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Background Traffic Simulator - The Tool for WLAN Background Traffic Generation in ns-3 Environment

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***Abstract*—In the paper, the BTS (Background Traffic Simulator) tool is proposed to capture network traffic and then reproduce it in a simulations using the ns-3 simulator extension module. This new method of generating background traffic allows for repetitive testing of simulation scenarios under real network conditions. The authors described the differences between the previously available methods and the proposed solution. The operation of all the most important elements of the proposed tool has been described. The influence of the generated background traffic on the simulation scenario was presented as well as the results of the operation.**

***Keywords*—background traffic, ns-3, simulator, traffic generation, WLAN**

I. INTRODUCTION

The paper presents a new method of traffic generation in ns-3 simulator [1] and examples of its use. The proposed BTS tool is particularly important in scenarios that reflect real network environment. It allows to reproduce in simulations the conditions of a typical radio channel. The purpose of such mapping may be to study the influence of external conditions on the analysed radio technology. The tool consists of two modules, the first is used to record traffic in the wireless environment over a specific time period, and the second is to represent wireless conditions in the simulation. Additional functionality of the first module is the possibility to transform the existing records in PCAP format into a form compatible with the simulation environment. This functionality makes it possible to check how emerging technologies work in some environments when the specific radio conditions cannot be reproduced. An essential aspect of the described tool is the possibility of repeating the experiment numerous times in the same analysed environment.

The work consists of five chapters. The second chapter provides an overview of the related literature. The third chapter presents the principles of operation of both modules. This chapter describes how ns-3 was modified to extend its capabilities. One of the most crucial aspect is the problem of capturing the wireless traffic to reproduce real radio conditions in the simulation. This part of the work also covers the procedure of using the sniffer module. The fourth chapter presents the results of the developed solution in simulation scenarios. Pros and cons of described extension compared to previous methods are also presented in this section. Moreover, the difference between modeling of traffic in ns-3 and using copies of WLAN traffic is explained. The last chapter summarizes the paper and presents conclusions.

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II. RELATED WORKS

Generating traffic in the simulator is an essential aspect from the point of view of the research related to the analysis of dense networks. Voicu et al. [2] modeled the cooperation between Wi-Fi and cellular networks in the ns-3 simulator. The results were presented for both technologies operating in the 5 GHz band, using the methods of generating traffic in the simulator. The authors in [3] also used traffic generation for research on the cooperation of various technologies in the same frequency band, however, the tool used to saturate the Wi-Fi and LTE transmission channels was the iperf application [4]. Performance analysis of Wi-Fi and LTE-U networks cooperating in the same area was also conducted in [5]. The model was prepared using numerical methods without any real traffic input.

Another method for generating traffic in ns-3 is a TAP interface which allows the real machine to participate in the simulation. In this way, the Internet traffic from the simulation can be transferred to the physical machine and in the opposite direction. This solution introduces traffic to the simulated device at the second OSI/ISO layer. After that, traffic can be transmitted using simulated wireless networks and thus according to the parameters given in the specific simulation. The TAP interface could be used to prototype and emulate complex network infrastructure. The wide applications of the TAP interface are described in [6]. That expands possibilities to investigate network traffic similar to a real wireless environment, reducing the need to use real devices. Communication between the client and server via emulated network was presented in [7]. The devices connected through the virtual environment used the TAP interface of the ns-3 simulator. In [8], authors demonstrated the impact on network performance using background traffic in simulations for communication between client and server using

TAP interfaces. An increasing number of nodes in simulated environments influences throughput and availability measured using the time of connections and average request and response time. More wireless connections in the background reduce the performance of the emulated network.

Sometimes to meet research needs developing new modules or extensions for the ns-3 simulator is obligatory. For example, the replacement of the standard RF channel in ns-3 by the Visible Light Communication module allowed researchers to evaluate that technology in a simulator [9]. In this case, ns-3 extensions allow verification of techniques previously unsupported. On the other hand, some ns-3 modules need to be more accurate or extended, i.e. the building model can only simulate simple structures. In [10], authors improved the ns-3 building model. The proposed extension allows building models to be closer to real structures.

The ns-3 is a powerful tool with many options and is able to represent wireless communication close to the real one [11]. There are many components and parameters to define channel [12]. So, reproducing the natural conditions is a complex process that could contain many steps and iterations to prepare a good-working simulation scenario.

III. BTS TOOL

The BTS tool proposed in the article consists of two main components. The first is a sniffer, which provides real data for simulating wireless local area network traffic. The second is a module that extends the ns-3 simulator with the functionality of simulating real traffic based on data collected by the first component. Data for performing the simulations can be obtained directly by capturing the network traffic or based on previously collected traffic data traces.

