Software Impacts 1 (2019) 100004

Contents lists available at ScienceDirect

Software Impacts

journal homepage: www.journals.elsevier.com/software-impacts

# TeraSim: An *ns-3* extension to simulate Terahertz-band communication networks

Zahed Hossain, Qing Xia *, Josep Miquel Jornet

*Department of Electrical Engineering, University at Buffalo, The State University of New York, Buffalo, NY 14260, USA*

ARTICLE INFO

*Keywords:*
Terahertz communication
ns-3
Network simulation tool

ABSTRACT

Terahertz (THz)-band (0.1–10 THz) communication is envisioned as a key wireless technology of the next decade, able to support up to multi-Terabit-per-second wireless links in 6G systems. Parallel with the design of THz devices, simulation tools are needed to expedite the development of communication protocols tailored to THz paradigm. In this paper, TeraSim, an extension for ns-3 to simulate THz communication networks, is presented. TeraSim defines and implements separate modules for the THz channel and the physical and link layers. It enables the design and testing of higher layers of the protocol stack without delving with the lower layers technologies.

Code metadata

| | |
|---|---|
| Current code version | v1 |
| Permanent link to code/repository used for this code version | https://github.com/SoftwareImpacts/SIMPAC-2019-9 |
| Legal Code License | GNU General Public License (GPL) |
| Code versioning system used | git |
| Software code languages, tools, and services used | C++ |
| Compilation requirements, operating environments & dependencies | |
| If available Link to developer documentation/manual | For example: https://github.com/UBnano-Terasim/Terasim-ns3/tree/master/thz/doc |
| Support email for questions | zahedhos@buffalo.edu, qingxia@buffalo.edu, jmjornet@buffalo.edu |

## 1. Introduction

Over the last decade, wireless data traffic has drastically increased due to a change in the way today's society creates, shares and consumes information. This change has been accompanied by an increasing demand for higher speed wireless communication anywhere, anytime. Following this trend, wireless multi-Gigabit-per-second (Gbps) and Terabit-per-second (Tbps) links are expected to become a reality within the next five years.

The commercial 5G networks are barely operational in the United States right now, but it has not stopped engineers and wireless researchers form thinking ahead to 6G. In March 2019, FCC opened the 95 GHz to 3 THz spectrum for experimental purposes, creating legal ways for companies to test and sell post-5G wireless equipment.

In this context, Terahertz (THz)-band (0.1–10 THz) communication is envisioned as a potential 6G wireless technology to satisfy the need for much higher wireless data rates [1–4]. This frequency band, which lies in between millimeter waves and the far infrared, is still one of the least explored regions in the electromagnetic (EM) spectrum.

In order to provide a starting point for the networking research community to both develop new solutions for THz networks and contribute to the development of the simulation platform. We present TeraSim [5], the first simulation platform for THz communication networks which captures the capabilities of THz devices and the peculiarities of the THz channel. TeraSim implements recently proposed wireless communication solutions tailored to both nanoscale communication networks (average transmission range usually below one meter) and macroscale communication networks (longer distances). More specifically, in terms of channel, we have developed a common channel module that implements the frequency selective channel model introduced in [6]. At the PHY and MAC layers, two parallel set of modules for nanoscale and macroscale scenarios have been developed [7,8]. In relation to the capabilities of THz devices, we have implemented an assisting energy harvesting model and a THz directional antenna model. We have

* Corresponding author.
*E-mail addresses:* zahedhos@buffalo.edu (Z. Hossain), qingxia@buffalo.edu (Q. Xia), jmjornet@buffalo.edu (J.M. Jornet).

https://doi.org/10.1016/j.simpa.2019.100004
Received 22 June 2019; Received in revised form 12 July 2019; Accepted 15 July 2019

thoroughly validated the functionalities of the models by comparing the simulation outputs to the analytical and numerical results available in the literature.

TeraSim is built as an extension for *ns-3*, and available to the community under the GNU General Public License. More specifically, TeraSim is compatible with the existing models in *ns-3*, including protocols at the network, transport and application layers as well as traffic and mobility modules, and it facilitates the analysis of the performance of existing protocols at the higher layers, when built on top of the THz channel and physical and link layers.

