Networking

How data transmitting services have evolved to work effectively and reliably in today's congested airwaves

By STEWART MITCHELL

Racecar telemetry and data transmitting systems have come a long way since the days of huge data logging boxes mounted inside the cockpit collecting analogue sensor input data at low resolution. The information back then was crude and challenging for engineers to decipher after the car came back to the pit lane.

Data logging technology's evolution saw it move to digital sensors and smaller data storage boxes uploaded to static computers in the pit lane when the car came back to the garage.

Then came radiotelemetry, which could transfer data from the car wirelessly to the pit lane. This was a true revolution for the racecar engineer. Radiotelemetry is still used extensively today, but has its limitations – fundamentally, coverage and bandwidth.

The challenges of coverage are a function of the distance over which radio transmitters can transfer signals and data. Radio doesn't go very far and causes major signal issues at large circuits, especially those with significant gradient changes such as the Nürburgring or Spa Francorchamps.

The Nürburgring is one of the most challenging race circuits for telemetry data transfer, but with multiple modems attached to a number of different mobile networks, the whole track can now be covered

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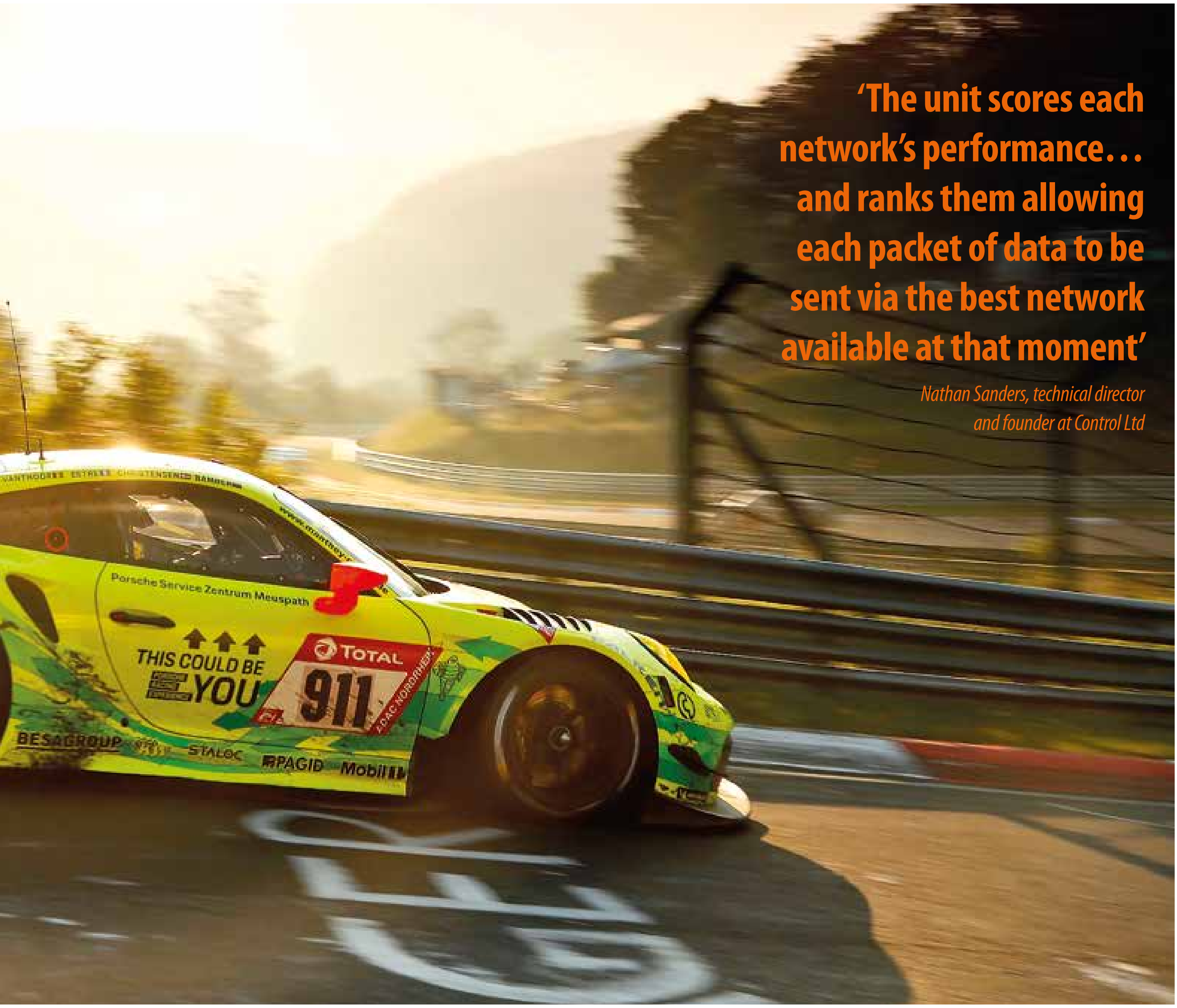
The Control TLM-P1 Cellular Telemetry Modem features three global modems attached to multiple mobile networks. The technology allows for ultra-high coverage resilience whilst delivering live data using the best network available at any point on the track



