Tactile Internet Technical Committee

- Dec. 2022 Newsletter -

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1. About the TI TC

Mobile communication plays a key role in the modern economy and society. At the same time, the current Internet has created a key infrastructure component for our modern world, touching almost every aspect of our daily lives. The Internet enabled access to information and has allowed emerging economies to participate in the global economy. The next big wave of the Internet innovation is now approaching: the Tactile Internet (TI), which is defined as:

"A network or network of networks for remotely accessing, perceiving, manipulating or controlling real or virtual objects or processes in perceived real time by humans or machines." [IEEE P1918.1].

The TI pushes boundaries of Internet-based applications to remote physical interaction, networked control of highly dynamic processes, and the communication of touch experiences. Hereby, the Tactile Internet with Human-in-the-Loop (TaHiL) will yield to innovation in quasi-real-time human–machine interactions in real, virtual, mixed, and remote environments enabling a broad range of new applications in various fields. Whereas senses like hearing (audio) and sight (visual), or a combination of them (audiovisual) are relatively less challenging to transmit, touch (haptics) has much stricter communication requirements. One reason for this is that stable and ultra-low-latency interaction needs to be guaranteed if the intention is to achieve sensorimotor control over the communication medium in perceived real-time. This interaction can be with a Human-in-the-Loop or with any virtual or real object, e.g., a machine.

Central to the TI is the more general realization of new realms of communication applications not only requiring the ultra-low-latency touch interaction, but also ultra-high reliability, security, and availability. Ultra-high reliability might also be required not only in TaHiL, but also in many other TI scenarios, namely machine-in-the-loop cases.

Within the context of the TI, components that comprise a TI system as well as the dedicated haptic human-interaction hardware, typically use different and often proprietary communication/interaction formats and means. Moreover, elements and structures of End-to-End (E2E) TI deployment might significantly vary and even be conflicting in different solutions. It is therefore of utmost importance to standardize aspects of the TI to harmonize such essentials. This will allow TI components to freely interact with each other directly out-of-the-box, without requiring custom/proprietary communication design that is dependent on the scenario and specific set of equipment used. Such standardization will also facilitate other aspects of the network supporting the TI to be deployed in a consistent way, such as network-side processing.

To this end, the Institute of Electrical and Electronics Engineers (IEEE) P1918.1 TI Standards Working Group (WG) was formulated initially out of the IEEE ComSoc Standards Development Board (COM/SDB) Fifth Generation (5G) Rapid Rapid Reaction Standardization Initiative (RRSI) as a collaborative effort of the TI TC members to bring a proposal for TI standardization to a RRSI meeting in Santa Clara, CA, USA, in November 2015.

The Tactile Internet Technical Committee aims to facilitate the worldwide harmonization of research, pre-standardization, and best practices for deployment of user scenarios of the global TI ecosystem. The TI TC therefore organizes events such as webinars, collaborates with other TCs and IEEE societies, sponsors tracks, symposia, special sessions, and workshops, hold regular meetings – in-person and/or online – and has members actively contributing to the IEEE P1918.1 TI Standards WG (and associated subgroups).

See more information: https://ti.committees.comsoc.org/

2. Awards/Distinctions for TI TC Members

2.1. TC Award Recipients

The Tactile Internet TC establishes a part of the TI activities the Service Award and Technical Contribution Award to recognize members.

The Service Award is provided for distinguished record of service to the TI TC.

The Technical Contribution Award is provided for significant contributions to the technological advancement in the areas of the Tactile Internet and Haptic Communications.

Recipients of the TI TC awards of 2021 are

Dr. Oliver Holland, Advanced Wireless Technology Group, Ltd, UK, received the TI TC service award for his outstanding contributions and continuous service to the TI TC as well as IEEE P1918.1 standardization WG leading to the visibility and success of the Tactile Internet.

Prof. Zaher Dawy, American University of Beirut, Lebanon, received TI TC technical contributions award for his excellent contributions to the design of the Tactile Internet architecture, and his fundamental contributions to Tactile Internet research.

Awardees of 2022 will be announced in the next edition of the newsletter.