## 2. Impact

TeraSim is the first comprehensive network simulation platform tailored to THz communication networks. As such, it captures the peculiarities of the THz-band channel, namely, the impact of molecular absorption in the propagation of broadband signals, as well as, the capabilities of THz devices, including high-speed rotating directional antennas as well as energy harvesting systems for THz devices.

TeraSim provides the starting point for researchers willing to develop and test new networking protocols for THz networks. Thus, the teams involved in the standardization group, i.e., IEEE 802.15 TAG THz, as well as other networking/protocol stock design groups in industry and in academia can easily access TeraSim and develop and test their own protocols on top it. In light of the simulation results, the THz networking community can provide feedback or an ideal list of capabilities to the THz device community and influence the development of the supporting hardware, as opposed to waiting for the hardware to be ready, and then make the best protocols for it. This is supposed to lead to optimal solutions.

TeraSim has enabled the Ultra-broadband Nano Communication and Networking (UB Nano) group to develop, test and refine new Medium Access Control (MAC) and routing protocols for THz communication networks. More specifically, TeraSim has been tested and validated [5] by comparing the values of different outputs generated by TeraSim simulations with those produced by analytical models. These include the path loss, channel behavior, received power, directional antenna gain and MAC protocol performances of both the CSMA/CA based MAC protocol and the new receiver-initiated 1-way handshake protocol [8]. By setting customer-defined parameters, e.g., time slot duration, packet generation rate and nodes distribution density, the users can effectively obtain the system performance, e.g., throughput and packet discarding probability through TeraSim simulations. This helps the users to easily evaluate and refine their protocol design.

Other than the link layer design, TeraSim is also used to develop and test new solutions for some ongoing projects such as expedited neighbor discovery algorithms, multi-hop relaying strategies, buffer-limited routing protocol for directional THz communication networks, and so forth.

TeraSim has been contributed to the ns-3 community and will be submitted to the ns-3 app store shortly. By sharing the platform to the nascent THz networking community, it is expected that TeraSim can help more groups with their projects and, thus, accelerate the development of the field at a much faster pace. The publications enabled by TeraSim includes [5,8].

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgments

This work was supported in part by the U.S. National Science Foundation (NSF) under Grant No. CNS-1846268 and the Air Force Research Laboratory (AFRL), USA under Grant FA8750-19-1-0502.

## References

[1] J. Federici, L. Moeller, Review of terahertz and subterahertz wireless communications, J. Appl. Phys. 107 (11) (2010) 111101.

[2] H.-J. Song, T. Nagatsuma, Present and future of terahertz communications, IEEE Trans. Terahertz Sci. Technol. 1 (1) (2011) 256–263.

[3] I.F. Akyildiz, J.M. Jornet, C. Han, Terahertz band: Next frontier for wireless communications, Phys. Commun. J. 12 (2014) 16–32.

[4] T. Kurner, S. Priebe, Towards THz communications-status in research, standardization and regulation, J. Infrared Millim. Terahertz Waves 35 (1) (2014) 53–62.

[5] Z. Hossain, Q. Xia, J.M. Jornet, TeraSim: An ns-3 extension to simulate terahertz-band communication networks, Nano Commun. Netw. J. 17 (2018) 36–44.

[6] J.M. Jornet, I.F. Akyildiz, Channel modeling and capacity analysis of electromagnetic wireless nanonetworks in the terahertz band, IEEE Trans. Wireless Commun. 10 (10) (2011) 3211–3221.

[7] J.M. Jornet, I.F. Akyildiz, Femtosecond-long pulse-based modulation for terahertz band communication in nanonetworks, IEEE Trans. Commun. 62 (5) (2014) 1742–1754.

[8] Q. Xia, Z. Hossain, M. Medley, J.M. Jornet, A link-layer synchronization and medium access control protocol for terahertz-band communication networks, in: 2015 IEEE Global Communications Conference, GLOBECOM, San Diego, CA, 2015, pp. 1–7.