A. Sniffer

The WLAN traffic capturing module called BTS sniffer, records traffic in radio channel for later reproduction in a simulation. It allows to transfer the real environmental conditions to the simulation environment. It supports IEEE 802.11 standard following the used physical interface [13]. The traffic capturing can be performed in a technique appropriate to the network interface card. The physical wireless interface which supports monitor mode is required. The sniffer listens and records the traffic on the channel selected by the user. The module automatically switches the selected network card to the monitor mode and returns to the managed mode after the capture operation finishes. The program performs tasks using the Linux shell. Traffic records were saved using Ubuntu 18.04 LTS.

The module can perform tasks in two modes:

- live - where real-time events are processed,
- offline - where data from previously recorded PCAP files are processed.

Each mode converts the input data into a CSV (Comma-Separated Values) file in a format suitable for the ns-3 simulator extension module. The layout of the input file consists of nine columns:

1) id - frame number,
2) timestamp - in EPOCH format with precision to microseconds,
3) type - frame type,
4) subtype - frame subtype,
5) dbm - received signal strength,
6) size - frame size in bytes,
7) l4proto - layer four protocol,
8) frequency - the frequency on which the frame was received in megahertz,
9) rate - transmission rate.

Capturing in the "live" mode requires the mode name to be specified as the value of the "mode" parameter. In addition, it is also necessary to provide the system name of the used interface (value of the "dev" parameter). The remaining options are used to specify recording details; the channel on which the network card will listen (value of the "ch" parameter), the recording time in seconds (value of the "dur" parameter), and the name of the output file (value of the "ofile" parameter"). In case of the output file, if a file with the given name exists in the system, its contents will be overwritten. "Live" mode operation requires the "root" user privileges.

Data conversion from PCAP to the accepted CSV file format requires the mode be specified as "offline" (value of the "mode" parameter). The remaining mandatory parameters are "ifile", which takes the path to the input file, and "ofile", which takes the path to the file resulting from the conversion. The other input parameters are listed below:

- "dur" (duration) defines the time interval between the first registered frame and record with an assigned timestamp equal to or lower than the sum of the first packet's timestamp and value of the dur parameter. Every data included in that range will be processed by the BTS tool,
- "start" defines the frame timestamp value from which to start the conversion of the recorded traffic. In case this value does not match the tag of any frame in the input file, the transformation will start from the smallest timestamp greater than the value passed to the program,
- "stop" takes the timestamp value corresponding to the last processed frame in the PCAP file. If there is no frame with the given timestamp in the file, the last entry processed will be the last frame with the timestamp value less than the given value.

In order to run the traffic capturing program, it is required that the recording computer has the Python 3.8.10 interpreter with the Scapy 2.4.5 library installed. The only hardware requirement is a network interface supporting the monitor mode.

This module allows the extraction of critical data from the recorded traffic in order to recreate the actual radio channel load in the simulation environment. It is essential to limit the traffic features to a minimum in order to make optimum use of the simulator's capabilities, while maintaining a saturation level of the network close to the real one. The parameters extracted and saved in the output file have been selected so that the simulator could represent an environment similar to the real one. The usage of commonly used PCAP files allows reproduction of the saved traffic, captured in any place and any time, in the simulation. The possibility of recording in real-time could be used in various conditions, for example, recording wireless traffic using a mobile station.

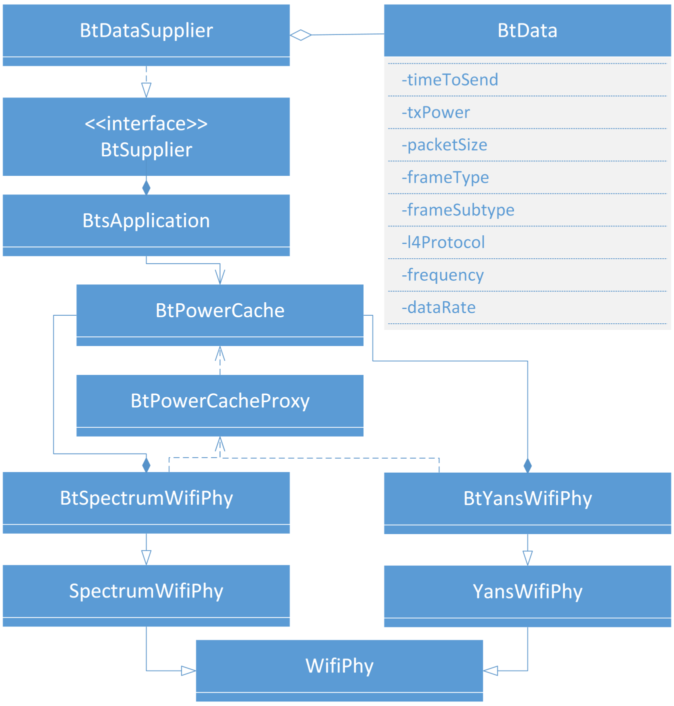

Fig. 1. UML diagram of main modules of BTS extension for ns-3 simulator.

