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INTELLIGENCE ON ALL THINGS WIRELESS
Timing is everything:
Synchronization and 5G networks
By Kelly Hill
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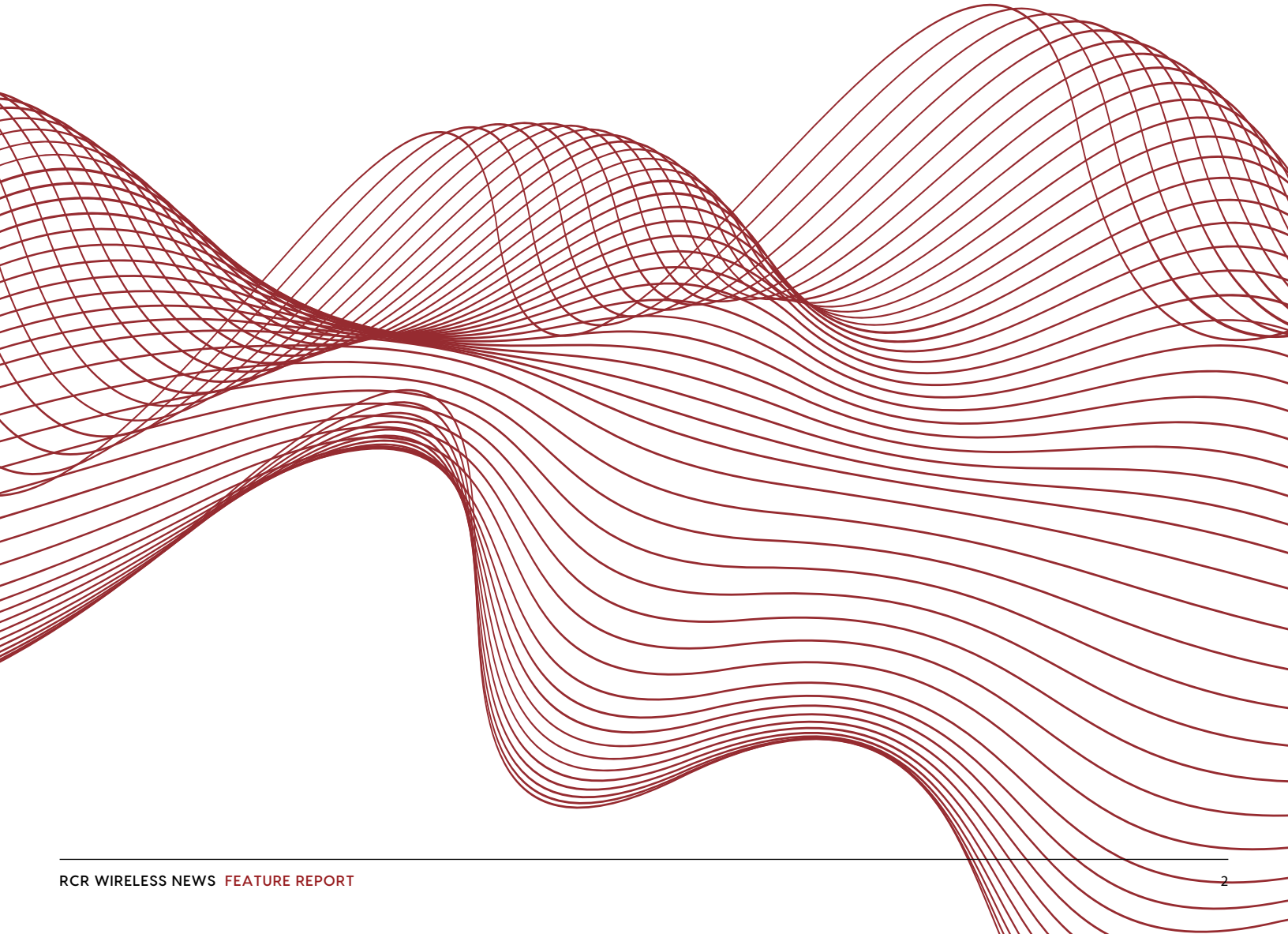
INTRODUCTION

Telecommunication networks are fundamentally about sending and receiving signals accurately. In order for the network to accurately juggle the complex transmission and reception of data from many devices in various locations, accurate timing and synchronization is absolutely crucial. As one semiconductor company has put it: "To create a shared experience, the network must provide shared time, just like it provides a sharing of information. 'Now' must be the same everywhere on the network." And when timing and sync is off, network performance can collapse.

