Why Ultra-Wideband for Wireless Battery Management Systems?

Vincent Martinez, NXP System Innovations
Emiliano Mediavilla Pons, NXP BMS Applications and Solutions team lead

Wireless communication within battery packs is a breakthrough technology enabling greener, safer and more efficient electric vehicles. NXP Ultra-Wideband is the superior radio frequency technology for communication in Battery Pack applications as it guarantees a robust wireless link with highly synchronized data throughput in a secure environment.

Battery management systems

Many modern electrical systems rely on local energy sources, often involving batteries. This applies to small devices like cell phones and increasingly to larger systems such as electric vehicles (EVs) and battery energy storage systems (BESS). In these cases, a significant amount of energy is stored, posing a risk if it is suddenly released due to a fault. Therefore, it is crucial to safely control and monitor battery packs, especially under extreme conditions.

A Battery Management System (BMS) has a variety of tasks, including:

- Accurate control and estimation of the relevant battery State of X (SOX) estimation including state of charge (SOC), state of function (SOF) and state of health (SOH).
- Ensuring the efficiency of batteries by accurately measuring the cells and safeguarding cell operation margins.
- Ensuring safe monitoring of battery's health by measuring each cell individually. Precise monitoring facilitates balancing mechanism, preventing cells from overcharging, and discharging.
- Fulfilling legal requirements, e.g., information on the digital battery passport.

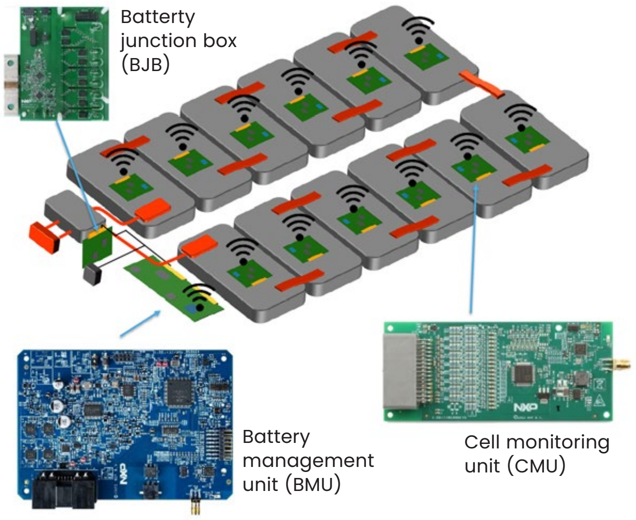


Figure 1: Modular Wireless BMS

Why going Wireless?

Modern battery packs, as used in EVs and BESS, often have a modular approach, as illustrated by Figure 1. A typical high voltage battery pack is divided into several modules. This allows a modular architecture enabling easy scaling. Next to the modules, the pack has a central Battery Management Unit (BMU) containing the processor controlling the modules and safeguarding the complete system. This BMU can communicate with all modules, collecting the voltage and temperature measurements from each module to ensure the system operates safely and properly. In these architectures, the greatest benefit is achieved by eliminating the wiring between modules and implementing a broadcasting scheme.

Wireless technologies implemented in battery packs come with the clear advantage of less cabling, weight and space required, thus maximizing the energy density of the battery pack. Long-term mechanical reliability is improved, because cables and connectors tend to fail over time. Fully automated battery pack assembly becomes easier to achieve since there is no need for fragile high voltage connector insertion. This eliminates the need for high voltage manual operations and saves space between modules for robotic insertion. Additionally, using wireless technology facilitates the reuse of modules, such as for refurbishment or in battery second life applications, since only the power lines need to be reconnected. Table 1 summarizes the advantages of wireless BMS communication. The combined advantages translate to a significant cost saving at system level.

Efficiency	**Reliability**	**Production**	**Life cycle**
• Weight reduction • Increased energy density • Increase battery architecture flexibility	• Connector reduction • Improved isolation • Removal of isolated wire harness	• Automated battery assembly for reduced manual labor • Scalability	• Easier serviceability • Easier reuse in second life • Improved sustainability

Table 1: Advantages of wireless BMS communication

Unique wireless BMS solution

Multiple technology options are available for replacing inter-module wired communication with wireless technology. NXP identified Ultra-Wideband (UWB) as a superior radio frequency technology compared to other wireless technologies such as narrow-band wireless systems typically operating in the 2.4 GHz ISM band (e.g., BLE, Zigbee).