B. *BTS extension of ns-3 simulator*

The BTS tool enables recreation of events observed in real wireless traffic in the ns-3 simulation environment. It makes it easier to study the impact of new or as yet unavailable technologies on the existing system and vice versa. The software is an extension of the ns-3 simulator version 3.35. The introduced modifications were implemented in such a way as to avoid inconsistencies with the previously developed ns-3 scenarios and subsequent versions of the simulator. In order to enable the transfer of collected information about the transmitted data power, a modification of the physical layer was required. The extension includes both available implementations of the first layer of the OSI/ISO WLAN model: Yans and Spectrum.

During the work on the BTS tool, it was decided to implement the solution by reading data from a previously prepared file instead of transferring the data received on the wireless network interface directly to the simulator via the TAP interface. The decision took into account the performance limitations of the ns-3 event simulator. Real traffic can be transferred on an ongoing basis only when the simulated scenario time is equal to or faster than the real-time. However, this method is unable to reproduce real radio conditions. Moreover, without capturing the traffic or using a known traffic source, the traffic is not reproducible either. Repeated reproduction of events in the simulation using a pre-configured traffic source, results in non-ideal real conditions being controlled and therefore does not reflect the wireless environment.

From the implementation point of view, three crucial sets of elements included in the BTS tool can be distinguished. They are: a source of information about traffic, a modified physical layer that allows manipulation of data related to traffic in the radio channel, and a connecting element between the application layer and the physical layer. A detailed representation of the module, including important classes, is shown in Figure 1. The BtSupplier interface defines the access to data collected by the sniffer software for the BtsApplication class. Based on the description of the collected real events represented by the BtData class, it is possible to generate events further in the simulator. The BtPowerCache class is responsible for passing information about the event's parameters based on its identifier to the classes representing the physical layer. Finally, the extended physical layer classes use the BtPowerCacheProxy class to handle the event properly. The modular structure and the use of interfaces between the layers allow for efficient implementation of the BTS solution for the purposes of simulating other wireless standards.

IV. Real wireless traffic simulation in ns-3

The advantage of the BTS tool, apart from transferring the real traffic intensity characteristics to the simulation, is the simultaneous provision of additional metadata describing the recorded events. The result is a more natural intensity characteristic depending on the distance from the simulated source of generated traffic.

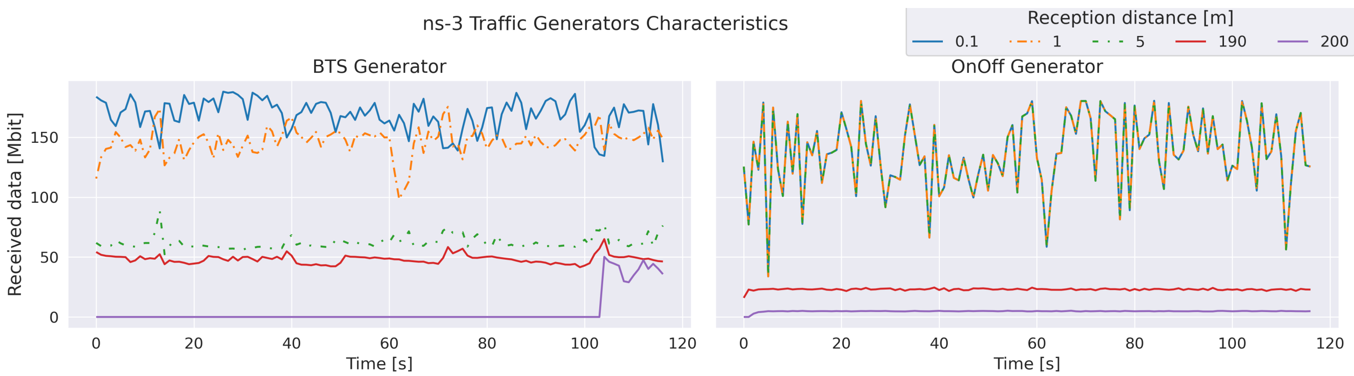

Fig. 2. Characteristics of traffic generators in the ns-3 simulation.

