

# Real-time Wireless Telemetry System for a Formula Student Electric Vehicle

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**Abstract**— The modern generation of motor vehicles comes equipped with a complex network of sensors and safety systems, which need to gather critical information in real time, like engine performance and fuel economy, as well as breaking parameters and the steering angle. This data is constantly analyzed by engineers to offer the driver the safest and most efficient transportation option, uncovering faults and inefficiencies. This paper will offer insight into the design of such a system and the current development of vehicle communication structures, focusing on different state-of-the-art solutions and a novel approach to telemetry systems in Formula Student cars. The solution proposes using the radio technology LoRa in a different context than it was designed for, and combining different programming paradigms like fog computing and Cloud Storage, finally packaging it all in a plug-and—play enclosure and install system.

## I. INTRODUCTION

Over the years, checking the performance of any technology at the data level was a difficult task, thus underlying the need for a system that can transmit that data remotely and pairing it with intuitive visualization. In the automotive industry, such a system proves critical in the development and testing of automobiles, and every company has its own unique solution to this problem. When testing a vehicle, **wireless** data transmission is preferred, since a wired system would make things significantly harder.

The purpose of a telemetry system is to collect data in a place that is remote or inconvenient and to relay this data to a point where it can be evaluated. Typically, telemetry systems are used in the testing of moving vehicles such as cars, aircraft, and missiles. Telemetry systems are a special set of communication systems. When the telemetry system is used for both control and data collection, the term *supervisory control and data acquisition* is applied. [1]

The basic concept of telemetry has been in existence for centuries. Various mediums or methods of transmitting data from one site to another have been used. Dataradio provides a wireless method for transmitting information. Telemetry using radio waves or wireless offers several distinct advantages over other transmission methods. Some of these advantages are [2]:

- No transmission lines to be cut or broken
- Faster response time
- Lower cost compared to leased lines
- Ease of use in remote areas where it is not practical or possible to use wire or coaxial cables

- Easy relocation
- Functional over a wide range of operating conditions

Modern automobiles are becoming increasingly electromechanical and even the parts that remain mechanical are being tuned to work more efficiently by drawing data via sensors monitoring them. This phase of development of the vehicle is split into the initial static tests on a test bench and dynamic field tests.

For the initial static testing, where the main setup and tuning is done, the engineers require high resolution and high data rates as some of the more critical sensor data is being acquired, logged and analyzed here. For this, the DAQ (Data acquisition) system is highly essential, whereas the telemetry option is used only to monitor for safety. For the dynamic field testing, the engineers find the wireless telemetry option to be of higher importance, while the on board DAQ runs and only parts of the data are analyzed where an anomaly was noticed through the telemetry data. In both phases, due to heat from various components, vibrations of the moving vehicle, the inherent nature of each sensor and so on, the data being acquired by the sensors ends up being affected by noise. In order to filter out the noise, the use of filters is unavoidable and is highly essential.

Thus, it is seen that both systems play an extremely important role in the research and development phase of a vehicle, and having said so, there seems to be a scarcity of manufacturers who have products that cater directly to the automobile industry in this regard. Most companies have universal application type systems that work well but cause an unnecessary hike in the overall power consumption and cost. Furthermore, the end users are expected to develop their own filtering stages and so on to get the system to fit their application. [3]

**Vehicle-to-Everything (V2X)** is a generic term that refers to a wireless communication system that allows the exchange of data in real time between a vehicle and any entity in its environment, including other vehicles (V2V), infrastructure (V2I) and communication networks (V2N). The main purpose of this technology is to improve safety on the road and reduce traffic. [4]

**Vehicle-To-Network (V2N)** is a form of communication that allows the vehicle to transmit information to a large, infrastructural network like cloud servers, data centers and mobile networks to offer external information like traffic

conditions and weather, thus permitting the vehicle to take more informed decisions and to enhance driver experience. [5]

**Vehicle-To-Vehicle (V2V)** is a technology that makes real-time communication between two vehicles possible, without the need for an intermediary infrastructure. They can send information, like speed, direction, braking times and location to better road safety. [5]

In the case of V2V, V2N and V2B/I, as presented in Figure 1, these technologies can be integrated as separate solutions focusing on different problems (in the case of V2V to minimise accidents and V2N to accurately predict traffic data), and the ideal goal is to incorporate them into a unified, distributed, city-wide system.

