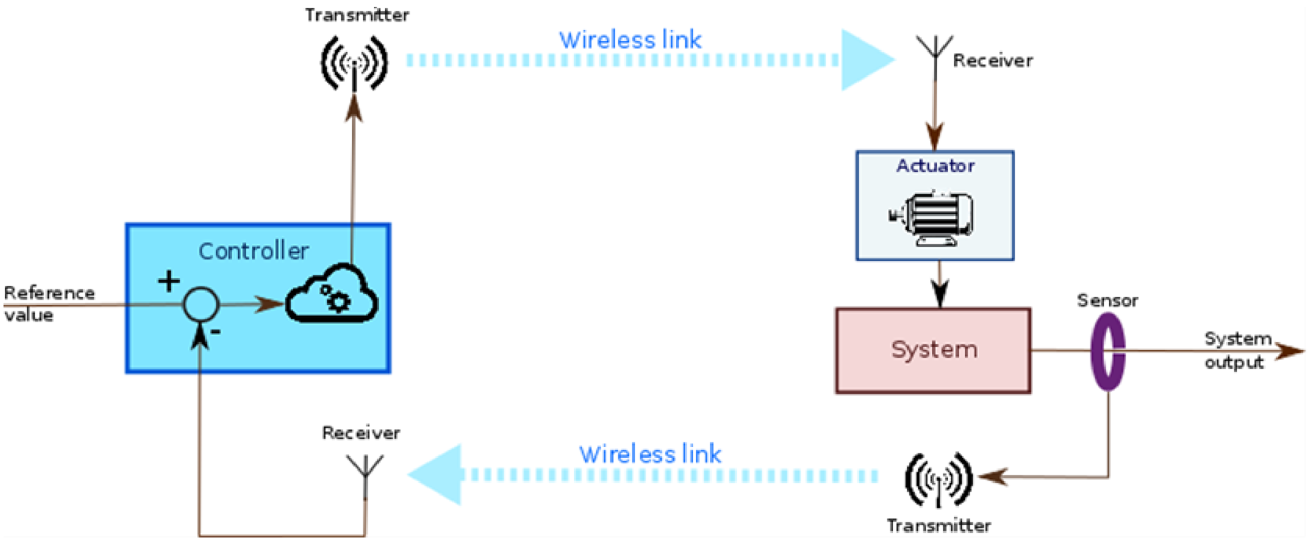
RETIS

Wireless solution for industrial automation and automatic control of fast processes

Wireless systems and connectivity have become an integral part of our lives. WiFi, Bluetooth or NFC systems are widely used in everyone's everyday life. While streaming of big data volumes (WiFi) or collecting data from relatively slow sensors (temperature, smart watches, medical monitors) is widespread, using wireless link in time sensitive applications is still in its infancy. The gap is caused by lack of wireless systems allowing deterministic data exchange of relatively small packets with high reliability, low latency, low jitter and high packet rate. With current progress in RF technology URLLC (Ultra-Reliable Low Latency Communications) are being adapted into wireless communications and opening doors for new types of use cases. Factory automation including real-time control of machines and fast industrial processes, autonomous driving, robots and motion control, virtual and augmented reality, tele-diagnosis and tele-surgery in health care, smart grid networks or even gaming industry – all are calling for wireless URLLC.



Schema of automatic control in a closed loop using wireless sensors and actuators. The depicted setup is especially suitable in applications, where the wireless link can save problematic wiring to moving or rotating parts.

Inspired by LTE and 5G concepts and TSN protocol, REX Controls has developed proprietary wireless solution called **RETIS** targeting at **fast real-time automatic control**, monitoring and diagnosis applications. This MIMO wireless system working simultaneously at multiple frequency channels or even bands, allows highly deterministic and reliable data exchange between controller and sensor or actuator nodes with latency below 350 µs and refresh rates above 4 kHz. Moreover, sub-µs clock synchronization between all distributed nodes allows synchronized operation at all nodes, which is essential for control of fast systems.