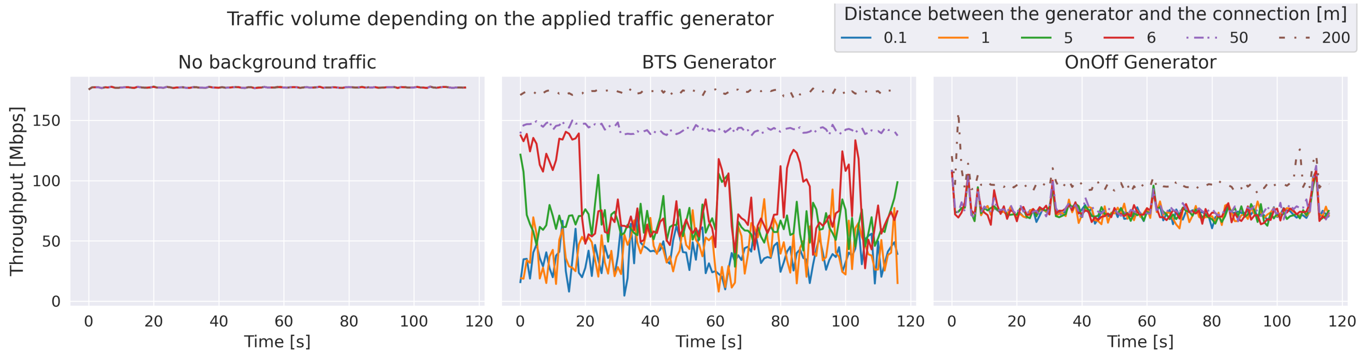

Fig. 3. Connection throughput depending on the background traffic generator used.

A. Variable reception

The phenomenon of varying volume of received data depending on the distance from the traffic source is presented in Figure 2. For the needs of the BTS generator, traffic was captured in a test room. Three computers with the iperf 3 application turned on in server mode were wired to the router [4]. Each of the computers was also connected with its own client wirelessly. The wireless communication was provided within a single network. A Wi-Fi network based on the IEEE 802.11ax standard was used, operating in the 2.4 GHz frequency band [14], [15], [16]. The access point was in the center of the room, and the computer with the network traffic recording module turned on was between the second and third stations working in client mode. Each network card in the computers used was equipped with three antennas, and the access point used had eight antennas. In order to obtain the above results, a test scenario was prepared using the YANS model [17]. The network devices were modeled based on the previously used physical devices. For comparison, the On-Off type traffic generator was selected in the configuration of 200 Mbps of the offered load, and the active and inactivity time parameters as variables from the homogeneous distribution appropriately in the range of [0; 1] and [0; 0.5].

B. Impact on the transmission

In order to present the impact of the application of the background traffic generation method on the simulated wireless network, the previous scenario was extended with an additional pair of nodes, an access point, and a station forming the test network. The pair of nodes was configured similarly to the previously discussed physical devices and placed at a distance of 5 m from each other concerning the y-axis. The traffic of constant intensity was modeled in the network. The successive distances of the test network in relation to the background traffic generator on the x-axis and the impact of this distance on the traffic capacity in the test network are shown in Figure 3. The comparison perfectly reflects the differences in the intensity characteristics depending on the distance from the simulated source of generated traffic, caused by different power levels of recorded frames, as opposed to the standard OnOff generator traffic profile. In the case of the scenario with the BTS generator, the instantaneous performance of the network shows much lower stability for short distances. However, for much larger distances, it allows us to obtain the throughput limit from the control scenario.

It is possible to model such a diversified traffic using the existing ns-3 simulator tools. However, in most cases, to reach a similar level of reproduction of the traffic it will be associated with substantially more work compared to the BTS solution.

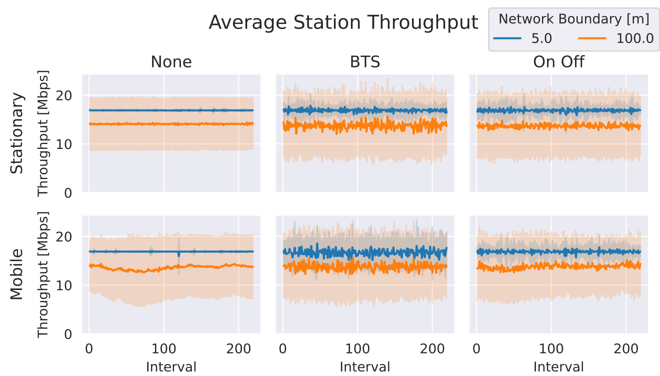

Fig. 4. Average station throughput in the 5 node network under various configurations. Stations' mobility, type of background traffic, and station location restriction are parameterised. The translucent bands represent the standard deviation of the collected data.

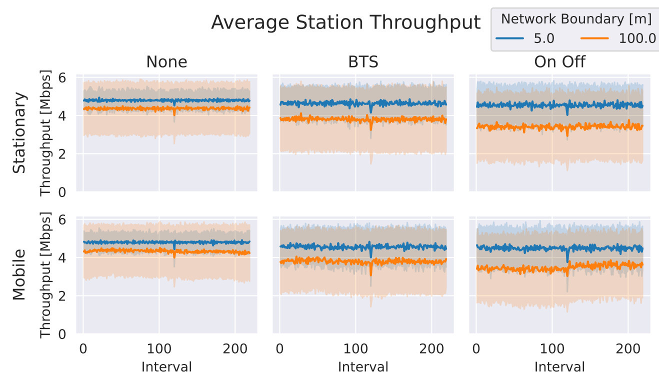

Fig. 5. Average station throughput in the 15 node network under various configurations. Stations' mobility, type of background traffic, and station location restriction are parameterised. The translucent bands represent the standard deviation of the collected data.