3. Past Events

3.1. Invited Talks/Keynotes/Presentation

- **DAAD NeT-AI**
      2022-03-08 , Online, Frank Fitzek, Stefanie Speidel, Shu-Chen Li
      CeTI AI presentation

- **Programming Conference**
    2022-03-23, Porto (Portugal), Johannes Mey
    Reusing Static Analysis across Different Domain-Specific Languages using Reference Attribute Grammars
- **Keynote ITG-conference on broadband supply**
    2022-06-07, Berlin, Frank Fitzek
    Randomness the Motor for the Tactile Internet
- **Innovation Summit**
    2022-06-14, Dresden, Frank Fitzek
    5G and quantum communication
- **TryEngineering Tuesday**
    2022-07-19, Dresden, Frank Fitzek
    Metaverse: Tactile Internet and the Need for Novel Communication Approaches

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3.2. Tutorials

- **Computing in Communication Networks – From Theory to Applications** - IEEE ComSoc Training Course [online]
- **Computing in Communication Networks: The Road Ahead** - Tutorial at VTC2021-Fall [online]
- **Goal-Oriented Communication for Networked Intelligent** Systems – Tutorial at IEEE SPAWC 2021

3.3. Workshops

- **MINT TANK digital**
    2022-01-14/15, Online, Sebastian Bodenstedt & Adrian Brettschneider, TU Dresden
    Use of AI in surgery
- **Feature-oriented Software Development (FOSD 2022)**
    2022-03-21, Vienna, Clemens Dubslaff
    Feature Causality with Uncertain Effects
- **ETAPS 2022**
    2022-03-04, Munich, Clemens Dubslaff
    System Configurations Matter – An Experience Report on Reproducibility
    Iterative Variable Reordering: Taming Huge System Families. 5th Workshop on Models for Formal Analysis of Real Systems (MARS 2022)

Feature Causes of Quantitative Effect Properties". 3rd Workshop on Quantitative Aspects of Variant-rich Systems (QAVS 2022)

3rd Workshop on Quantitative Aspects of Variant-rich Systems (QAVS 2022)

- **HSOZH Fieldtrip**

    2022-04-05, Dresden, Frank Fitzek

    "Dresden – von der Barock- zur Innovationsstadt"

- **IEEE SPAWC 2021 Special session on Information Freshness in Real-Time Communication**
- **6G-life: Digital transformation and sovereignty of future communication networks;** Virtual Workshop on B5G and 6G, Yonsei University, Sydney
- **CeTI: Tactile Internet with Human-In-The-Loop** – Workshop on Robotics in Industry 4.0; Université Paris Saclay, France [online]
- **Globecom 2023 Workshop** planned on Tactile Internet for Telepresence and Immersive Experiences

3.4.   Projects and Other Activities

- Worldwide new TI centers/research groups are opening, e.g., Canada, Germany, UK, Abu-Dhabi, Lebanon, and the USA
- CeTI Summer School, Smart Textiles & Wearbales, Sept 2021 – Planned for Sept 2022 as well!
- "Semantics-Empowered Communication for Networked Intelligent Systems", Swedish Research Council (VR) , (2022-2025)
- "Information Handling in Industrial IoT", ELLIIT, (2021-2025)
- ADAMO (Adaptive Fluid dynamics for Motorbikes)
- 5G-enabled Remote Robotics Control
- Resilience in Connected Worlds

3.5.   Engagement/Collaboration with other TC/Societies

- Engagement with other TCs, e.g., IoT, Ad Hoc & Sensor Networks, Information Infrastructure & Networking, Network Intelligence (ETI)
- Engagement with IEEE ComSoc SCV chapter
- Engagement with IEEE Computer Society SCV chapter
- Collaboration with IEEE Robotics and Automation Society Telerobotics TC
- Discussion with other TCs from other IEEE societies ongoing
- Organization of online webinars in collaboration with the IEEE ComSoc SCV and IEEE Computer Society SCV chapters

3.6.   SIG Activities

- SIG: IoT in the Tactile Internet

- Together with the IoT, Ad Hoc & Sensor Networks TC a cross-TC SIG has been formed on ""
- The SIG activities will be coordinated by Dr. Sharief Oteafy (soteafy@depaul.edu) from DePaul University and Dr. Nikolaos Pappas (nikolaos.pappas@liu.se) from Linköping University
- An online kick-off meeting on June 23rd, 2021 with an invited talk on "Cyber-Physical-Social Systems (CPSS) in the 6G Era: From Tactile Internet to Internet of No Things" by Martin Maier
- Please, reach out to Sharief Oteafy and/or Nikolaos Pappas in case of interest
- Other SIGs currently under discussion
  - Please, reach out to us in case you are interested to lead a SIG activity