UWB works by encoding data bits in very narrow pulses, resulting in a very wide frequency spectrum bandwidth signal, hence the name Ultra-Wideband, as showed in Figure 2. For the proposed UWB technology, the bandwidth of the signal is 500 MHz, resulting in a pulse width in the order of 2 ns, ideally suited for systems operating under frequency-selective fading conditions, such as battery pack environments. These pulses are then directly upconverted to the carrier frequency, for example approximately 8 GHz for UWB channel 9 (as defined in IEEE 802.15.4 Standard).

Ultra-Wideband is a radio technology that can be used at an incredibly low energy level for short-range, high-bandwidth communication over a large portion of the radio spectrum.

The payload mostly consists of the BMS measurements (voltages, temperatures etc.), which can be transmitted from the modules to the BMU. For compatibility and seamless integration with BMS upper layers, the same payload format as for wired BMS can be re-used with added encryption for security and integrity.

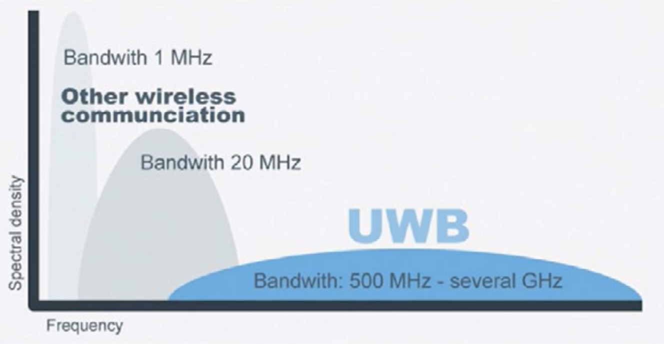


Figure 2: Ultra-Wideband technology

Unprecedent battery pack RF communication

Why is the difference between narrow-band wireless and Ultra-Wideband technologies relevant? The RF situation in a battery pack is very specific and significantly different from communication in open air, for which most wireless systems are optimized. A modular battery pack consists of multiple battery modules packed in a metal enclosure. The metal casing generates many reflections, and the signal bounces around for some time, yielding a rich multipath environment. This translates into a highly frequency-selective fading, which highly depends on the position of the antennas and the openings/corridors between the modules. Additionally and non-predictable interference from other systems operating in the same band may also affect transmissions in the battery pack. These two factors severely impact narrow-band systems, implying complex and adaptive channel selection algorithms. As each antenna may require a different frequency for optimal communication in narrow-band systems, this also limits broadcast-type of communication. For the UWB type of pulsed signal, narrow frequency notches in the band hardly impact the signal quality, as energy is harvested over a wide bandwidth. This ensures robust data communication performance for all the transmitter – receiver links inside the battery pack, thereby enabling broadcast-type of messages.

Due to its robustness inside battery packs environments, UWB supports reliable communication at raw data rates up to 7.8 Mbps. This is significantly higher than many narrow-band technologies and allows new use cases and applications that request faster measurement cycles and/or high data rates.

Another benefit of UWB is its very accurate timing and synchronization capability, leveraging the narrow pulses/high bandwidth characteristics. Although BMS applications are currently mostly based on data communication capability, the exceptionally precise timing of UWB allows for extremely accurate synchronization of measurements, for example to synchronize current and voltage measurements (typically measured at different subsystems in the battery pack) to well below-µs alignment, while most narrow-band technologies today stay at the multiple-µs level.