C. Impact on the network

As a subsequent step, the impact of the real wireless traffic on the simulated network was studied. The previous analysed configuration was adjusted. The extended variation of the recorded wireless traffic was used as a BTS background traffic source. The On-Off type background traffic generator was selected in the configuration of 100 Mbps of offered load, and the active and inactivity time parameters as variables from the homogeneous distribution in the range of [0; 0.9] and [0; 0.2] accordingly. The two-node connection was replaced by the 5- and 15-node test network. The test network AP was placed randomly inside a disc of 2 m in radius; the background traffic source was placed at the centre of this disc. The test stations were placed similarly, but the disc radius was 5 m or 100 m, depending on the studied scenario. Furthermore, the stations were either stationary or mobile. In the latter case, their mobility model was set to RandomWalk2dMobilityModel; the speed parameter ranged from 0.5 to 2 m/s, and the bound was declared as a square with a side equal to the diameter of the placement disc. During simulations, instantaneous throughput was measured in 1-second intervals.

The average station throughput results for 5- and 15-node networks configuration are presented in Figure 4 and Figure 5, respectively. In terms of this particular performance metric, the difference in the background traffic generator used is not apparent. However, the distinction becomes more evident when the average throughput of the test network is analysed. As shown in Figure 6, the configurations with BTS background traffic influence the traffic characteristics of the test network differently.

For close proximities, the differences are not significant. This aspect can be observed during an analysis of the average throughput of networks - Figure 6. The application of the recorded background traffic in the scenarios with a 5 m boundary does not influence the test network in a new way. The On-Off generator has similar impact. This outcome is associated with the BTS input data. The power-related metadata for the recorded events are not leveraged here. Overall, the On-Off generator is a valid option for generating generic traffic that is comparable to real-world traffic recordings.

However, the BTS produces more variation in the collected results for distances between nodes that are better suited for the recorded traffic (the 100 m boundary scenarios in Figure 6). The standard deviations of the acquired test network results are higher for BTS compared to On-Off traffic.

In order to further demonstrate the performance of the BTS generator, additional metrics were devised to depict the state of the test network. The first metric illustrates the ratio of network utilisation by the top n best-performing stations to the total capacity of the test network. For configurations with 5 nodes, the metric presents the ratio for the single best station, and in scenarios with 15 nodes for the top 3 stations - Figure 7. In the case of an equal distribution of resources between stations, the metric should indicate approximately 0.2. The second metric represents the number of stations with a throughput below the