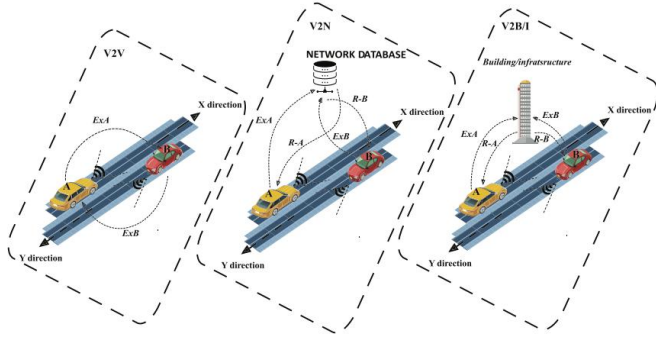


Fig 1. Different conceptual working principles for V2V, V2N, V2B/I, respectively

In this paper, we will first take a look at existing solutions under the “Relevant Work” section, and after that, we will analyze the architecture of the Formula Student Electric Vehicle ART TU E17, developed by team ART TU Cluj-Napoca that is part of the Technical University of Cluj-Napoca. Then, we will cover the requirements of the telemetry system that is being developed, along with the conceptual architecture and how the telemetry system will incorporate itself with the existing vehicle architecture under the section “Conceptual Architecture of the ART TU E17 Wireless Telemetry System”. In the final part of the paper, I will present the conclusions and future directions for research and development.

The focus of this paper is to give you an insight into the importance of a telemetry system in the automotive industry and the harsh conditions in which this system must operate, alongside a visualization concept where the data can be seen and analyzed.

## II. RELEVANT WORK

In [6], the authors present a solution to this difficult task, developing and testing an IoT-based telemetry system that uses OBD-II data and GPS, having 3 components:

1. **On-board hardware module.** It uses an ELM 327 OBD-II interface connected to an Arduino Mega 2560 to log engine parameters like RPM, speed, coolant temperature and throttle position as well as the GPS position, storing the data to a microSD

and transmitting over Bluetooth (HC-05) and GSM/GPRS.

2. **Android application.** It provides the functionality of a user interface and GPS data provider, receiving the engine data from the server, displaying live statistics and uploading information for speed-of-transmission analysis.
3. **Web server and database.** Based on PostgreSQL, it handles the receiving, storage and visualization of the telemetry data.

As for the results, for 611 entries, 91.5% of them had transmission intervals less than 10s, and most common was approximately 5s, having lost around 2% of the data due to traffic or GPS loss. These tests were done on a Honda Stream 2010 and Toyota Rush 2017, monitored over 20 hours.

In terms of challenges and limitations, the GSM/GPRS connectivity posed a problem because of the data processing delays, alongside the variability of the data formats. Because each car had a different ECU, they require different commands to get the data and thus complicating the standardization. A unified design across varying vehicle architectures is needed for broader deployment and analysis.

In [7], the authors proposed a system for solar car races that integrate real-time video, GPS positioning, and velocity tracking to monitor and broadcast data.

It uses GPS for live location and speed, using a Raspberry Pi as an Onboard Unit (OBU), a camera system for live video capture and a wireless transceiver for transmitting all telemetry and video data.

A wireless point-to-point link is used to establish a connection between the solar car and the tracking vehicle, so there is not a very big distance between them. The transmission supports video and telemetry and is an interesting solution to monitor the status of the vehicle.

In [8], the authors propose a robust solution for secure remote vehicle diagnosis and maintenance over 5G Vehicle-to-Network (V2N), addressing critical safety and privacy issues with a dedicated authentication scheme. The system includes 3 primary components:

1. **Vehicle-side module (VMCS and UE):** Vehicles are equipped with a Vehicle Maintenance Control System (VMCS) and User Equipment (UE), enabling vehicle owners or drivers to initiate remote diagnostic services. Users authenticate via identity, password, and biometrics. The VMCS communicates securely with the Vehicle Networking Control Center (VNCC) over 5G, leveraging extended Chebyshev chaotic maps to protect session keys and data integrity.
2. **Vehicle Networking Control Center (VNCC):** Acting as a centralized trusted authority, the VNCC manages registration, authentication, and service coordination. It authenticates both vehicles and Vehicle Service Centers (VSCs), relays fault data, and establishes secure channels for maintenance actions. It also supports direct fault

resolution from its database, bypassing the need for a VSC if a fix is available.