Features

- MIMO wireless system working simultaneously at multiple frequency channels or even bands (Sub-GHz ISM, 2.4 GHz)
- Wireless replacement of wired electrical or electronical feedback
- Highly deterministic, low latency, low jitter, high sample rate data exchange
- High robustness and reliability – optional TX data redundancy, possibility to configure multiple data paths at different RF channels or bands
- Inspired by LTE, 5G and TSN principles to achieve highest performance but still keeping low hardware complexity
- Uses TFDM (Time-Frequency Division Multiplexing) techniques to avoid unnecessary packet collisions
- No SIM card or provider infrastructure required
- Compliant with the IEEE 802.15.4 standard (in 2.4 GHz band)
- TSN interfacing according to IEEE 802.1 under development
- Sub-µs clock synchronization between all nodes allows synchronous operation at all nodes, which is essential for control of fast dynamic systems
- Native integration with REXYGEN real time control system, graphical network configuration
- No competition – currently the only choice for integration of wireless sensors/actuators into control loops with control period under 1 ms
- Data exchange rate up to 4 kHz (quadruple MIMO) with delivery latency down to 350 µs

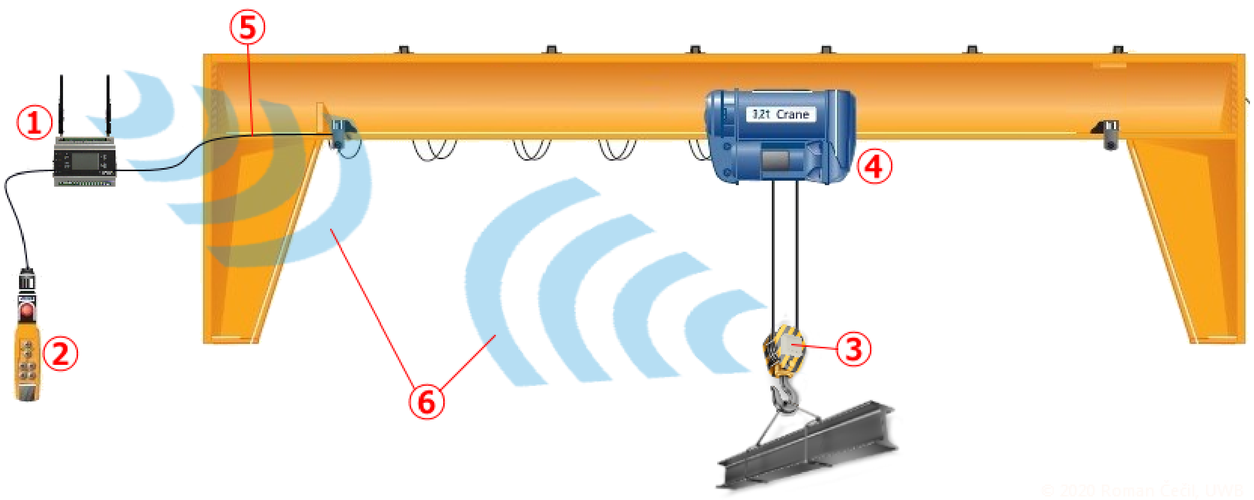
Wireless RETIS modules

Typical applications

- Motion control
- Vibration monitoring and damping

- Fast remote sensing (IRC, accelerometers, strain gauges, generic digital/analog inputs)
- Remote safety switches

In cooperation with University of West Bohemia was implemented a demo application for active damping of gantry crane loads during movement. Link: http://www.kky.zcu.cz/cs/sw/AntiswayDemo



Example application - Active antisway control of gantry crane load during crane movements

1 *AIC Controller*

2 *Control console*

3 *Wireless RETIS IMU sensor EduR01*

4 *Drive*

5 *EtherCAT link to the motor inverter*

6 *Wireless communication channel (RETIS)*

HW modules

Currently supported are 3 modules, however development of custom modules on request is possible as well.

