LORD TECHNICAL NOTE

LXRS® and LXRS+

Wireless Sensor Protocol

Using LXRS and LXRS+ For Long-Term Monitoring and High Bandwidth Test and Measurement

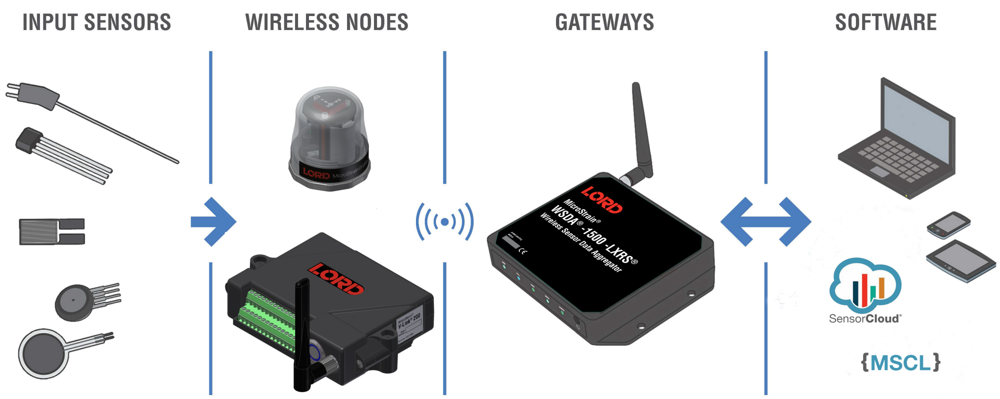
Introduction

LORD Sensing has developed and deployed two communication protocols for sending data from networks of wireless sensors. These protocols, labeled LXRS and LXRS+, feature node-to-node synchronization of 50 us, lossless data throughput, and unmatched wireless sensor network data throughput. These functions are accomplished while maintaining low power requirements required for long battery life.

LXRS and LXRS+ are unique because they were created specifically for applications such as flight test and heavy machine monitoring, which require large amounts of raw sensor data and synchronization between nodes, without losing data. The differentiating factor between the two protocols is that LXRS+ sacrifices communication range in favor of a four times larger network bandwidth. In the following sections, we explore the methods used by LXRS and LXRS+ and compare their effectiveness to other networking protocols such as Zigbee, WirelessHART, and Bluetooth LE.

Networking Topology

LXRS uses a star network topology for bi-directional communication between one gateway and multiple wireless sensor nodes. All nodes communicate directly to the gateway, and each network operates on a designated frequency channel within the 2.4 GHz license-free ISM band.



LORD Wireless Sensor Network
Multiple nodes communicate through gateway using star network topology

Synchronization

A wireless beacon packet is broadcast every second, on the second, by the WSDA gateway. The beacon contains a UTC timestamp and is used by the wireless sensor nodes to synchronize sensor sampling and accurately schedule transmissions.

To have a tightly synchronized and scalable network of wireless sensors, each WSDA and sensor node uses a high-precision, temperature-compensated oscillator as a time source. The drift rate of this part is within +/- 5 ppm over the full temperature range, only requiring the node to resynchronize at periodic intervals to maintain synchronization to within +/- 50 microseconds of the reference.

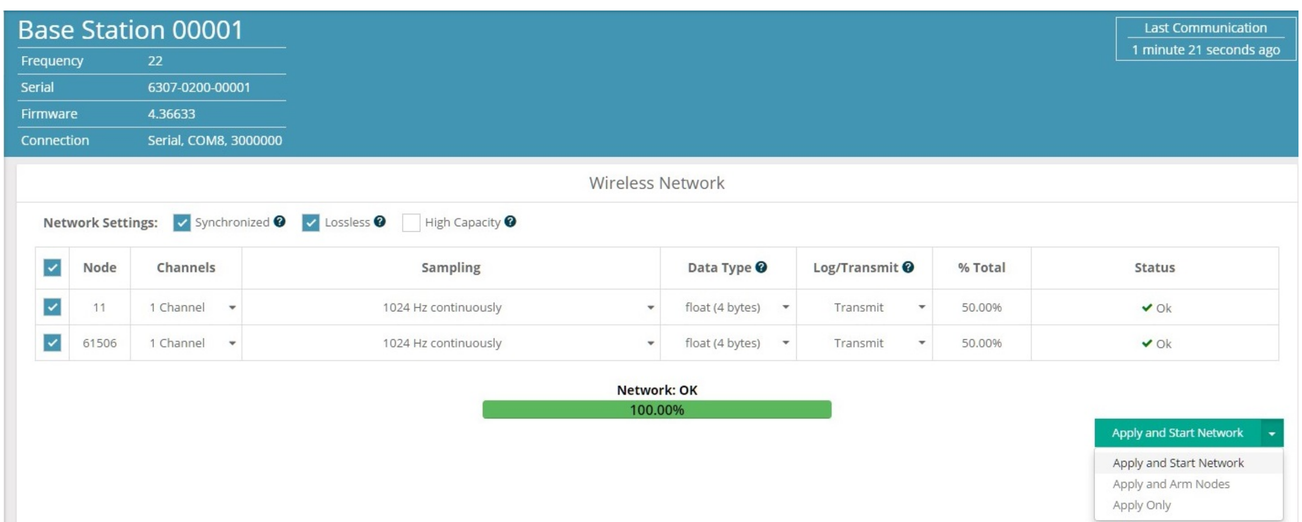
WSDA gateways will synchronize their time clock to the network, local PC, or GPS depending on their model and configuration.