In modern networks, timing and synchronization are taking on increasing importance for several reasons: The widespread deployment of Time-Division Duplex (TDD) midband spectrum for 5G, and because increasingly exact coordination is being demanded of the network for advanced air interface features such as carrier aggregation or massive MIMO, and services such as positioning (which is inextricably linked to timing). As MNOs shift their attention from initial 5G roll-outs to optimization and densification, and as customer uptake of 5G puts more traffic onto the new networks, it is crucial to be able to quickly and efficiently identify and remediate timing and synchronization errors.

This report will explore the increasing importance of highly accurate timing and sync, some of the contributing technological factors and strategies for field testing and troubleshooting of timing and synchronization errors, with a focus on the Radio Access Network (RAN).



(Image courtesy of 123.RF)

THE EVOLUTION OF TIMING & SYNC IN TELECOM NETWORKS

"Timing alignment is fundamental in telecom," explained Kishan Shenoi, timing and synchronization architect for Intel, during a session at ATIS' recent Workshop on Synchronization and Timing Systems (WSTS).

In early wireless networks, Shenoi said, synchronization was often referred to under the umbrella of frequency or time "accuracy", with a focus on the impact on handovers.

After all, the ability to move and maintain a connection is one of the defining and most important characteristic of a cellular network. Base stations have to be both synchronized relative to moving user equipment, accounting for Doppler shift, as well as coordinate with their neighbor base stations in order to facilitate smooth handoffs. Cellular networks also require synchronization to an external or absolute source of time across all network nodes, in order to avoid interference and to be able to successfully leverage the advanced RF features mentioned earlier.

This was all a lot simpler in previous generations of cellular technologies, when 1) Frequency Division Duplexing (FDD) was the primary mode in 3GPP systems, in which different frequencies are used for uplink and downlink communications, and 2) RF transmission and reception was less complex, relying on lower frequencies, single spectrum bands rather than carrier aggregation, and single-input-single-output or lower-order multiple-input-multiple-output antennas as opposed to modern massive MIMO systems.

Per Lindgren, group CTO and head of sync at Net Insight, which provides a network-based timing distribution solution, said that in 5G midband, TDD systems, the accurate synchronization of both time and phase is much more complex. The move to all carriers deploying TDD spectrum for 5G "was the big shift, and I don't think people realized what a big shift that was," he reflected. Since base stations typically have a GPS antenna built in, GPS was looked to as the default timing solution—but the signals can be vulnerable to weather issues or jamming, and carriers realized they needed a backup. Precision Time Protocol, or PTP, was introduced as a network-based timing synchronization standard that is meant to enable highly accurate synchronization, but network elements have to be upgraded to support PTP—and even if they are, Lindgren says, telecom operators often lease aggregation network capacity and don't control all portions of their backhaul and transport. This has led to timing source servers being more highly distributed toward the network edge.

(Image courtesy of 123.RF)

As systems have migrated to TDD and 5G, with increasingly advanced radio features, the range for allowable timing alignment error in cellular systems has also tightened over the years. In CDMA systems, base stations had to maintain a TAE less than 10 microseconds. In modern LTE and 5G systems, Shenoi explained, TDD requirements for TAE can be less than 3 microseconds, and for some services in 5G clusters, the timing alignment error must be less than 130 nanoseconds.

Carrier aggregation, geolocation, Multimedia Broadcast Multicast Services (MBMS, or eMBMS/5G Broadcast), Inter Cell Interference Coordination (ICIC or enhanced ICIC) are all examples of cellular network features or services which deal with signal processing and must by necessity be properly synchronized in order for them to function as they should.

"The degradation with lack of synchronization is dramatic," Shenoi warned.

"Very stringent timing requirement are now needed to for 5G and TDD to work correctly," said Sebastien Prieur, manager of RAN/mobile solutions at test company EXFO. "So this is quite a change, in an evolution that is still ongoing, that operators are still working into implementing."