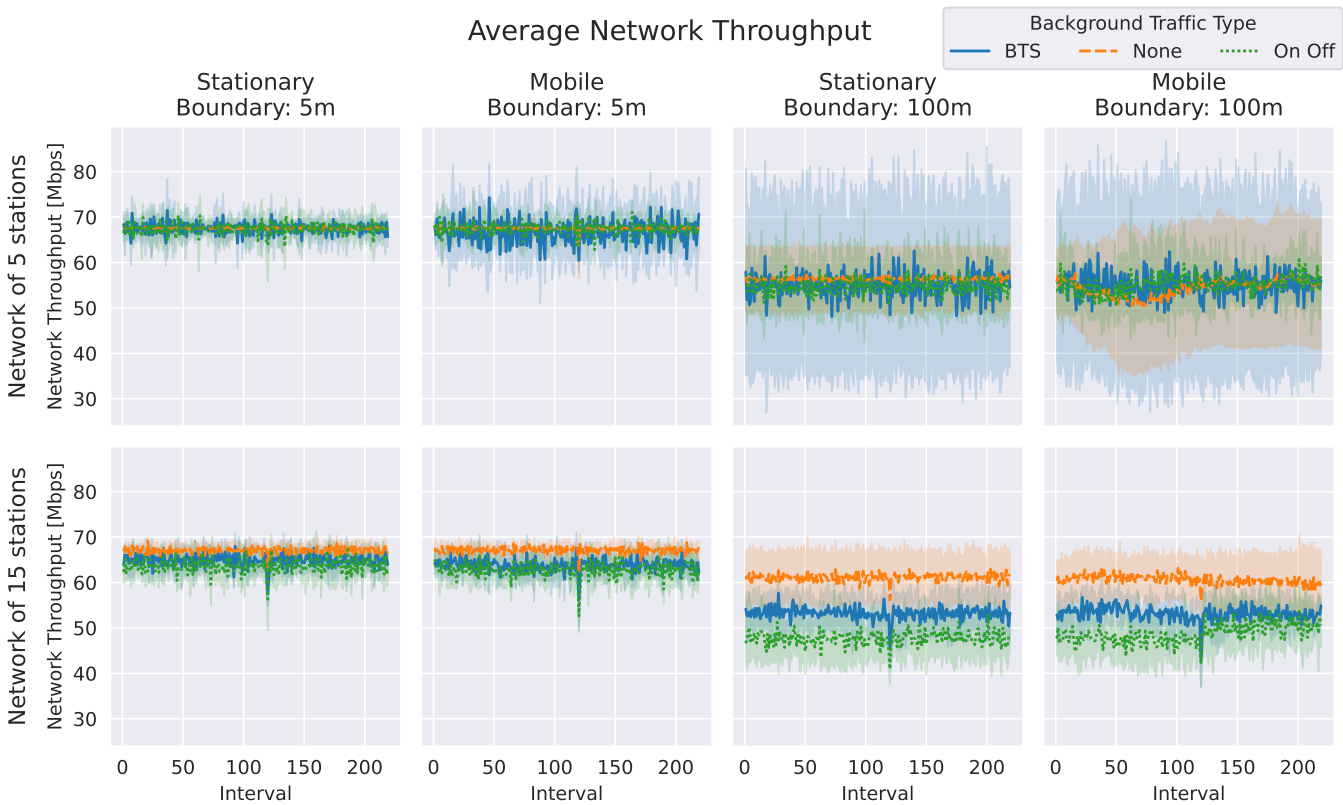

Fig. 6. Average network throughput under various configurations. Stations' mobility, type of background traffic, network size, and station location restriction are parameterised. The translucent bands represent the standard deviation of the collected data.

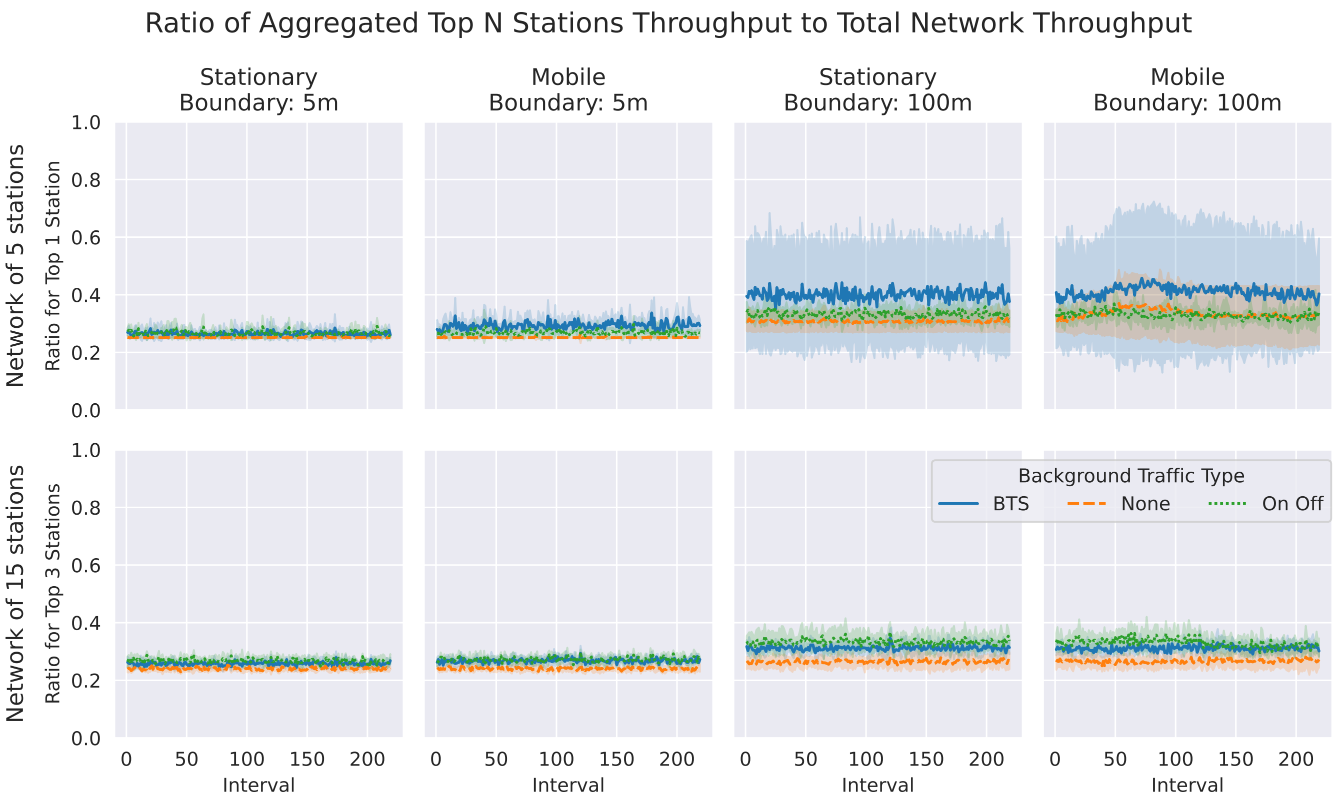

Fig. 7. The ratio of aggregated throughput of top N stations to total network throughput over time. Stations' mobility, type of background traffic, network size, and station location restriction are parameterised. The translucent bands represent the standard deviation of the collected data.