3.7. Webinar Series

- Started a webinar series with experts from diverse backgrounds

- 6G and Onward to Next G: Virtual Immortality, Eternal Life, and Other Metaverse Pastimes
  - December 14, 2022, 18:00-19:00 (CEST)
  - Prof. Martin Maier
- Networked Cyber-Physical Systems for automotive applications
  - October 19, 2022, 18:00-19:00 (CEST)
  - Prof. Stefano Giordano
- From Network Softwarization to In-Network Computing
  - September 28, 2022, 18:00-19:00 (CEST)
  - Dr. Giang T. Nguyen

3.8. Special Issues

- **IEEE Internet of Things Journal** ''Age of Information and Data Semantics for Sensing, Communication and Control Co-Design in IoT", Published Oct. 2021.
- **Frontiers in Communications and Networks**, Special Issue on ''Age of Information"
- **IEEE Communications Standards Magazine** "Autonomous Networks: Opportunities, Challenges, and Applications"
- **IEEE Network** "Zero Touch Networks: Opportunities, Challenges, and Potential Applications"
- **Planned:** IEEE Network "Tactile Internet"

3.9. Other Events

- STEM West 2022, Glasgow, 2022-11-21

- 5G Teleoperation, Scotland 5G Centre, Aberdeen Connect Hub, Aberdeen, 2022-10-03
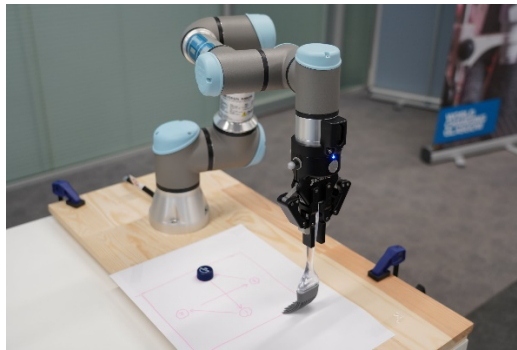

- 5G Haptic Teleoperation, Scotland 5G Centre, Dumfries Innovation Hub, Dumfries, 2022-06-16

- Remote Dental Inspection with Haptic Feedback, University of Glasgow, Glasgow, 2022-03-22

- Remote Control with Haptic Feedback, Engineering Day Event, University of Glasgow, Glasgow, 2022-02-08

- [Juniordoktor half time Event](#), Dresden, 2022-03-01

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- [Digital Gender Conference](#), Dresden, 2022-03-23

- [BeWISE 2022](#), Women in Science and Engineering, Dresden, 2022-04-27/29
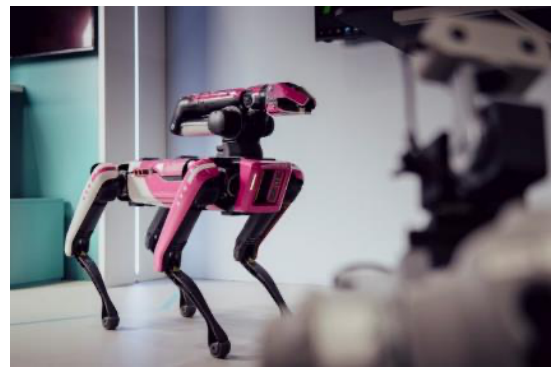

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- [NCT Benefit concert](#), Takte gegen Krebs, Dresden, 2022-05-07

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- [IEEE 5G++ Summit & CeTI General Assembly](#), Dresden, 2022-05-09/12

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- [Innovation Summit](#), Handelsblatt Innocation Days, Dresden, 2022-06-14

- **Leserreise Bild der Wissenschaft**, Dresden, 2022-06-27

- [Dresden Science Night](#), Dresden, 2022-07-08

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Publications within CeTI

- https://ceti.one/impact/

Awards

- Groß, Sonja; Breimann, Silija; Schwarz, Sascha; Ganguly, Amartya; Haddadin, Sami: Embedded 3D printing: A cost-effective development platform for tactile sensors. In: Proceedings of the Eurohaptics Conference (EuroHaptics), 2022, (Industrial Award, 3rd place).
- von Lengerke, Caspar; Hefele, Alexander; Guerrero, Juan A. Cabrera; Fitzek, Frank H. P.: Stopping the data flood: Post-Shannon traffic reduction in digital-twins applications. In: Proceedings of the IEEE/IFIP Network Operations and Management Symposium (NOMS), WS4: International Workshop on Technologies for Network Twins (TNT), 2022, (Best Paper Award).
- Senk, Stefan; Ulbricht, Marian; Acevedo, Javier; Nguyen, Giang T.; Fitzek, Frank H. P.: Flexible measurement testbed for evaluating time-sensitive networking in industrial automation applications. In: Proceedings of the IEEE International Conference on Network Softwarization (NETSOFT), 2022, (Best Student Paper Award).