Meanwhile, Open RAN introduces additional timing and synchronization complexity by way of the disaggregation of RAN functions across fronthaul and midhaul connections in addition to the typical backhaul. In fact, in O-RAN, synchronization is such a vital concept that it is considered a separate plane: There is a data plane, control plane and the synchronization plane or S-plane. "It has been elevated, it's not just an afterthought any more," Shenoi said.

The demands on timing and synchronization are only expected to get more challenging in 5G Standalone and in future 6G systems, where timing accuracy is expected to be extreme in order to support use cases such as joint communication and sensing in the network.

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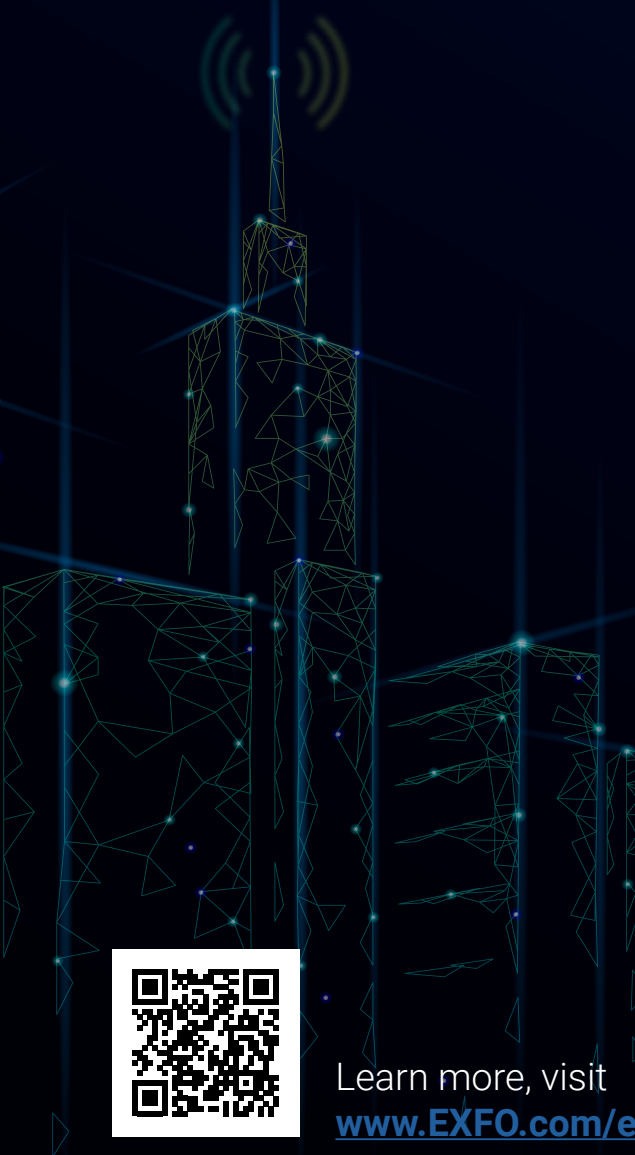

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TIMING IS POSITIONING, AND POTENTIALLY, MONETIZATION

Lindgren says that timing and synchronization is ultimately fundamental to monetization of the network. He lays out three aspects of this argument. The first is that many services require accurate positioning information, such as autonomous moving robots in factories that must follow exact paths.

"In the end, accurate synchronization translates to accurate positioning," he points out.

The second aspect is network availability and uptime—which are negatively impacted if timing and sync is off. Having high-availability infrastructure is key to supporting remote locations where interactivity has to be supported on the network, such as control of remote control of mining or agricultural equipment, Lindgren said. Proper, consistent and redundant synchronization is necessary for network reliability and performance.

Thirdly, Lindgren said, timing—and specifically, an absolute timing source that isn't GPS or GNSS—is also considered both a national security priority and a practical one, considering timing's importance. Russia has been suspected of jamming GPS signals that has impacted thousands of flights in Europe; both Ukrainian and Russian forces are known to be jamming GPS signals to thwart drone attacks. Satellite signals can also be impacted by solar storms, weather or other environmental factors. Additional options are being sought. For example, positioning company NextNav filed a petition with the Federal Communications Commission earlier this year which argued in part that the agency should grant a band reorganization of spectrum in the lower 900 MHz band (902-928 MHz) so that NextNav can support a terrestrial positioning, navigation and timing (PNT) network alongside 15 megahertz for 5G mobile broadband, because of the importance of having alternative PNT sources.