3. **Vehicle Service Center (VSC):** Each VSC includes a server and employees who must also authenticate using identity, password, and biometrics. The VSC can access vehicle data through a secure channel established by the VNCC, allowing diagnosis and online software/firmware repairs. Only if the fault is resolvable online is service performed remotely; otherwise, physical service is suggested.

The paper primarily focuses on the security and performance analysis rather than experimental transmission results. Using formal tools like the Tamarin Prover and a random oracle model, the authors demonstrate that their scheme meets essential security properties, including mutual authentication, perfect forward secrecy, identity anonymity, and resistance to known attacks. Efficiency is confirmed through comparisons to other recent protocols in terms of computational and communication overhead.

The authors note that practical implementation faces challenges such as ensuring secure storage and processing of sensitive data on all devices (e.g., VMCS, UE, and VSC-S), protecting against device theft or side-channel attacks, and handling variability in user roles (e.g., owner vs. driver). They emphasize the importance of collaborative authentication when the driver is not the vehicle owner, and highlight the need for continued protection even if long-term keys are compromised.

### III. ART TU E17 ELECTRIC VEHICLE ARCHITECTURE

#### 3.1. Low Voltage System Overview

##### Electronic Control Unit (ECU)

The ECU is the center of the electric vehicle and is responsible for gathering and sending all the data, including sensors, temperatures, dashboard, and many more important information that keeps the vehicle running efficiently and safely.

Developed in-house, it is based on the Teensy 4.1, and has a lot of communication protocols in it (SPI, UART, RS232, CAN Bus, I2C) for all types of sensors.

The ECU controls the vehicle with Arduino code, from the threshold at which certain systems activate to motor control. Figure 2 presents a 3D render of the ECU, so as to better conceptualize how it looks and how it fits in the car, having standard automotive plugs and an easily interchangeable Teensy 4.1, if anything were to happen to it.

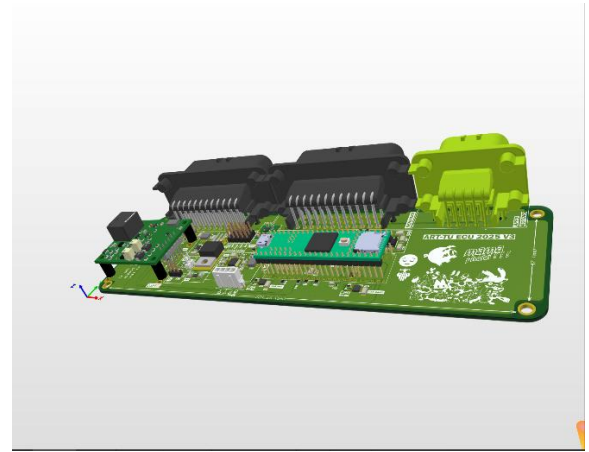


Fig 2. 3D render of the ECU printed circuit board

##### Traction System Active Light (TSAL Main)

The TSAL Main board signals through the use of multiple LED's the status of the Traction System, with green and red light. Green indicates that the voltage in the vehicle is below 60 VDC and the contactors are all disconnected, mainly every power relay in the car is opened, meaning that there is no hazard from the 200 VDC of the vehicle's battery.

Red indicates that the voltage exceeds 60 VDC and the vehicle is not safe to drive and handle, especially if a fault is detected.

All TSAL circuitry must be hard-wired electronics, excluding software control, with red and green circuitry operating independently.

##### TSAL and Dashboard Indicators

The indicators serve the same function as the TSAL Main board, but it extends the signal to the cockpit and main hoop, visible to the driver in direct sunlight. The same rules apply to these PCB's too, no software components, only hard-wired components.

As well as the Main board, all the signals must be Safety Critical Signals (SCS), between 0.5V to 4.5V.

The dashboard indicators show the driver the status of the Insulation Measurement Device (IMD), Accumulator Management System (AMS) and the TSAL green or red status.

##### TSAL Measurement

This board separates the Low Voltage System from the High Voltage system by a 6mm gap, connected by an optocoupler. It detects if a voltage above 60 VDC is present at the measurement points and that the contacts in the power-up sequence are closed. Same rules as the TSAL Main, only hard-wired components and all signals must be SCS.