Projects

- 3 new professorships within CeTI:
    - Riccardo Bassoli, Junior professorship Quantum Communication Networks, TU Dresden
    - Yitian Shao, Junior professorship in Smart Materials for Human-Computer Interaction, TU Dresden
    - Merle Fairhurst, Junior professorship Chari of Acuostic and Haptic Engineering

4. Ongoing Research Projects/Grants

4.1. Priority Programme Resilience in Connected Worlds – Mastering Failures, Overload, Attacks, and the Unexpected (Resilient Worlds)

Vision and Goals (recap)

The goal of the Priority Programme is to disrupt fundamental limits of connected worlds by adding resilience as a core building block (cf. Figure 1). Resilience is the ability of a system to provide and maintain an acceptable level of secure and safe service delivery, even in case of failure or compromise of some of its components, and also under completely unexpected situations. Machine learning (ML)-based solutions help making our complex network infrastructures more resilient but at the cost of reduced controllability – and with reduced abilities of experts to help in critical situations. Thus, we are faced with even more challenges in terms of resilience in critical network infrastructures.
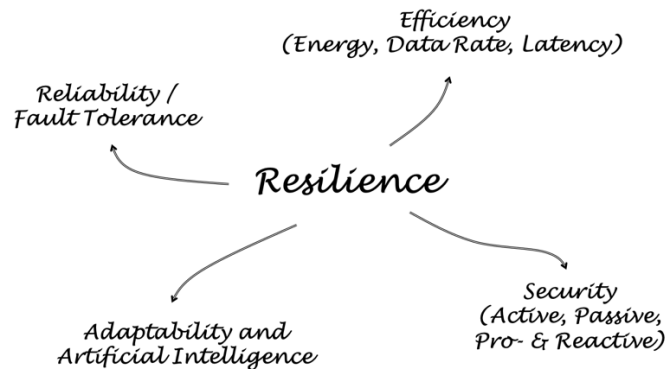
Figure 1: Resilience as a core property of next generation connected worlds

Resilience, as an emerging research field, is strongly required as a core property of the network infrastructure, from the global internet to the internet of things (IoT), from connected cars to complex cyber-physical systems (CPS); and resilience will be a primary research objective for the coming years. Resilient Worlds will provide resilience throughout the complete protocol stack, from the hardware layer to wireless communications and to applications. We expect that in modern communication networks unknown and unforeseen events could be handled both from the network as well as utilizing external capabilities to prevent a collapse of this critical infrastructure. This requires a holistic approach to resilience, leading to appropriate, understandable, and easily applicable solutions.

In Resilient Worlds, the focus will be on the investigation of a resilience-by-design approach, which is already very challenging; however, adding resilience to (legacy) systems that were not designed for it can be even more demanding. It is therefore the goal of the Priority Programme to address resilience from a new, multi-disciplinary perspective including, but not limited to, communications and networking, semiconductor electronic hardware systems, information security, and machine learning.

Research Program (update)

Following up on the review process that took place in spring 2022, 12 research projects have been selected for funding by German Research Foundation, which are about to kick-off early 2023.

- **Automated Resilience Verification and Resilience by Design**
  PIs: Boche, Holger and Schaefer, Rafael
- **NIC-Level Co-Processors for Resilient Coded Networking and Computation**
  PIs: Carle, Georg and Herkersdorf, Andreas
- **ResCTC: Resilience through Cross-Technology Communication**
  PIs: Dressler, Falko and Wunder, Gerhard and Zubow, Anatolij
- **One Code to Rule Them All: A Coding-Based Solution for Resilient Future Communication Networks**
  PI: Fitzek, Frank Hanns Paul
- **Collective Resilient Unattended Smart Things (CRUST)**
  PIs: Förster, Anna and Hollick, Matthias
- **Resilient Power-Constrained Embedded Communication Terminals (ResPECT)**
  PIs: Herfet, Thorsten and Schröder-Preikschat, Wolfgang
- **ReNO: Resilient Integration of Machine Learning for Enhanced Network Operation**