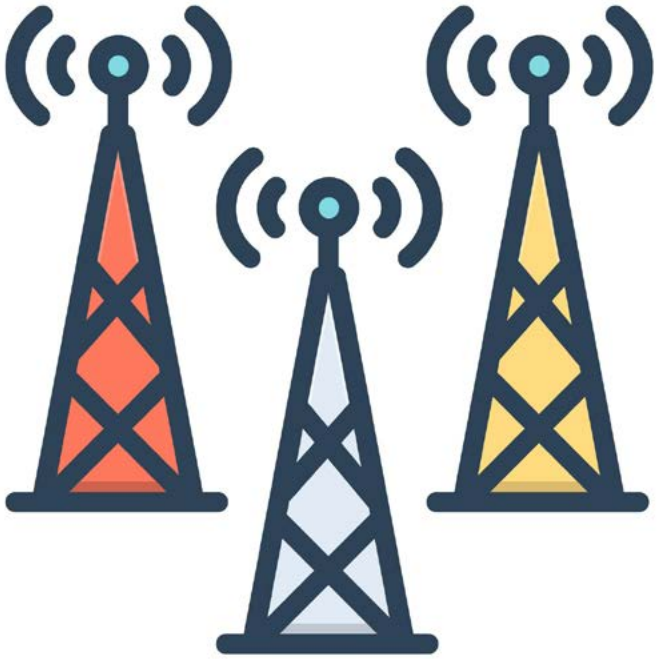
As spectrum gets harder and harder to come by, timing and synchronization is also expected to play a crucial role in enabling advanced, dynamic spectrum sharing strategies. "Accurately time-synchronized wireless networks and devices can participate in much more effective spectrum sharing and co-existence schemes, adding time-domain multiplexing on top of spatial and frequency domain separation schemes," wrote Nokia Bell Labs fellow and Nokia's head of North American standardization Devaki Chandramouli in a 2023 IEEE paper on timing and synchronization possibilities from 5G-Advanced to 6G. "This enables more aggressive utilization of spectrum and a much higher density of private wireless networks and co-existence of different access technologies to the same spectrum." That paper also noted that absolute time synchronization can provide highly accurate delay measurements for assessing quality of service/quality of experience, and that consumer use cases including XR services rely on synchronized media layers and need time synchronization to align playout buffers. Timing and synchronization is also fundamental for automation. "To unleash … machine learning based optimizations, timestamping of captured real world events is an essential capability to extract meaningful correlations and actions," Chandramouli wrote.

TIMING AND SYNC IN THE FIELD

But more immediately, and more relevant to the consumer user experience, is that timing and synchronization errors in 5G TDD networks degrade a site's ability to provide consistent call quality and good data performance. And being able to identify a timing error isn't always obvious.

"The kind of problem that a timing issue will create is very similar to what an RF interference or a PIM interference issue will create," explains Prieur. The problem at a site may be related to timing, he continued, but usually will start as a Received Signal Strength Indicator (RSSI) problem and perhaps customer complaints related to performance. "At that point, you're not sure. Is it an interference problem, is it a passive intermodulation problem or is it a timing problem? Because the symptoms are very similar for whether it's timing or an RF interference problem," Prieur adds. "You will have cell sites that will be interfering with each other, that will create handover issues for a user: corrupted data, slower throughput dropout and such. So the symptoms for the user are very similar, whether it's timing or RF. And for the person responsible to troubleshoot that issue, it's not obvious to determine at first from where it's coming."

Ideally, of course, establishing and enforcing best practices in the installation process for correct configuration will help head off timing issues. But mistakes happen and sometimes issues aren't discovered until the site is handling live traffic and there is a problem. At that point, Prieur says, a good first step for troubleshooting is to validate that the cell site is within its time-error requirements, that timing is well-distributed to the site and all the network equipment and elements are within timing specifications. "Making sure that a tech is not dealing with a timing problem is probably the best step to start with," Prieur says. "This is something that is pretty quick to do. You can start with that, put that aside and then start to look for something more complex, like an RF interference or passive intermodulation problem"—which is likely to require more time, and might eventually require a tower climb.