##### Wireless Telemetry

This sub-system needs to communicate the data of the vehicle while operating (speed, temperatures, state of charge, state of contactors) to the on-ground team using a wireless system to a server.

It also serves the purpose of storing the past measurements for analysis through graphs.

Figure 3 presents a diagram which depicts the Low Voltage System of the ART TU E17 electric vehicle. The ECU is the component where all the data is stored and processed, and the connection with the wireless system should mainly be done with the ECU, in order to better gather and transmit the data after it has been aggregated in the ECU.

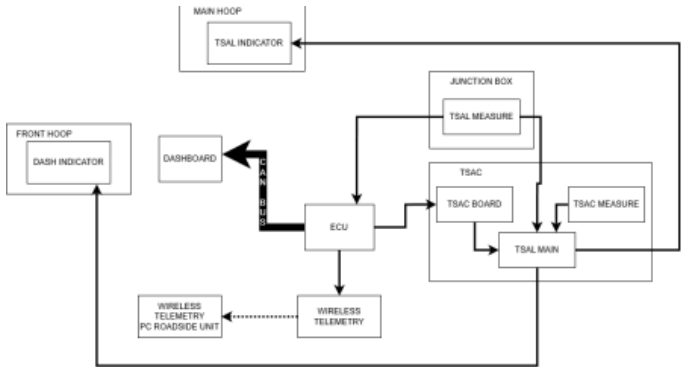


Fig 3. Graphical Depiction of ART TU E17 Low Voltage System Architecture

### 3.2. REQUIREMENTS OF THE TELEMETRY SYSTEM

For the scope of this telemetry system, these are the functional requirements it must achieve:

- 1. Collect and store the relevant data from the electric vehicle.** The system must acquire data from all the relevant sensors of the vehicle and to recognize their data type.
- 2. Store the data in a data structure that is efficient for transmission.** The system must store the data temporarily in a data structure that is adequate for transmission over long distances.
- 3. Configure and manage the transmission medium over the long distance.** The system must be configured in-tune with the available hardware to cover the most distance possible without compromising the data.
- 4. Communication between the electric vehicle and the server.** The system must provide a stable and reliable communication between the electric vehicle and the server over the course of the dynamic testing, without interruptions and without compromising the integrity of the data, over a distance of 0.8 to 1 kilometer non-line-of sight. Figure 4 presents the difference between line-of-sight transmission (left) and non-line-of-sight transmission (right) in order to better understand the importance of the resilience of the telemetry system. This is important because in a moving vehicle, different objects can (and will) interfere with the transmission medium.



Fig 4. Visualization of line-of-sight transmission and non-line-of-sight transmission [2]

- 5. Process and store the data produced by the vehicle.** The system must have the capacity to aggregate the data transmitted from the vehicle into a processable form and store them in an efficient manner in terms of memory and time of processing.
- 6. Real-time monitoring of the data.** The system must incorporate a real-time visualization of the data generated by the vehicle's sensors and safety systems, being updated every second.
- 7. Visualization of the data after the transmission is finished.** The system should provide the user with an easy-to-read visualization of the data after the transmission is finished so it can be analyzed with ease and comparing them for development purposes.

As for the non-functional requirements of the system:

- Performance.** The system should offer high responsiveness to monitor the data at the minimum refresh rate.
- Scalability.** The system must offer the possibility, be it from architecture or implementation, to be adapted to a large quantity of data or to a larger transmission distance.
- Security.** The system must incorporate a way to secure the data during the transmission and while stored so that unauthorized people cannot access the data of the electric vehicle.
- Availability and Accessibility.** The system must offer stability and availability to constantly access its services constantly, on whatever device might the user access it from.
- Flexibility.** The system must be "plug-and-play", having easy installation, modification process and maintenance for the different needs of the development team in the coming seasons.
- Intuitive Design.** The system must easily be used by a user at first sight and easy to navigate for a user that is not familiar with IT.