‘The unit scores each network’s performance… and ranks them allowing each packet of data to be sent via the best network available at that moment’

Nathan Sanders, technical director and founder at Control Ltd

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For events attended by hundreds of thousands of people, multi-modem systems can choose the best cellular set up to transfer car data while simultaneously sharing bandwidth with the crowd

Without a repeater, complete radiotelemetry coverage at these circuits is impossible.

As for bandwidth, most radiotelemetry systems run at 9600 bits per second, which, for engineers in the upper echelons of motorsport, isn't sufficient capacity to give a complete picture of a car's performance.

Cellular modems

Since cellular networks have become more widespread, especially in rural areas where racetracks frequently are, it solves both radiotelemetry challenges.

As cellular coverage reaches further than radiotelemetry, repeaters all around the track are no longer required. The available bandwidth is also much greater. However, public cellular networks can be unreliable and, despite the available bandwidth, must be distributed between all users of that network.

Suppose a race team uses a public cellular network for sending data from the racecar to the pit lane and the team's factory, it is merely a passenger on someone else's infrastructure. If there is inadequate coverage at the circuit on the day, or that coverage breaks, they are left blind.

Even if a team has examined a cellular network on test day and deemed it sufficient for the race, because public cellular networks distribute capacity to all devices on the network, there will be undoubtedly be a surge on race day with everyone at the circuit fighting for connection. Consequently, the connection and bandwidth impact on everything up and down the pit lane.

Multi-modem systems

In the last few years, cellular data transmitting systems have evolved to combat this in the form of multi-modem units.