(Image courtesy of 123.RF)

Prieur said that operators are increasingly aware that timing is important in their 5G deployments, but that doesn't necessarily trickle down to the workforce in the field, where he sees a major need for education and support. "It's a topic that is probably well understood from the engineering and planning side of things, but when you hit the field, then you see there's a gap—an incredible gap—on what the engineering team thinks is implemented in the field, versus reality," he added. Prieur said that operators are still at the point of creating a standard operating procedure that can be easily and consistently followed in the field in order to test and address timing issues, and are also looking for more workforce education and training on timing and sync issues and how to test for them.

"The theory behind timing and synchronization may sound complex, and it is," Prieur concluded. "That being said, for a cell tech to test that in the field with the right standardized processes—it is very simple." Techs can load a fixed configuration that has been predetermined with an operator, get a time reference from a GNSS receiver and run a test for a predetermined period of time laid out by the operator, which would determine if a site is in sync or not. EXFO's testing solutions support both options to validate timing over the fronthaul/backhaul fiber interface or the over-the-air RF interface, he said.

But that is also only a first step, he adds, depending on the features that operators want to support—and it will get more complex as 5G continues to evolve. In COMP, or coordinated multi-point (simultaneous communication of a UE with multiple base stations, for a more robust connection at the cell edge), use of millimeter wave spectrum and other advanced radio features, "the more you are progressing and introduce these features … the tighter the synchronization requirement would be," he noted. "Already today, with the simpler, easiest level—which is to support a process in the field to make sure synchronization is configured correctly—we're not there yet. And this will just be harder and harder, and more and more critical, to make sure that timing is delivered correctly and meets very tight requirements."

Network equipment configuration is the biggest issue that EXFO sees in the field currently with timing and sync, Prieur says—for example, due to something like cable delay that hasn't been configured correctly in an edge grand master and which directly impacts and introduces error in the time being distributed to the network. Timing and sync is also very sensitive to asymmetry in the transmit and receive network paths. "If any change in the network introduces asymmetry, this will directly translate into an error on the timing," he said. "So again, this all needs to be engineered correctly at first, and then you need to make sure along the way when you are in operation, that these parameters don't change."

(Image courtesy of 123.RF)

Prieur sees operators taking action to better control some of the potential ways that timing can be thrown off. For instance, because of the sensitivity of the primary timing protocol to differences in the transmit/receive paths in fiber networks, Prieur says that the use of bidirectional single-fiber is becoming more common as a clever way to control that asymmetry, particularly in fronthaul networks. "Open RAN principles and modern 5G network principles are implying more and more visualization, more and more centralization, more and more desegregation of different network elements," he said. "So we see more and more fronthaul and midhaul, and more and more timing being distributed by these interfaces."

This range of factors, however, means timing issues are not uncommon—and operators may not yet be fully aware of their impact, or how regularly they need to validate timing to keep it in line with requirements.

Prieur said that in recent testing in a carrier network at half a dozen different sites—in the same region but different cities—timing was an issue at all six. "We test in the field and find issues, and every time, it's an eye-opener for [carriers]," he said. "They realize, okay, timing, we probably will have to go back and readjust to make sure everything had been configured correctly—and they are currently finding out that it's not." Because timing and synchronization can be impacted by network changes, the fact that a site has been working doesn't mean it will continue to. And because Prieur, too, sees timing as one of the key underpinnings of 5G optimization and monetization, he expects that the importance of proper timing and synchronization will only grow. "We're moving in to a phase where operators want to monetize 5G. So now, performance is getting more important, a bit more top-of-mind on the 5G network. And, we are transitioning to Standalone 5G," Prieur said. "This timing issue will start to impact more and more, and show up more and more."