PIs: Hohlfeld, Oliver and Schmid, Stefan
- **Resilience meets secure networked control**
  PIs: Jager, Tibor and Schulze Darup, Moritz
- **Resilience by multi-connectivity network design in industrial IoT environments**
  PIs: Jorswieck, Eduard Axel and Wolf, Lars Christian
- **Resilient Safety-Critical Systems through Run-time Risk Assessment, Isolation, and Recovery (RESURREC)**
  PIs: Katzenbeisser, Stefan and Krauß, Christoph
- **Multi-Agent Reinforcement Learning Framework towards Automotive Resiliency and Survivability of Mission-Critical Networks against Volatile Resource Flow**
  PI: Maghsudi, Setareh
- **Resilient Communication with Programmable Hardware**
  PI: Menth, Michael
- **Coordination Funds**
  PI: Dressler, Falko

Coordination Team
- Falko Dressler (Coordination)
  TU Berlin, School of Electrical Engineering and Computer Science, Telecommunication Networks (TKN)
- Matthias Hollick
  TU Darmstadt, Dept. of Computer Science, Secure Mobile Networking
- Milos Krstic
  IHP, System Architectures Dept. and University of Potsdam, Institute of Computer Science, Design- and Test Methodology
- Konrad Rieck
  TU Braunschweig, Computer Science Dept., Institute of System Security
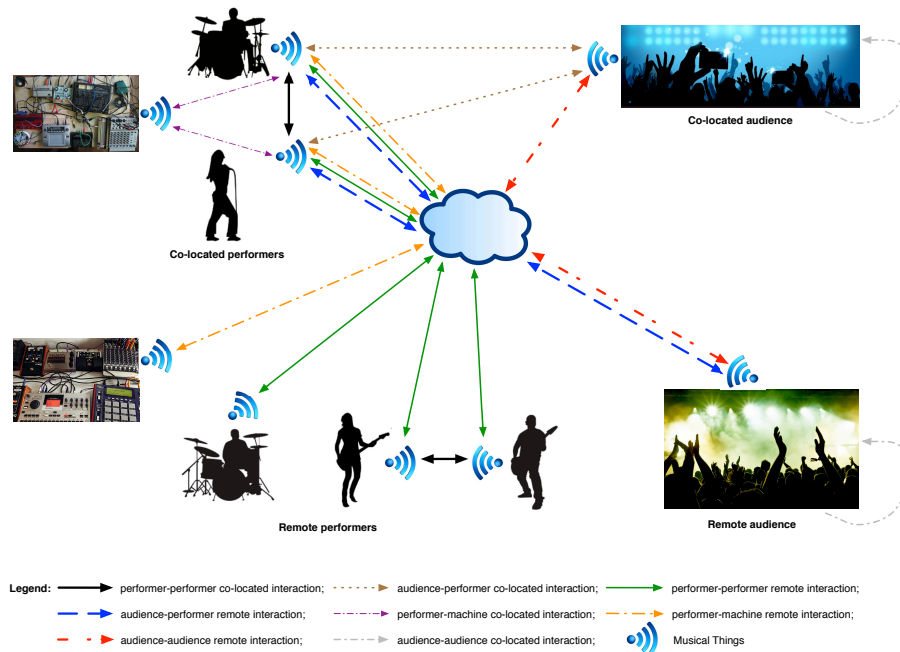- Antonia Wachter-Zeh
  TU München, Dept. of Electrical and Computer Engineering, Coding and Cryptography

For more information, please visit the program's web site https://www.resilient-worlds.org

4.2. Musical applications of the Tactile Internet: the case of the Internet of Musical Things

The Internet of Musical Things (IoMusT) is an emerging field that extends the Internet of Things paradigm to the musical domain. The IoMusT refers to the network of "Musical Things", which are computing devices embedded in physical objects dedicated to the production and/or reception of musical content. Musical things, such as smart musical instruments or wearables for musical applications, are connected by a wireless and wired network infrastructure that enables multidirectional communication, both locally and remotely. This

ecosystem of interoperable devices multiplies the interaction possibilities between a wide variety of stakeholders such as performers, composers, students, teachers, conductors, studio producers, live sound engineers, and audience members.

Legend: —— performer-performer co-located interaction; ·····> audience-performer co-located interaction; —— performer-performer remote interaction; ——> audience-performer remote interaction; —·—> performer-machine co-located interaction; —·—> performer-machine remote interaction; —·—> audience-audience remote interaction; ·····> audience-audience co-located interaction; ·)) Musical Things

One of the building blocks of the IoMusT is represented by Networked Music Performance (NMP) systems, which aim to interconnect musicians over a wired or wireless network link achieving the same conditions as instrumental on-site performances. To enable credible musical interactions, the musicians interacting over the network need to stream the content they produce with a latency below the 30 milliseconds and constant jitter. This strict threshold has been determined by several perceptual experiments. It corresponds to the maximum latency tolerable by musicians playing together in a shared real environment, who are spatially separated by about 9 meters (considering the speed of sound in the air at 343 m/s in normal conditions). A second requirement is a sufficiently high audio quality. This is mainly related to a low amount of packet losses occurring during the communication over the network, with probabilities less than 0.01 (considering an efficient packet error concealment algorithm at the receiver side which reconstructs the lost packets).