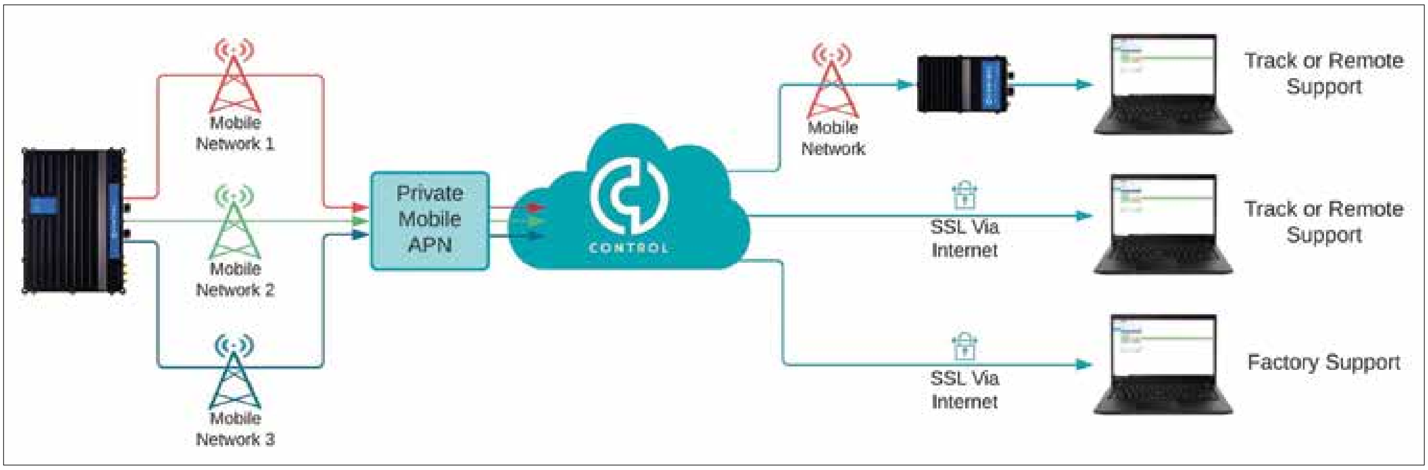
Basic cellular data systems use an industrial modem designed to send serial data between one machine and another, but the latest motorsport telemetry transmitting systems feature bespoke PCBs and a complete software stack specifically designed for the application, which enable it to use multiple SIM cards to connect to numerous networks at once.

The connection and bandwidth impact on everything up and down the pit lane

They can also switch between modems connected to different networks, which allows the telemetry units to deliver live data to the garage using the best network available at any point on the track. They can also transmit across the three modems at the same time.

The TLM-P1 Modem from Control Ltd is currently the only example of a multi-modem telemetry unit for motorsport with three modems connecting to different cellular networks.

'The unit scores each network's performance, including speed, latency and jitter [the variation in latency] and ranks them allowing each packet of data to be



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Flow chart explaining the data transfer infrastructure within the Control TLM-P1 Cellular Telemetry Modem sent via the best network available at that moment,' explains Nathan Sanders, technical director and founder at Control Ltd.

'It also transmits this network information via CAN to the vehicle logger, allowing teams to generate graphs of signal strength around the track to understand where coverage is good and bad on different networks.'

This tool allows on-the-fly switching of networks as the car moves around the track, which can be crucial in a highly congested network, for example, at Le Mans. The driver can push a button to send a CAN message from the logger onboard the racecar to change the modem's behaviour to send data through all three connected networks at the same time, or to switch to a lower bandwidth 'data set' to maximise the limited connectivity.

The data is then de-duplicated before it is passed onto the consuming telemetry server. Some telemetry transmitter system firms even offer private mobile networks behind the scenes for security. The SIMs use the public radio area network to connect, but then come back through the roaming agreement into a private network.

Data management

As the information coming off modern racecar data loggers can be vast, contemporary data transmitters with multi-modem can send data to multiple places from the ethernet, serial or CAN connections inside the car.

Should the team / driver want to, they can change where the data is sent using a switch in the cockpit. The Control telemetry system can receive data via its private APN cloud service and stream it over a VPN connection, or receive data directly from an additional modem connected to the telemetry server in the pits. This allows teams to switch to an alternative, non-internet connectivity reliant connection.

Products such as the TLM-P1 Modem also have a feature to suppress transmission to prevent data transmitting all the time the unit is powered up. Not only does this make it easier to control costs, it prevents the system from consuming vast amounts of the data quota at times when the engineers don't want to collect data from the car.

Further 'space saving' techniques include real time, over-the-air compression, whereby the modem compresses the telemetry data stream, and then decompresses it at the receiving end to improve coverage and reduce cost by lower data consumption.

With motorsport's drive for a more sustainable future, cost saving and consumption in every element of the sport must be analysed, and systems like Control Ltd's TLM-P1 offer both significant cost savings and efficiency gains across the board.

Sanders explains: 'The industry is starting to understand that sophisticated telemetry systems are critical for motorsport's sustainability.