RETIS RF plug-in card for AIC (Advanced Industrial Controller) system

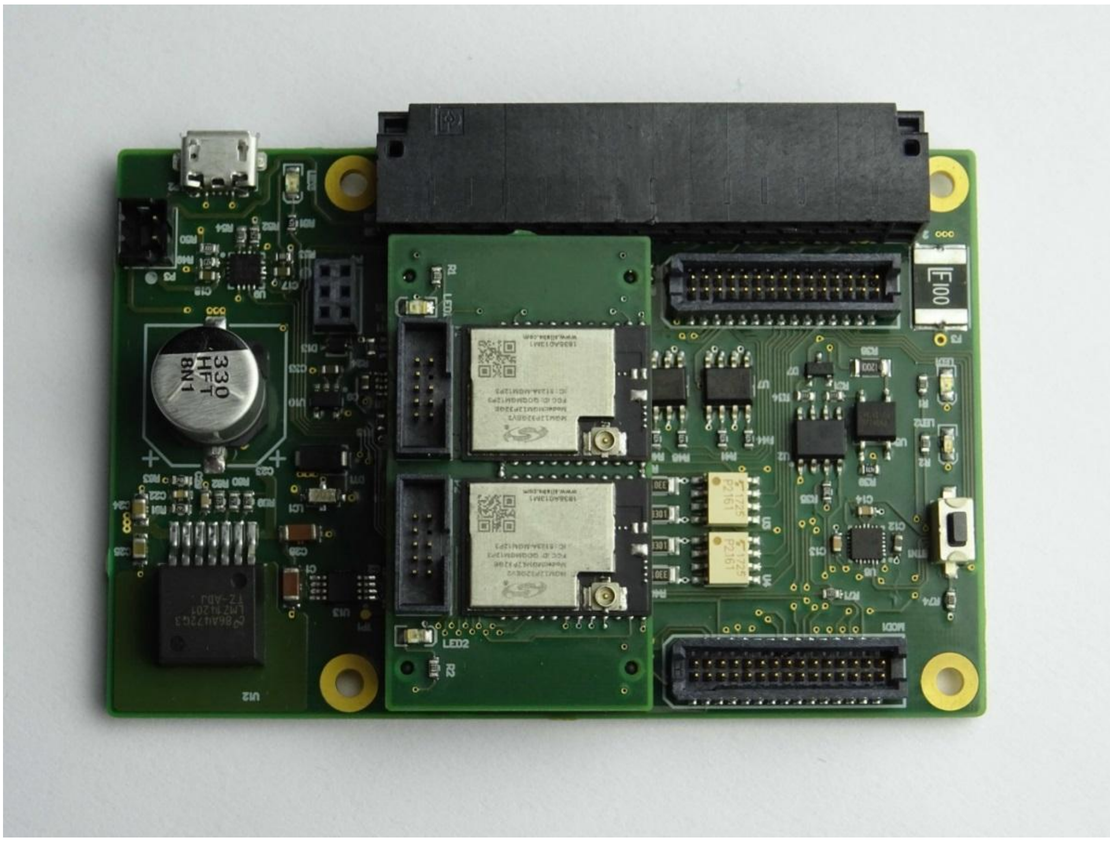
- Serves as RETIS RF network master
- Native integration of wireless RETIS solution into REXYGEN real-time control system
- Preserves complete REXYGEN functionality including industrial connectivity, control & monitoring capabilities, logging, etc., while adding TSN wireless connectivity

AIC (Advanced Industrial Controller) equipped with RETIS RF plug-in card.

Sensor node EduR01

- Single Lion cell (3.7V) powered, USB charging capability, node powering via charger supported as well
- 9-axis IMU unit

- 4x AIN 0-10 V / 0-20 mA, range SW selectable
- 4x DIN, optocoupler
- 4x DO (open collector)
- 1x QENC, optocoupler
- 2x AOUT
- 1x RS485



RETIS sensor node EduR01 with rich set of peripherals –
9-axis IMU, 4x AIN, 4x DIN, 4x DO, 1x QENC, 2x AOUT, 1x RS485

Remotely controlled active LED marker

- Small, coin cell powered device
- Active motion capture LED marker synchronized wirelessly with camera shutter
- Used to obtain differential image of the scene from multiple cameras
- Nearly 100% point correspondence among multiple cameras
- μs precision – timing and duration

Remotely controlled active motion capture marker for differential motion capture applications.
Left - final solution, right - unboxed board.