Various NMP systems are available either at experimental or commercial stage, including JackTrip, Jamulus, and LoLa. One of the most advanced NMP systems today is Elk LIVE (https://elk.live/), which allows to interconnect reliably up to 4 geographically displaced musicians within a range of 2000 Km depending on the network quality, streaming high quality audio content (the sampling rate is at least 48KHz and the bit depth is at least 16 bits). The achievement of the communication latency requirement of 30 milliseconds is facilitated by a Linux-based ultra-low latency operating system optimized for musical applications. At the sender side it converts within 1 millisecond the analog signals from the musical instruments into digital signals to be sent over the network, and with the same time it performs the digital to analog conversion at the receiver side. This allows to reserve a higher time budget for the network transmission compared to other solutions.

The last frontier in this space is represented by architectures based on technologies such as 5G NR URLLC (New-Radio Ultra-Reliable Low-Latency Connection) which, when widely deployed, will enable musicians to play together at a distance from anywhere. Various experimentations are currently undergoing in both academic

and industrial settings, fostered by a high demand from musicians for remote collaboration tools and services, which arose during the COVID-19 pandemic.
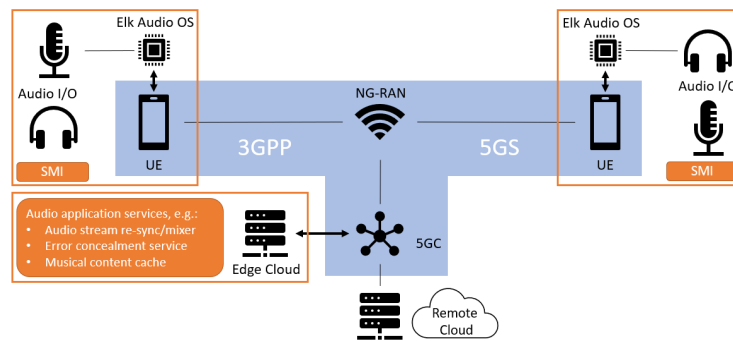
Musical interactions represent a peculiar and illustrative use case for the Tactile Internet given the particularity of the signals to be transmitted, which are continuous and periodic (i.e., audio packets are constantly transmitted every few milliseconds), as well as the perception-based requirements of low-latency and high-quality communications. To enable the IoMusT vision still much research has to be conducted. Such research will benefit from the close interaction of practitioners from different disciplines, including music technology, networking, and human-computer interaction.

More details about IoMusT technologies can be found in the following publications:

- Turchet, L., Fischione, C., Essl, G., Keller, D., & Barthet, M. (2018). Internet of musical things: Vision and challenges. *IEEE Access*, *6*, 61994-62017.
- Rottondi, C., Chafe, C., Allocchio, C., & Sarti, A. (2016). An overview on networked music performance technologies. *IEEE Access*, *4*, 8823-8843.
- Turchet, L., & Fischione, C. (2021). Elk Audio OS: an open source operating system for the Internet of Musical Things. *ACM Transactions on Internet of Things*, *2*(2), 1-18.
- Jiang, X., Shokri-Ghadikolaei, H., Fodor, G., Modiano, E., Pang, Z., Zorzi, M., & Fischione, C. (2018). Low-latency networking: Where latency lurks and how to tame it. *Proceedings of the IEEE*, *107*(2), 280-306.
- Centenaro, M., Casari, P., & Turchet, L. (2020). Towards a 5G communication architecture for the Internet of Musical Things. In *2020 27th Conference of Open Innovations Association (FRUCT)* (pp. 38-45). IEEE.

Author: Luca Turchet

5. Upcoming Special Issues Organized by TI TC Members

Upcoming Events

- **GAIN 2022,** Bonn, September 2022
- **CeTI Summer School**, Dresden, September 2022
- **Robotics Festival,** Leipzig, September 2022
- **European Wireless Dresden,** September 2022

6. Acknowledgement

We would like to thank those who have provided their inputs and the newsletter content.