TDMA Networking

LXRS uses time-division multiple access (TDMA) for collision avoidance. With TDMA, time slots are assigned to each node for scheduling buffered data transmissions and acknowledgments.

SensorConnect™ is used for kicking off LXRS sensor networks. When the program applies network settings, TDMA time slots are allotted to nodes based on the total amount of data each sensor needs to transmit per second. When lossless is enabled, at least 50% additional bandwidth is allotted to each node to allow nodes to resend dropped packets. For applications that do not use SensorConnect, the MSCL API may be utilized for applying network settings.

To maximize network density, LXRS does not allow for dynamic slot allocation. If new nodes are added to the network, or changes made to any node's sampling operation, then the whole network must be stopped and restarted with the new settings.



Apply and Start LXRS Network using SensorConnect

Lossless

The LXRS wireless network protocol was designed to maximize communication success rate, even in harsh environments such as rotorcraft and heavy machinery, where multipath, moving parts, and other anomalies can cause significant challenges. This is accomplished through the use of buffering, acknowledgments, and re-transmissions without compromising the energy-constrained nature of the devices.

All data collected by each node is time-stamped and immediately pushed into a high-speed circular RAM buffer, with their corresponding time stamps. Data is pulled from this buffer and transmitted in packets by the wireless sensor node on a first-in first-out basis. The WSDA sends acknowledgment messages to the node immediately on receipt of each packet. If the ACK is not received by the node within a certain time-frame, it will retransmit the same packet in its next allotted time slots until successful. The bandwidth overhead inherent in LXRS networking allows the wireless sensor to “catch-up” after dropping packets. Data is only lost if the number of dropped packets have filled the node's RAM buffer, in which case, the oldest data is discarded first.

Data Buffering

The amount of time it takes to fill the circular data buffer is dependent on the RAM size, sample rate, number of active channels, and sample resolution (16, 24, or 32-bit). The table below gives an approximation of the buffer duration for the G-Link®-200 or V-Link®-200 sampling continuously with the given sample rate, number of channels and 16-bit data conversions.

	Number of Sensor Channels		
Sample rate	1	2	4
4096	16 s	8 s	4 s
2048	32 s	16 s	8 s
1024	64 s	32 s	16 s
512	128 s	64 s	32 s
256	245 s	128 s	64 s
128	512 s	256 s	128 s
⋮	⋮	⋮	⋮

Table 1. RAM Buffer Size - Approximate duration (in seconds) of sampled data the RAM buffer can hold on the V-Link-200 and G-Link-200 while continuously sampling with the given sample rate and number of active channels.

Throughput and Scalability

The maximum throughput possible for a network of wireless sensors is dependent on the number and size of time slots, and the amount of data permitted per packet. Below is a comparison of LXRS and LXRS+ with several common wireless protocols used with wireless sensors. These networks are being compared on how many separate wireless nodes they can support, while each wireless node is sampling 1 sensor with a 16-bit ADC at 1024 Hz continuously.

Wireless Protocol	Topology	Supported nodes with 1 kHz sampling on 1 x 16-bit channel	Synchronization	LOS range
LXRS+	Star	16 per gateway	±50 us	400 m+
LXRS	Star	4 per gateway	±50 us	1 km+
SmartMesh WirelessHart[1]	Mesh	1	< 1 ms	1 km+
Zigbee[2]	Star or Mesh	2	HW dependent	1 km+
BLE v4.1[3]	Star or Mesh	8	HW dependent	100 m

Table 2. Throughput Comparison using different Wireless Sensor Networks

[1]SmartMesh WirelessHart Networks allow 24 packets/s with 90-Byte payload for each.
[2]Zigbee calculation based on maximum throughput rate of 35kbps with security disabled, 1 hop, and "router-router" communication. A more realistic throughput rate is 21kbps, which takes end-node networking into consideration.
[3]BTLE calculation uses fastest connection interval of 7.5ms, 6 packets/interval, and 20-Byte payload.