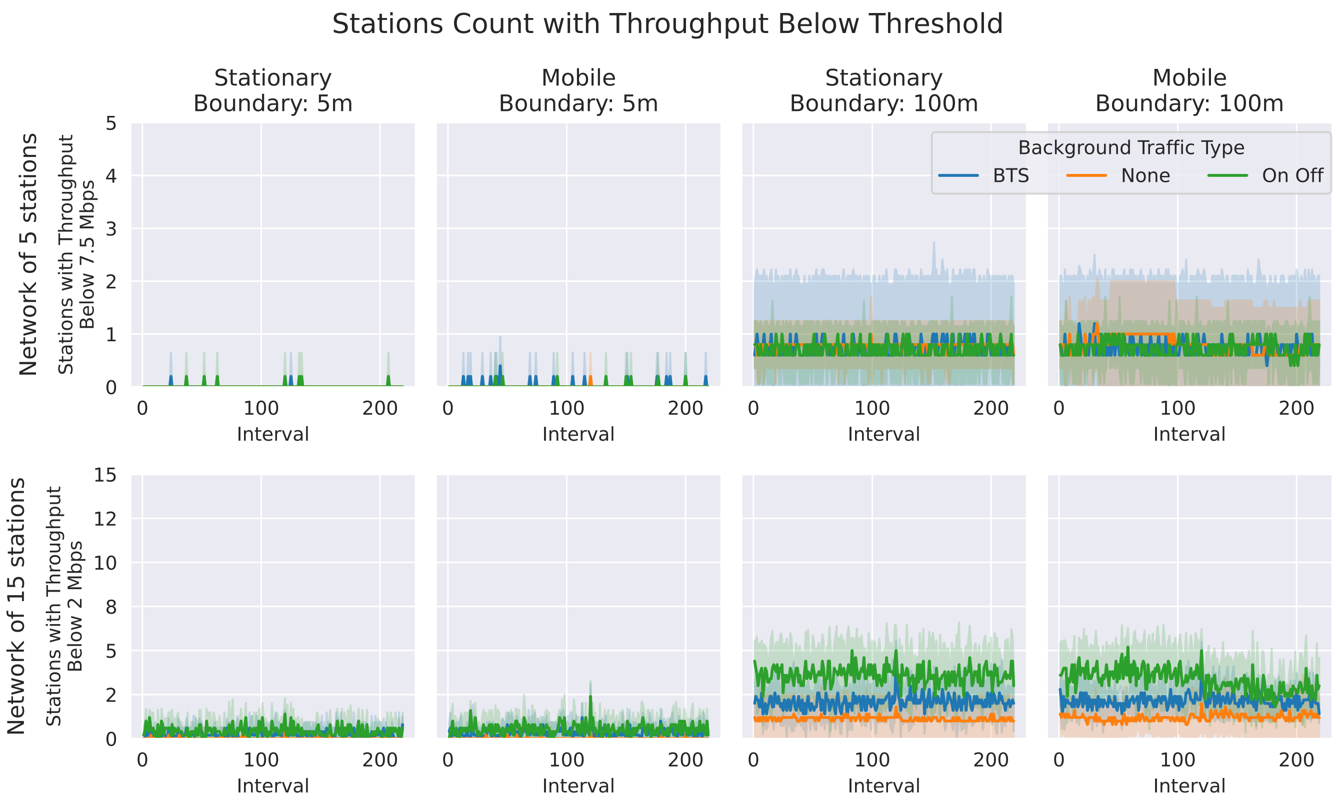

Fig. 8. Number of stations with throughput below the threshold over time. Stations' mobility, type of background traffic, network size, and station location restriction are parameterised. The translucent bands represent the standard deviation of the collected data.

specified one. Half of the average node throughput in a given test network was set as the threshold value. The results are shown in Figure 8.

V. Conclusions

The proposed tool allows to transfer the environmental conditions to the simulation space and to analyse the operation of known and new methods in a defined environment. It introduces a new method of generating traffic, extending the capabilities of the well known and accepted by the scientific community ns-3 simulator with the functionality of generating traffic in accordance with the environment in which it is tested. This allows for testing new solutions for frequency band sharing by various technologies, as well as to anticipate problems with the implementation of subsequent wireless communication methods in a place where other systems are already operating. So far, this required advanced traffic modeling in simulation scenarios or the use of controlled methods of network infrastructure load, such as applications for transmitting fictitious data. The BTS tool simplifies this process and allows for repeating test scenarios many times in real, previously recorded conditions. Moreover, it does not exclude the use of already available traffic recordings in PCAP format.