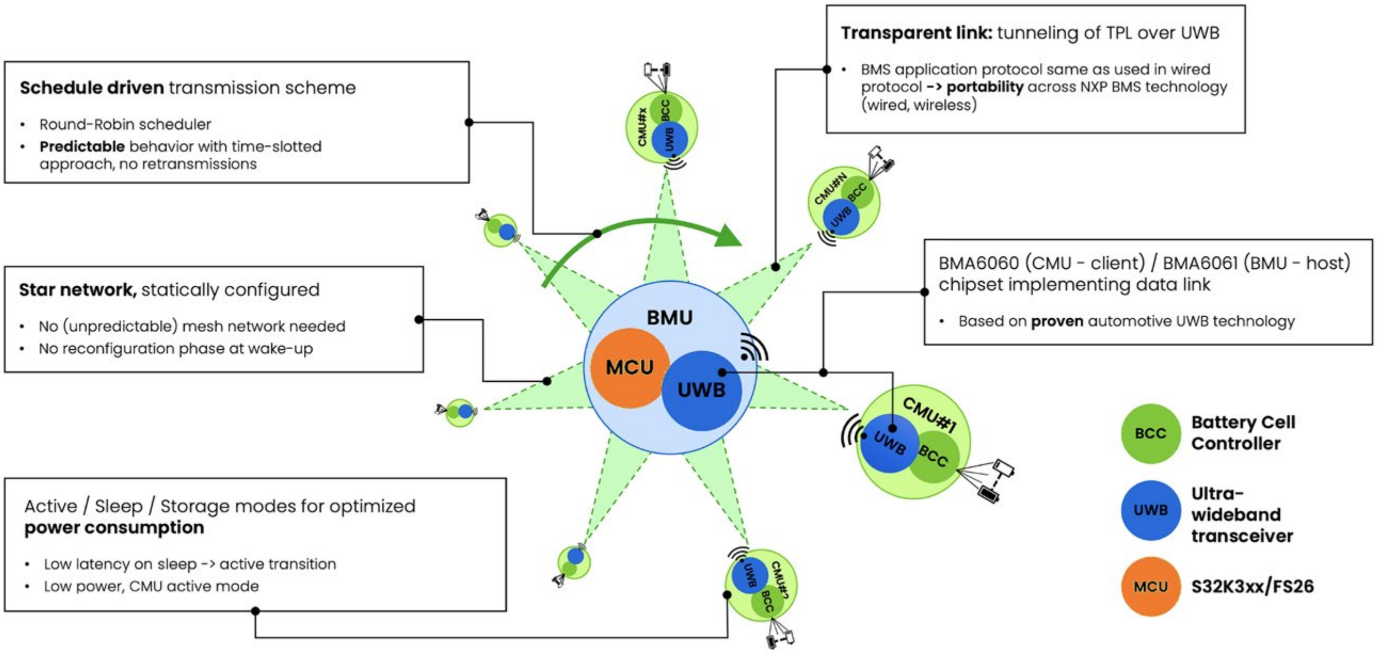
With its increased communication robustness, higher data rates, and extremely accurate synchronization capability, UWB paves the way for new emerging and more demanding BMS applications, like Electrochemical Impedance Spectroscopy (EIS).

Advantages of the NXP Chipset BMA6060/BM6061 devices based on proven automotive UWB technology

NXP's BMA6060 and BMA6061 pair is a wireless UWB link designed specifically for BMS systems. It replaces the wired communication between the NXP battery cell controllers and the central MCU while remaining protocol-level compatibility. In addition to the general advantages of UWB compared to narrow-band solutions, NXP's implementation of Ultra-Wideband Wireless BMS includes several specific enhancements that increase reliability and predictability.

One enhancement is the use of optimized UWB packet structure, designed to maximize performance under battery pack environments.

A second enhancement, enabled by the fixed BMS network in a closed battery pack, is the use of a time-slotted scheduling approach. As illustrated by Figure 3, each node (e.g., each module) has a fixed time slot to receive or transmit. This eliminates the needs for complex channel access and allocation schemes, that would be needed in general purpose systems where the network configuration needs to be flexible. No frequency hopping, no collisions, and strong timing predictability, by design.



Schedule driven transmission scheme

- Round-Robin scheduler
- **Predictable** behavior with time-slotted approach, no retransmissions

Star network, statically configured

- No (unpredictable) mesh network needed
- No reconfiguration phase at wake-up

Active / Sleep / Storage modes for optimized **power consumption**

- Low latency on sleep -> active transition
- Low power, CMU active mode

Transparent link: tunneling of TPL over UWB

- BMS application protocol same as used in wired protocol **-> portability** across NXP BMS technology (wired, wireless)

BMA6060 (CMU - client) / BMA6061 (BMU - host) chipset implementing data link

- Based on **proven** automotive UWB technology

Figure 3: NXP BMS UWB network highlights

As a result, NXP's UWB technology, when applied to the BMS application results in highly reliable and predictable communication that achieves packet error rates lower than 10^{-6} with a single transmission. This allows pack design with fewer iterations, and less susceptibility to design optimizations.