The network sizes shown for LXRS and LXRS+ are examples of real world results. They account for multiple nodes in the field, acknowledgments, and with 50% overhead built into the scheme for recovering dropped packets. The calculations made for Zigbee, SmartMesh, and BTLE are very optimistic and rely on using all available user Bytes for data. They also do not add additional overhead to recover lost data.

The scalability of both LXRS and LXRS+ is shown in the chart below. Scalability is represented by the number of nodes the network can support assuming all nodes are sampling continuously and configured with the given sample rate and number of channels.

Number of sensor channels	1	2	3/4	1	2	3/4
Sample rate	LXRS			LXRS+		
4096	1	--	--	4	2	1
2048	2	1	--	8	4	2
1024	4	2	1	16	8	4
512	8	4	2	32	16	8
256	16	8	4	63	32	16
128	31	16	8	127	63	32
64	63	31	16	255	127	63
32	127	63	31	255	255	127
16	127	127	63	255	255	255

Table 3. Network Scalability for LXRS and LXRS+

When using LORD Sensing wireless sensors with LXRS, additional networks may coexist on separate frequency channels, of which there are 16. To avoid cross-channel interference, there should be some distance between the gateways on separate frequencies. Using frequency channels more than 2 channels apart also helps isolate separate networks.

Operation Modes

LXRS accommodates nodes using one of three main sampling operations: continuous, periodic burst, and event triggered. Nodes within a network do not need to be configured similarly, the network will accommodate nodes using a mixture of these operation modes, sample rates, and other configurations.

A. **Continuous** - The node collects data continuously at the configured sample rate. All data is transmitted and/or logged to flash memory until a "Set to Idle" command is received.

B. **Periodic Burst** - The node performs short sampling bursts at periodic intervals. This operation allows longer battery life and increased network sizes in applications where continuous monitoring is not required.

C. **Event Triggered** - The node collects data continuously at a fixed sample rate. However, it only transmits and logs the data if one of the configured threshold conditions has been met. When the condition is met, all active sensor channels will transmit and log both pre- and post-event data. The benefits of this operation mode include increased battery life, reduced data sets, and increased network size.

Latency

There is inherent latency for nodes within an LXRS network. The latency is necessary to extend battery life and to increase network throughput.

While the "lossless" feature is enabled, latency is not deterministic and will be dependent on how many packets are being dropped at any given time.

With "lossless" disabled, the maximum latency is deterministic and may be found with the formula:

$$Latency \leq \frac{1}{TransmitRate} + TransmitDelay$$

Latency is a value in seconds that represents the maximum estimated time between a sensor measurement and when the user can expect to receive that information.

TransmitRate is a value expressed in transmissions per second, allocated by SensorConnect.

TransmitDelay is the maximum delay due to a full packet being transmitted and then pushed from the gateway to a CPU. This value is 7.8ms for LXRS and 3.9ms for LXRS+.

LXRS and LXRS+ Specification

Both LXRS and LXRS+ utilize the 2.4 GHz ISM band for worldwide license-free RF communication. While LXRS uses an IEEE 802.15.4 compliant protocol, LXRS+ makes use of a proprietary 2 Mbps radio architecture for higher speed communication. Below is the specification for both LXRS and LXRS+.

	LXRS	LXRS+
Radio		
Radio frequency	2.4 GHz ISM band	2.4 GHz ISM band
Communication standard	IEEE 802.15.4	Proprietary
Number of RF channels	16	16
Radio modulation	DSSS with O-QPSK	FSK
Radio Tx rate	250 kbps	2 Mbps
Output power	0 dBm to +20 dBm	0 dBm to +20 dBm
LOS range (approximate)	2 km	400 m
Protocol		
Topology	Star	Star
Addressing	16-bit	32-bit
CRC	16-bit	32-bit
Security	--	Optional AES256
Synchronization	±50 us	±50 us
TDMA slot size	7.8 ms	3.9 ms
TDMA slots per second	127	255
Maximum packet size	127 Bytes	255 Bytes
Network capacity	4096 Samples/second	16,384 Samples/second
Timestamp resolution	1 ns	1 ns

Table 4. LXRS and LXRS+ Specification

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