'For example, if a damage occurs and the driver hasn't noticed, but an engineer sees it in data, calling the car to stop, or telling the driver to slow down and bring it back into the pits, could be the difference between the pit stop time lost vs destruction of the car.

'Direct cost savings during races, car development on a test bench or track during a test day can also be enormous.

'Teams use engineers at the circuit to make decisions on things like wing adjustments, engine maps and suspension damper changes. With sophisticated modems on board the car, the engineers can see all the data live, analyse it and make decisions about set-up changes, without the traditional delays incurred in uploading and distributing data, all while the car is out racing on track.

'Then, when the car arrives back in the pit box, as it's taking on more fuel and new tyres, the engine engineer can upload a new engine map, and the wing and damper mechanics know exactly how many clicks they're going to change.

'By the time fuelling is complete, engineers can finish all set-up changes and recalibrations, and the car is ready to go out again. It's transformative.

'These systems allow teams to arrive at set-up optimisation earlier, and the time engineers can save could amount to huge savings in track time, days in the season's testing schedule and tens of thousands of pounds.'

As cellular modem users use internet access to receive the data, the equipment they need is nothing more sophisticated than some software installed on their computer. That's it.

Allows on-the-fly switching of networks as the car moves around the track, which can be crucial in a highly congested network

Porsche

With some race grids, such as the Nürburgring 24 Hours, contested by as many as 150 cars, engineers need to know that data transfer from every individual car will be fast, reliable and secure

'As is the nature of internet access, said computers could be anywhere in the world, and in multiple different places, so you can have data coming into the garage and the factory simultaneously,' remarks Sanders.

'The engineering team can be scattered around the world, minimising the number of personnel required at the circuit, and in turn reducing the team's expenses and carbon footprint.'

Race strategy

Today's upper echelons of motorsport, such as Formula 1 and Le Mans Prototype racing, feature regulations that are forcing contenders to become increasingly more efficient, and

without live, reliable data, teams can be at a fairly significant disadvantages in terms of race strategy. Things like understanding the car's fuel burn can make a difference, especially in changeable conditions such as slow zones, safety cars and changeable weather conditions.

Here, ultrasonic flow measurement devices are used to provide consumption data. These must integrate with the car's onboard telemetry and data logging systems, and engineers calibrate them with the type of fuel used, target flow rates and prevailing conditions.

In a series where ultrasonic technology is financially and technically inaccessible, race engineers can investigate fuel consumption using the fuel injectors' performance information table, calculating the fuel volume that passes through the nozzle at any rpm. Software can then total the fuel used based on how often and how long the injector nozzles are open. Together with the fuel pressure, this can form a basis for calculating fuel consumption.

However, this technique has a margin of error, as nozzle characterisation must be calibrated against all fuel types, duty cycles, fuel pressure and temperature. As temperature and density are inversely proportional, fuel temperature is critical to accuracy. But the coefficient of thermal expansion is not a constant over the full range of temperatures at which fuel might find itself in a racecar, and additives such as ethanol have differing expansion characteristics to the base fuel.

The higher the fuel's temperature, then, the lower its density, and so a higher volume must pass through the injector to supply the desired mass.

Some software types use open-loop exhaust gas temperature and oxygen sensor inputs. These calculate fuel consumption as a function of the exhaust gases' constituents. The proper air / fuel ratio, and the absolute amount of fuel used per cycle, are extrapolated from these sensors.

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The Control TLM-P1 Modem installed in a modern racecar alongside a logging unit, ECU and power distribution modules

Engineers can then use this information to amend the air / fuel ratio based on the exhaust gas temperature, oxygen sensor readings, air temperature and moisture levels.

Engineering the car and engineering the strategy are closely linked and rely on accurate, fast, reliable and complete telemetry. If this data is transferred in real time and tailored to be easily understood by strategy engineers, or strategy software, it can be a game changer.

'Strategy software linked to data coming in from the car can tell the team that, at a given pace and taking into account all the telemetry off the car, the best time to pit is on x lap,' notes Sanders.