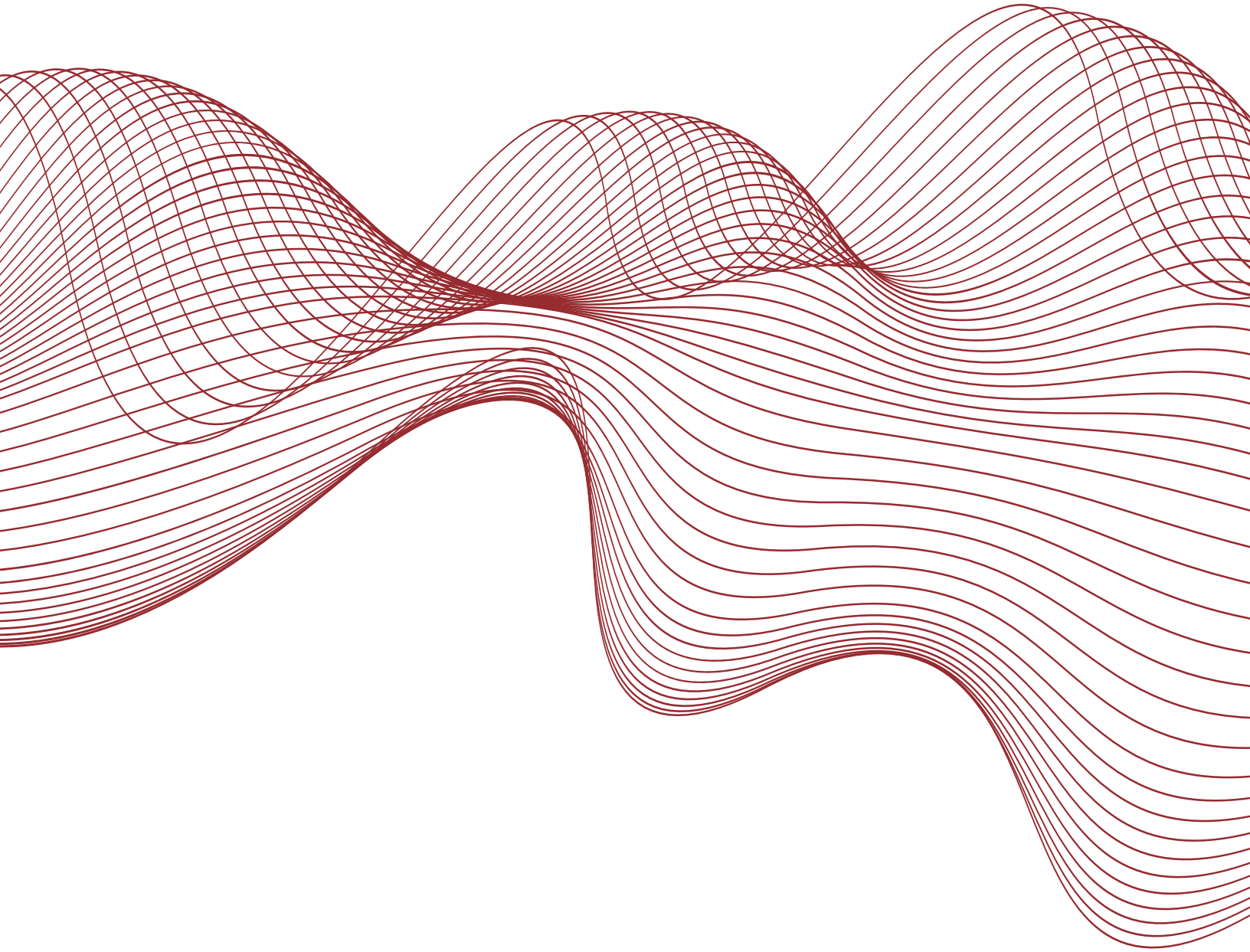
(Image courtesy of 123.RF)

KEY TAKEAWAYS:

-Timing and synchronization demands on 5G networks are getting increasingly strict, due to both the widespread use of midband TDD spectrum as well as new and complex radio features that require precise coordination, as well as Open RAN implementations.

-Timing and synchronization is crucial for support of XR services, automation, precise positioning and other monetization and operational aspects of 5G. Expectations are that timing requirements for future 6G systems will be even more extreme.

-Testing and validation of timing and sync isn't a once-and-done deal, and it should be one of the first steps toward eliminating possibilities when troubleshooting.



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