NXP's UWB BMS is also power efficient. NXP's concept is designed as a static star network configuration with a time-slotted schedule. All the UWB transceivers in the network are well synchronized and 'know' when a packet is expected to be received or transmitted. This switches operation modes to enhance the energy consumption (in contrast to a generic use case where a receiver must be enabled continuously). Due to this approach and the higher data rates, up to 7.8 Mbps that allows transmitting the same amount of data in much shorter cycles, NXP's UWB BMS has an average power consumption that is favorably comparable to other wireless or wired technologies.

In addition to the RF-specific advantages, NXP has implemented several other features that are beneficial for this application. The system ensures message privacy and integrity by protecting against eavesdropping and false message insertion through encryption using a built-in hardware security engine. A short-lived session key, where each message is encrypted using AES-128 (or optionally AES-256), a widely accepted solution, attempted to consolidate and identify the encryption message.

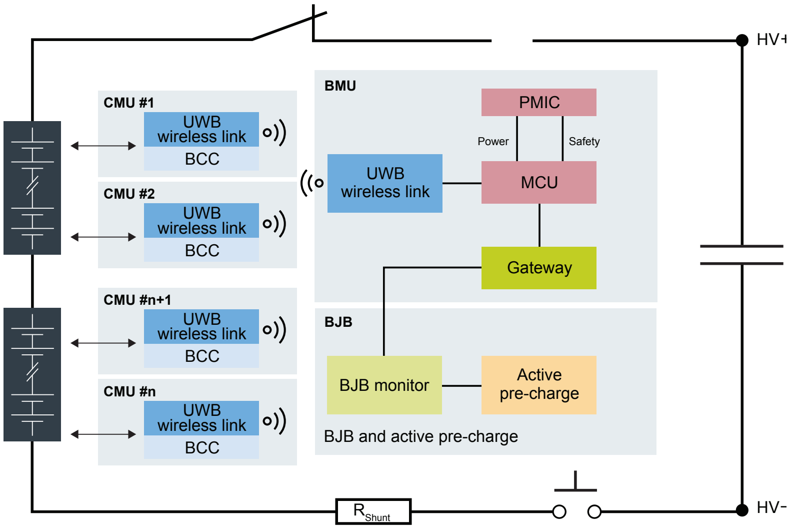


Figure 4: Block diagram battery pack with wireless inter-module communication

The NXP Ultra-Wideband wireless BMS approach

NXP provides a full solution for wireless integration into the battery enclosure:

- Complete battery management system devices solution, including RF transceivers, battery cell controllers, battery junction box, active pre-charge and battery monitoring devices.
- Software support on product and system level, including production ready and reference software, reducing time to market and software development cost. NXP's software is developed according to ASPICE level 3, MISRA 2012 and following the development process described in the ISO/SAE21434.
- Reference designs to simplify and shorten implementation and testing, saving time and resources.

Conclusions

Ultra-Wideband is a breakthrough technology to implement communication in a closed, metal environment such as EV battery packs. It offers clear advantages over narrow-band communication technology, as being immune to frequency-selective fading; improving reliability, ease of design and other areas, while being power and cost effective. This is making UWB the most robust and reliable technology for implementing a wireless communication in a battery pack.

How to reach us

Home Page: www.nxp.com
Web Support: www.nxp.com/support

USA/Europe or Locations Not Listed:
NXP Semiconductors USA, Inc.
Technical Information Center, EL516
2100 East Elliot Road
Tempe, Arizona 85284
+1-800-521-6274 or +1-480-768-2130
www.nxp.com/support

Europe, Middle East, and Africa:
NXP Semiconductors Germany GmbH
Technical Information Center
Schatzbogen 7
81829 Muenchen, Germany
+44 1296 380 456 (English)
+46 8 52200080 (English)
+49 89 92103 559 (German)
+33 1 69 35 48 48 (French)
www.nxp.com/support

Japan:
NXP Japan Ltd.
Yebisu Garden Place Tower 24F,
4-20-3, Ebisu, Shibuya-ku,
Tokyo 150-6024, Japan
0120 950 032 (Domestic Toll Free)
www.nxp.com/jp/support/

Asia/Pacific:
NXP Semiconductors Hong Kong Ltd.
Technical Information Center
2 Dai King Street
Tai Po Industrial Estate
Tai Po, N.T., Hong Kong
+800 2666 8080
support.asia@nxp.com

nxp.com