'Together, the high-quality telemetry data, combined with strategy software, can assist in changes in preparation for the next stint.'

Teams in high-level series often use proprietary software implementations linked to onboard telemetry units to pull fuel burn information out and pass it into the strategic tool to provide another parameter it can use to form those predictions.

These predictions have only one goal – finding the quickest way to the finish line.

'Doing predictive analysis on when your competitors will stop, understanding traffic management and how the car's potential and behaviour changes as the fuel load drops

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and the tyres degrade are primary inputs into race strategy,' says Sanders.

'Delivering telemetry is the biggest part of the strategy as it allows the team to know how the car is functioning *now* so they can know what to do *next*.'

Safety considerations

In some branches of motorsport, especially today's hybrid and electric classes, if telemetry isn't connected and running, teams won't even run the car because it's not considered safe to do so for the driver, or because of the sheer cost of damaging the car should something so wrong.

With telemetry, engineers can work around many problems that could be terminal for the car if left unchecked. In endurance racing in particular, the victors aren't always the fastest competitors, but the ones who mitigated the problems that occur during the race the quickest. Monitoring your own car's behaviour for performance and pit stop strategy is vital, but so is observing its state for longevity. And as many race series now have limits on the number of parts consumed throughout the season, ensuring the use targets can be met is critical to championship success.

Likewise, being able to remotely monitor and report back on electrical safety, especially at a series level, will become more critical as motorsport's future will likely see more electrification and hybridisation of cars.

Suppose a car crashes, knowing the electrical systems are okay might be the difference between telling a driver to get out or stay in the cockpit and not touch anything. Or to inform marshals whether or not it is safe to approach a car. In all safety-critical conditions, real-time data from the car is vital.

Machine learning and AI

Control Ltd's products use machine learning running in the background.

'Our modems send up information every two minutes to our cloud platform about what percentage coverage they've got, what their signal strengths are and what network they're on,' explains Sanders. 'We can work out the race track they're at based on the cell towers they can see.

'We put all of that into a machine learning model, and it works out the best network or combination of networks for a given racetrack. It also carries out diagnostics like antenna anomaly detection.

'If, for example, there are 50 modems at one racetrack on one network, the machine learning algorithm clusters the signal strengths. If there's a modem with signal strength consistently outside the cluster, it will automatically fire an alert to us, allowing us to notify our customer.

'It's not yet AI levels capable of making decisions based on the information, but that's not impossible for the future.'

The major challenge related to using machine learning and AI in motorsport, as elsewhere, is the volume of data required to be analysed before the computer can make an accurate decision. The more parameters an AI system has inputs for – and in a racecar, there are hundreds – the harder it is to accept and process the data. The accuracy of this data is also critical, as it is for a human interpreter. And like a human, an AI system is only as smart as its inputs.

Easy access to vast computer processing power and memory via cloud services and data processing centres has been a critical enabler for AI that makes it more suitable now than in the past.

Although direct AI control of racecar parameters is currently outlawed, investigating the conditions that could lead to power unit failure is an application that is already an area acceptable for AI.

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Nathan Sanders, technical director and founder at Control Ltd

For example, where an engineer would analyse the data from a power unit failure to identify the failure's instantaneous moment, an AI system could explore all the engine parameters when the engine failed and potentially identify the cause, too.

For this kind of system to work, each operating parameter of the power unit, each parameter's operating window, the factors that influence any parameter and the influence any one parameter has on another must all be 'taught' to the AI system. The AI's ability to then prioritise each dynamic operating parameter analysed is vital to the system's success.

AI is currently extensively exploited in simulation, testing and developing race strategy before a race using previously collected data. It's safe to say, then, that AI has its place in motorsport, and it's all based on reliable telemetry transmission.

XPB Images

Like all the other electronics in modern-day motorsport, telemetry systems must be robust to withstand all racing and environmental conditions, including occassional airborne moments