RETIS principles

RETIS was tailored for industrial automation and fast real-time control applications where reliability, low latency, low jitter, high data exchange rate and simultaneous sensor readings at specified time moments across distributed system are a must. It is rather a solution than communication protocol as it includes definitions and services across multiple OSI layers as well as proprietary hardware design based on discrete RF transceivers capable to implement the required features. Both HW and SW components were carefully selected to deliver best performance at price allowing mass deployment in real-world industrial applications. Depending on the number of utilized RF transceivers (per node), the performance of the network node and network itself can be adjusted. For example in case of quadruple MIMO (4 transceivers on board) packet TX/RX rate of 4 kHz with delivery latency below 350 µs can be reached.

Additionally to the used common URLLC principles, process control applications have additional requirements on communication services. In order to close control loop and repeatedly evaluate actuator interventions it is necessary to periodically deliver usually small chunks of data from sensors to controller and from controller to actuators. This forms the vast majority of the network traffic in data links of control systems. The transmitted datasets has always the same structure (data from the same set of sensors is used as input for the control algorithm). Here is space for optimization – process data group - binary blob with structure defined only once can be transmitted. And of course, except of the periodical data readings it is necessary to provide mechanism for asynchronous data delivery – for notifications, control commands or alarms. The both mentioned aspects have been considered for RETIS design.

TFDMA and MIMO

To bring determinism into the communication and avoid packet collisions and thus increase the transmission reliability, RETIS adopts Time-Frequency-Division Multiple Access (TFDMA) at MAC layer.

Multiple frequency channels that are further subdivided in time domain into transmission slots are used. The slots are then assigned to individual nodes (Figure 1). A similar principle is used for example in LTE. The channels can be in the same RF band, however they can be also distributed across several bands (for example Sub-GHz ISM and 2.4 GHz) and even use different modulation and other PHY settings.

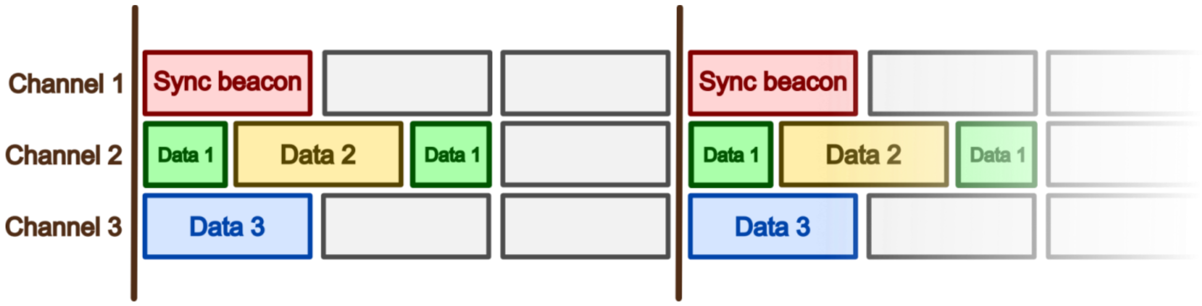


Figure 1: *Time-frequency division multiplexing used in the proprietary RETIS wireless solution. The T-F slots are granted to nodes by network controller and thus efficiently mitigating packet collisions. The number of RF channels used is configurable and for most RF modules range from 1 to 4.*

The network configuration contains information about:

- number of frequency channels, their frequencies and PHY settings
- basic period of the communication cycle
- slot assignment to individual nodes

The first frequency channel is control. There must be at least one slot dedicated to the transmission of synchronization beacons transmitted by the central node. These packets carry information about the length of the communication cycle and also gradually (in several consecutive cycles) transmit the network configuration information so that newly added nodes can "read" the configuration and step on the network activity. This mechanism ensures that the configuration is stored only in the master node and distributed by it to the slave nodes.

Slot allocated to certain node is determined by time offset from the beginning of the communication cycle and slot length (both in microseconds). The allocated slot length depends on the expected amount of data transferred and may vary by node. A node may have one or more slots assigned. Each node has the right (but not the obligation) to use the assigned T-F slots for transmission. Outside the dedicated slots it must not transmit. Each node is allowed to send only one physical packet per slot, however single packet can encapsulate one or more messages. The length of the packet is arbitrary, but its transmission time must not exceed the duration of the granted slot.

The network topology is star, however the central node of the star can act as a slave node in another network, thus forming a hierarchical tree structure (Figure 2).