### 3.3. CONCEPTUAL ARCHITECTURE OF THE ART TU E17 WIRELESS TELEMETRY SYSTEM

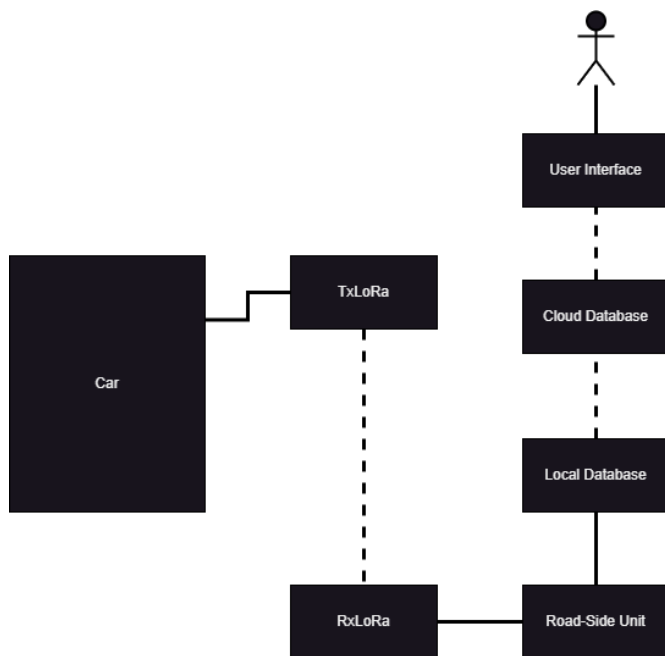


Fig 5. Conceptual Architecture of the Wireless Telemetry System

In figure 5, I am proposing the telemetry system's conceptual architecture, comprising of 4 main components:

- Transmitter LoRa (TxLoRa). Gathers the data from the ECU in a message that is transmitted every second, compresses the message and stores the data in the appropriate data structure to prepare it for transmission. Another step in the transmission is the encryption, adding it to the packet before the transmission. This approach provides the easy installation of the system with the current vehicle architecture, while also providing easy to maintain and read code and hardware, while also providing security and reliability, making this a very suitable option for incorporating the transmitter.
- Receiver LoRa (RxLoRa). Receives the packet from the transmission medium and decrypts the data, while also storing it in the adequate data structure. This provides a buffer for the data until it is stored in the local database, providing an extra level of redundancy, making the system more robust and resilient.
- Road-side Unit. It acts as the server, processing the data while providing a way for the users to connect to the User Interface, while also centralizing the data.
  - Local database. Its purpose is to store the data locally for easy access on the user interface. This approach is known as fog computing and is an ingenious way to provide very good response times for the interface with new data, while also having another layer which stores the data, adding

redundancy and making the system all the more effective and efficient.

- User Interface. This is what the user sees and is responsible for displaying the data in a easy to read format, usually visualisations and the like for debugging and fault-finding. Getting the data straight from the local database, its response time is very quick and can be easily modified.
- Cloud Database. The data is uploaded here after the transmission ended, providing a way to access the data while it is not in real-time, proving very useful to the development team. It adds redundancy and a much needed feature in the automotive industry.

When choosing a technology stack for this solution, I frequently referred to [2], giving some insight into what I need to keep in mind:

The main criteria for selection of the wireless protocol are power consumption and range. Due to the vehicle moving around a large track during testing or a race, Bluetooth and IR were immediately eliminated as options, as the range of Bluetooth is very limited and IR requires line of sight for communication, which would not be possible.

For the selection of the microcontroller, the multiplexing of the sensor signals through a single ADC seems like an option, it causes parts of the data to be lost, and this is especially important for signals that change within fractions of seconds in a vehicle. Hence the microcontroller was required to have a minimum of 8 on board ADCs to make the process of design and programming simpler.

And as for the implementation of GUI and filters, the user was required to select the data parameters to be viewed on each graph, then the filtering process the data was to go through and run the program. The telemetry interface required a different approach from the simple graph layout taken with the DAQ side. Since this data would be viewed live, and needed to be immediately interpretable, along with the raw numerical data being shown, a calibration option was provided so that a simple digital value of say, voltage could be converted to a throttle position percentage and so on.

The paper proposes a system that incorporates several components to achieve the requirements listed above:

- The connection between the vehicle's ECU and the telemetry system is done using CAN Bus (Controller-Area-Network) technology. While the CAN-Bus is specifically developed for automotive communication purposes, ISO-TP (ISO 15765-5) provides a much-needed feature in this system. By default, the CAN-Bus support only 8 bytes per CAN frame, but with ISO-TP, we can send as many bytes as necessary because it splits the large messages into multiple CAN frames and reassembling them on the receiving end. The adoption of ISO-TP provides the necessary scalability and flexibility to transmit extensive telemetry data, such as sensor arrays without compromising CAN-Bus's real-time capabilities.