References

[1] Nsnam, "ns-3 network simulator," date accessed: October 27, 2022. [Online]. Available: https://www.nsnam.org/

[2] A. M. Voicu, L. Simić, and M. Petrova, "Modelling broadband wireless technology coexistence in the unlicensed bands," in *2021 IEEE 22nd International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM)*, 2021, pp. 129–138, https://doi.org/10.1109/WoWMoM51794.2021.00026.

[3] N. Makris, A. D. Samaras, V. Passas, T. Korakis, and L. Tassiulas, "Measuring lte and wifi coexistence in unlicensed spectrum," in *2017 European Conference on Networks and Communications (EuCNC)*, 2017, pp. 1–6, https://doi.org/10.1109/EuCNC.2017.7980769.

[4] "iperf - the ultimate speed test tool for tcp, udp and sctp." date accessed: October 27, 2022. [Online]. Available: https://iperf.fr/

[5] Z.-J. Xu, Z.-H. Wu, F.-N. Chen, and Y. Gong, "Analyzing the wifi access probability in lte-u/wifi coexistence networks," in *2017 IEEE Globecom Workshops (GC Wkshps)*, 2017, pp. 1–5, https://doi.org/10.1109/GLOCOMW.2017.8269053.

[6] H. Fontes, R. Campos, and M. Ricardo, "Improving ns-3 emulation support in real-world networking scenarios," *EAI Endorsed Transactions on Industrial Networks and Intelligent Systems*, vol. 3, no. 9, 8 2015, https://doi.org/10.4108/eai.24-8-2015.2261074.

[7] A. Alvarez Gonzalez, R. Orea, S. Cabrero, X. García Pañeda, R. Garcia, and D. Melendi, "Limitations of network emulation with single-machine and distributed ns-3," *Proc. 3rd int'L. ICST Conf. Simulation Tools and Techniques*, p. 67, 03 2010, https://doi.org/10.4108/ICST.SIMUTOOLS2010.8630.

[8] A. Sahu, A. Goulart, and K. Butler-Purry, "Modeling ami network for real-time simulation in ns-3," in *2016 Principles, Systems and Applications of IP Telecommunications (IPTComm)*, 2016, pp. 1–8, https://doi.org/10.1109/IPTComm39427.2016.7780248.

[9] S. M. Sheikh, H. M. Asif, K. Raahemifar, and F. Al-Turjman, "Time difference of arrival based indoor positioning system using visible light communication," *IEEE Access*, vol. 9, pp. 52 113–52 124, 2021, https://doi.org/10.1109/ACCESS.2021.3069793.

[10] P. D. Bugarcic, N. J. Jevtic, and M. Z. Malnar, "An extension of building model for indoor communication in ns-3 simulator," in *2021 29th Telecommunications Forum (TELFOR)*, 2021, pp. 1–4, https://doi.org/10.1109/TELFOR52709.2021.9653272.

[11] M. Raj, N. Chacko, J. major, and S. David, "A comprehensive overview on different network simulators," *International Journal of Engineering and Technology*, vol. 5, pp. 325–332, 02 2013.

[12] M. Rudenkova, "A methodology of modeling the ieee 802.11 wireless lan using ns-3," in *2020 V International Conference on Information Technologies in Engineering Education (Inforino)*, 2020, pp. 1–4, https://doi.org/10.1109/Inforino48376.2020.9111782.

[13] "Ieee standard for information technology–telecommunications and information exchange between systems - local and metropolitan area networks–specific requirements - part 11: Wireless lan medium access control (mac) and physical layer (phy) specifications," *IEEE Std 802.11-2020 (Revision of IEEE Std 802.11-2016)*, pp. 1–4379, 2021, https://doi.org/10.1109/IEEESTD.2021.9363693.

[14] "Ieee standard for information technology–telecommunications and information exchange between systems local and metropolitan area networks–specific requirements part 11: Wireless lan medium access control (mac) and physical layer (phy) specifications amendment 1: Enhancements for high-efficiency wlan," *IEEE Std 802.11ax-2021 (Amendment to IEEE Std 802.11-2020)*, pp. 1–767, 2021, https://doi.org/10.1109/IEEESTD.2021.9442429.

[15] E. Khorov, A. Kiryanov, A. Lyakhov, and G. Bianchi, "A tutorial on ieee 802.11ax high efficiency wlans," *IEEE Communications Surveys & Tutorials*, vol. 21, no. 1, pp. 197–216, 2019, https://doi.org/10.1109/COMST.2018.2871099.

[16] M. S. Marek Natkaniec, Łukasz Prasnal, "A simulation analysis of ieee 802.11ax networks," *Przegląd Telekomunikacyjny + Wiadomości Telekomunikacyjne 6: 415 - 419*, 2019, https://doi.org/10.15.199/59.2019.6.63.

[17] M. Lacage and T. Henderson, "Yet another network simulator," *Proceeding from the 2006 Workshop on Ns-2: The IP Network Simulator*, 10 2006, https://doi.org/10.1145/1190455.1190467.