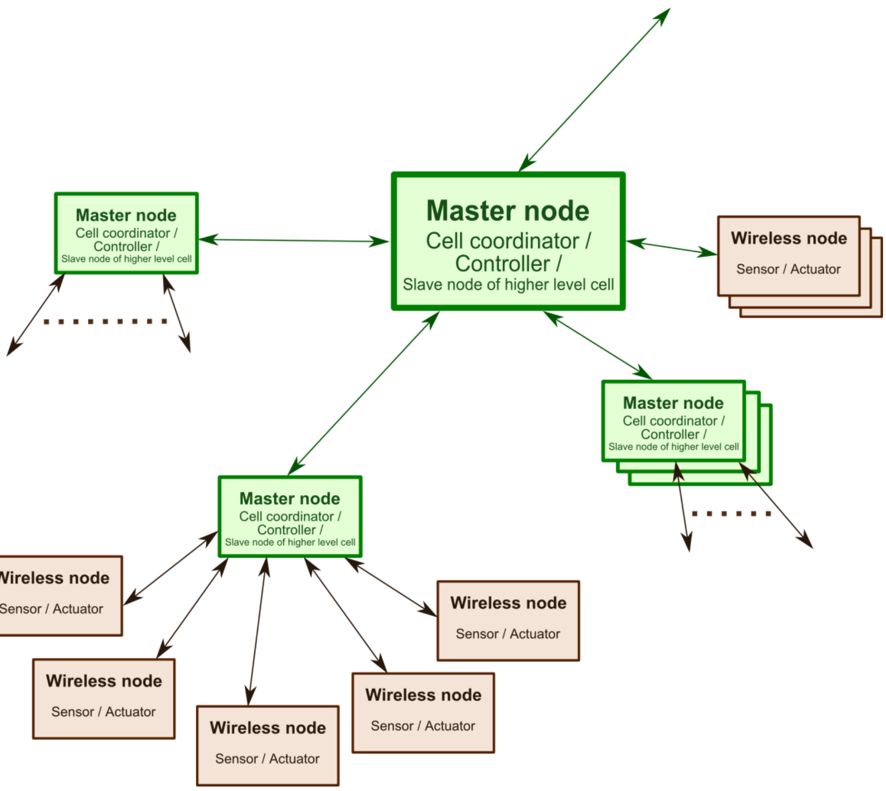


Figure 2: *RETIS network topology.*

Reliability

The transmission reliability depends strongly on performance of transmitter and receiver antenna as well as on bitrate and modulation. Apart from hardware properties and PHY settings, RETIS adds several mechanisms to increase communication reliability:

- **Duplicated transmission** – the same data might be transmitted twice or more times in time domain, frequency domain or both. I.e. the same packet can be transmitted again later on the same communication channel or simultaneously on another frequency channel or on another frequency later. The 2 channels can be even located in different bands. The number of repetitions can be selected according to the criticality of the controlled process and quality of the transmission path (amount of noise in the environment, distance, etc.).
- **FEC** – the packet data might be protected by FEC code to repair slight data corruptions. Turbo code is used.
- **ACK** – delivery acknowledgement is supported (but not mandatory). It allows algorithms at the application level to handle packet loss and if necessary request data retransmission.

Hardware platform

The hardware platform used for implementation of RETIS communication services must provide several key functionalities. Probably the most important is possibility to simultaneously transmit/receive data on multiple frequency channels. This functionality is supported either by SDR platforms equipped with DSP processor or by a cluster of simple packet oriented RF transceivers. In terms of price, energy consumption and modularity, the implementation based on cluster of packet RF transceivers was chosen for RETIS. Another advantage of this solution is fact that on the contrary to the SDR based platform, the frequency channels can be located in completely different bands.

High variability of the hardware platform is ensured by using structure shown in Figure 3. The first of the N transceivers (`RF0`) in the communication module acts as a master - it works on the primary RF channel and receives synchronization marks from the central node of the network. Based on them, it synchronizes its clock with global system clock and further provides precise synchronization to all chained `RF1`-`RFn` transceivers (through digital output `SYNC` and serial bus `UART_TX`).

