Networks
kevin.nichter@ondas.com
502-438-6950