- The transmission medium proposed is LoRa, a low-power, long-range wireless communication technology designed for sending small amounts of data over large distances, achieving 2-5 kilometers in an urban setting, while consuming very little power and offering good resistance to interference and obstacles due to spread spectrum transmission. It achieves the favorable distances by operating in the sub-GHz ISM bands, extending further under line-of-sight conditions, making it perfect for test conditions. Figure 6 presents a typical LoRa network, comprised of the end nodes that gather data, gateways that centralize the data and send it to the network server, which sends the data to the different application servers, which display or use the data, all the while this system being encrypted with AES.

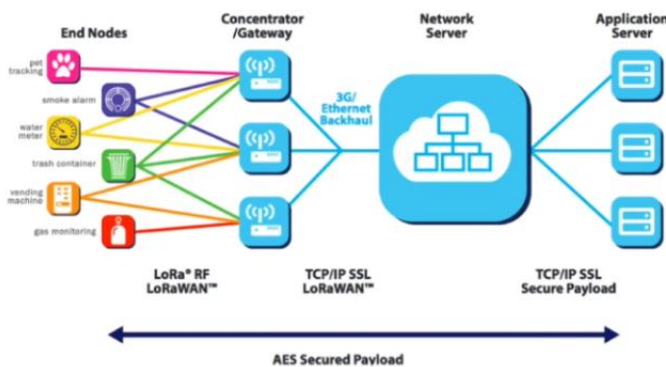


Fig 6. A typical LoRa network.

- For the software technology stack, the proposed solution uses Docker, making it easy to deploy and run applications inside containers, offering accessibility to anyone in the team intending to be the server node. It streamlines development and maintenance, encapsulating the application along with its dependencies, libraries and runtime environment into portable units that can run consistently across various computing environments, this minimizing the “works on my machine” problem.
- In terms of database selection, I propose InfluxDB, a time-series database that is designed to handle large volumes of time-stamped data, including measurements and sensor reading, making it perfect for this context. It will store and process the data locally, as to not impact the performance of the real-time data visualization. InfluxDB is optimized for handling high write and query loads of time-indexed data, supporting advanced functions such as aggregation, downsampling, and retention policies.
- For the visualization of the data, Grafana is the preferred option, offering a quick and elegant solution to create an interactive and responsive

dashboard. It has native integration with InfluxDB, making the connection seamless. Its support for various panel types and alerting mechanisms allows the team to monitor vehicle performance metrics in real time and receive notifications when parameters deviate from expected thresholds.

- For the persistence of the data, Firebase is used as a cloud service to store the data, and an in-house CSV plotting tool is then applied to visualize the data after the transmission ended. Firebase provides scalable data storage and synchronization capabilities, ensuring data durability and availability across distributed systems.
- The decision to use all these open-source solutions comes to cost. The components for this system are cheap, and the upkeep of the system is virtually free if we keep in mind the storage used by the Cloud service.

The system works in the following way:

1. The ECU aggregates the data into a ISO-TP CAN-Bus message with all the relevant and necessary data and sends it to the LoRa transmitter.
2. The LoRa transmitter then encrypts the data using AES-128 CTR encryption and forms it into a packet.
3. The LoRa receiver receives the packet, decrypts the data and stores it into a chosen data structure.
4. InfluxDB then receives the data through Influx Line Protocol and stores it locally for the duration of the testing session.
5. Grafana then gathers the data from InfluxDB and creates a easy to read panel with all the relevant information.
6. After the testing is completed, the system will upload the data to Firebase, where it will be stored for later use.
7. When the data is needed for analysis, the team can download the data from the Cloud using the CSV plotter and visualize it.

Figure 8 displays a theoretical dashboard which gathers simulated data from the transmitter, showcasing how the system will look and behave.



Fig 7. The real-time data monitoring dashboard for the Mechanical department

#### 4. CONCLUSIONS

This paper outlined the design of a wireless telemetry system tailored to the ART TU E17 electric racecar. After reviewing existing solutions and defining key requirements, we proposed an architecture centered around long-range, low-power communication, reliable data storage, and accessible visualization tools.

Future work includes integrating the system with the ECU, field testing during dynamic events, and refining the web-based dashboard for improved usability and real-time performance analysis. This approach offers a scalable and efficient solution for student teams and other motorsport applications.

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