All transceivers of the communication module are equipped with identical firmware. They are daisy-chained through the ID_{in} and ID_{out} ports. Their tasks are differentiated during system start-up, when the first of the transceivers whose `ID` pin is connected to the ground is identified as master. It then passes token to the next transceiver in the chain. Each of the following transceivers increments the passing token `ID` and determines its order in the chain. The definition of RF RX / TX slots for individual slave transceivers as well as requests for reading and processing sensor data are distributed by the master transceiver via a serial protocol on the `UART_TX` line. If necessary, responses to commands and possibly measured data are returned on the `UART_RX` line.

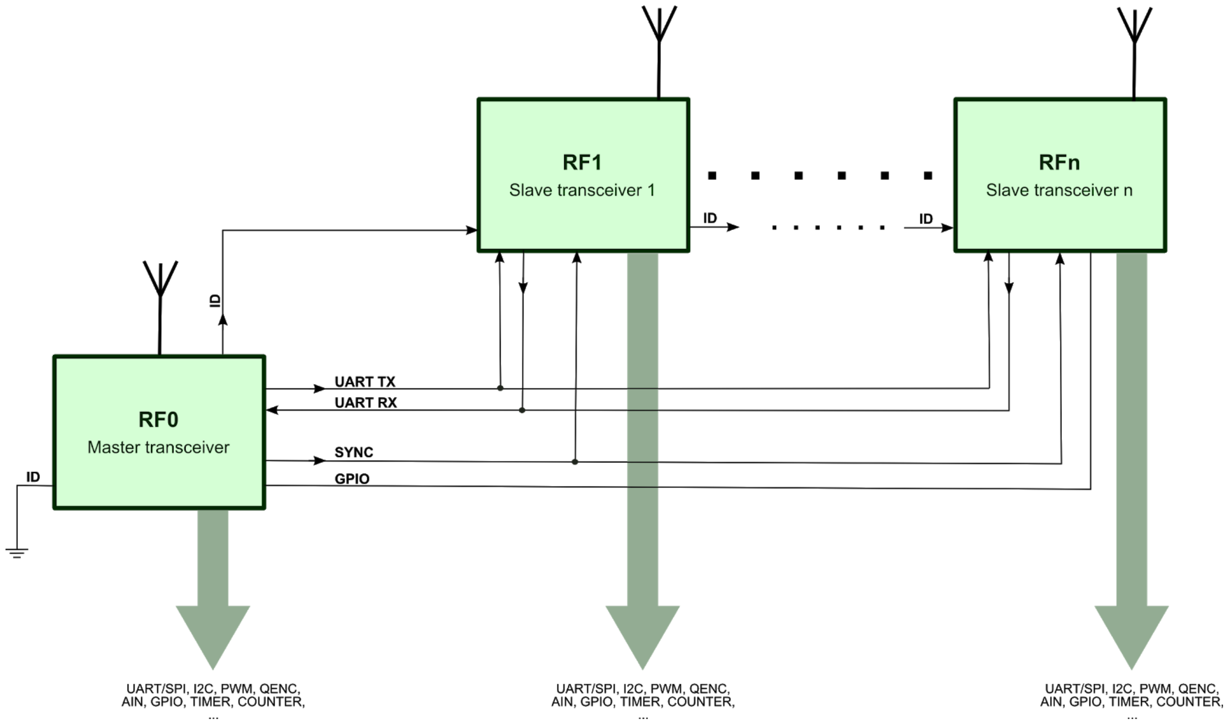


Figure 3: *Hardware structure of RETIS network node.*

The proposed structure of the communication module counts in general with arbitrary number of communication channels (N) and therefore N transceivers. Currently are available modules with 2 and 4 transceivers, however for demanding applications it is possible to develop custom modules with higher number of transceivers.

The number of 2 transceivers was not chosen randomly. Using `RF0` as a dedicated receiver and `RF1` as a dedicated transmitter, the communication module can continuously operate in full duplex mode. The module implemented in this way is therefore the smallest unit supporting continuous wireless full-duplex communication. 4-transceiver module then allows fully backed up (duplicated) full-duplex communication, where the redundant back-up channels can be located in different RF band and thus strongly increase the communication reliability in harsh environments.