РЕЗЮМЕТА
НА НАУЧНИТЕ ТРУДОВЕ

на гл. ас. д-р инж. Айдън Мехмед Хъкъ
за участие в конкурс за заемане на академичната длъжност: ДОЦЕНТ
в област на висше образование
5. Технически науки
по професионално направление
5.3 „Комуникационна и компютърна техника”
учебна дисциплина „Основи на компютърните комуникации“
към катедра „Компютърни науки и технологии“
Факултет по изчислителна техника и автоматизация
обявен от Технически университет – Варна,
ДВ, брой 2 от 05.01.2024г.
.

Резюметата на научните трудове са организирани в раздели както следва:

	Трудове за участие в конкурса за „Доцент“	**брой**
В.4	**Публикации равностойни на монографичен труд на тема „Методи и средства за подобряване качеството на обслужване при безжични сензорни технологии за IoT”**	**19**
Г	**Публикации извън групата на монографичния труд**	**24**
Г.7.	Публикации в реферирани и индексирани в световноизвестни бази данни с научна информация	6
Г.8.	Публикации в нереферирани списания с научно рецензиране	18

В.4 Публикации равностойни на монографичен труд на тема „Методи и средства за подобряване качеството на обслужване при безжични сензорни технологии за IoT"

B.4.1. Vasilev, R., **Haka, A.** Enhanced Simulation Framework for Realisation of Mobility in 6LoWPAN Wireless Sensor Networks. //Proceedings, 28th International Scientific Conference Electronics, ET 2019, 12-14 Sept. 2019, Sozopol, Bulgaria, Electronic ISBN: 978-1-7281-2574-9, Print on Demand(PoD) ISBN: 978-1-7281-2575-6, DOI: 10.1109/ET.2019.8878669

This paper proposes an improvement of the 6LoWPAN simulation product, expressed in the ability of end sensor micro-mobility simulation in a 6LoWPAN domain, also an improvement of the proposed traffic prioritisation algorithm for 6LoWPAN sensor networks.

Mobility is a change of the master device (Coordinator, 6LoWPAN Edge Router) which the Mobile Sensor Node (MSN) is connected to. In wireless sensor networks (WSN) this change can be caused by a variety of reasons - physical movements, environment changes, router failures, network characteristics (Delay, Packet Loss, Low Signal), etc. According to network topology and WSN applications, two types of mobility can be realised – micro-mobility and macro-mobility.

The proposed improvement of the simulation product is expressed in the possibility of simulating micro-mobility of end sensor nodes in a 6LoWPAN domain, as well as improvement of the traffic prioritisation proposal in 6LoWPAN sensor networks. Based on the added functionality to the simulator, which is expressed in performing mobility of end mobile sensor nodes, additional prioritisation parameters - movement and speed - are added to the proposed algorithm.

The improvements in the simulator consist of a new function, which includes a speed of movement and a direction for mobile end devices to be selected. The direction should be within the scope of the AP (Coordinator) and these are in a single 6LoWPAN domain. This allows the implementation of a mobility mechanism in the proposed simulation product. For each end device, a direction from its coordinator should be selected, which together with the distance to it, gives more accurate results for the mobility. Prior to the realisation of mobility, a network of 6LoWPAN coordinators working in one domain should be created. Links are built between the coordinators, setting a distance to and a direction of the adjacent coordinator. A minimum of 30% overlap is calculated. Finally, the end nodes are added, setting their direction from the coordinator and speed. This allows MSN's mobility simulation. Before the mobility is carried out, the traffic in the network is prioritised according to the implemented algorithm.

The proposed simulation product allows outputting statistical information about the mobility for both coordinators and MSNs.

B.4.2. **Haka, A.**, Aleksieva, V., Valchanov, H. Comparative Analysis of Traffic Prioritisation Algorithms in 6LOWPAN Networks. //2020 21st International Symposium on Electrical Apparatus & Technologies (SIELA), Bourgas, Bulgaria, 2020, pp. 1-4, doi: 10.1109/SIELA49118.2020.9167116, Electronic ISBN: 978-1-7281-4346-0, USB ISBN: 978-1-7281-4345-3, Print on Demand(PoD) ISBN: 978-1-7281-4347-7, DOI: 10.1109/SIELA49118.2020.9167147

This paper introduces a comprehensive comparative analysis between the suggested 6LoWPAN sensor network traffic prioritisation algorithm by the authors and five standard sensor network algorithms. There are two main classes of traffic prioritisation algorithms for sensor networks: Knowledge Free and Knowledge Based.
In the author's algorithm, according to the prioritisation initially, the highest priority scheduled requests containing Emergent Dispatch Header. This header identifies the packet as emergency. In the case of multiple Emergent Dispatch Header packages or ordinary packages, the requests from mobile devices served with high priority. When many movable devices available their requests prioritised, using their movement speed. With higher priority served requests from faster moving devices. In the presence of multiple mobile devices moving at the same speed, the next criterion on which the requests prioritised is the distance of the sensor to the coordinator. For this purpose, the principle of the Knowledge Based, Least Weighted Farthest Number Distance Product First mechanism used. Higher priority has the packets sent by the sensors closest to the coordinator. When at the equal distance to coordinator has many sensors, the requisitions prioritised using the sensor's type of application. With the highest priority served, the Healthcare applications and then Security and surveillance, Environmental monitoring, Animal tracking, Vehicle tracking, Agriculture and Smart Buildings.
The authors create a simulator, which used for investigation influence of the proposed and standard sensor network, traffic prioritisation algorithms on QoS.
The comprehensive comparative analysis presented for the proposed by the authors, traffic prioritisation algorithm for 6LoWPAN and five others. For complex comparison of algorithms for traffic prioritisation in 6LoWPAN a system of criteria proposed. Comparison of traffic prioritisation algorithms mainly based on the results of Delay, Throughput, Packet Delivery Ratio and Packet Loss Ratio. This comparison made for a specific type of traffic, for certain end nodes.
The suggested by authors traffic prioritisation algorithm in 6LoWPAN is better than others investigated, according to average arithmetic and average geometric complex estimations.

B.4.3. **Haka, A.**, Aleksieva, V., Valchanov, H. 6LoWPAN Network Analysis Using Simulations and Experiments. //IOP Conference Series: Materials Science and Engineering, Volume 1032, INTERNATIONAL SCIENTIFIC CONFERENCE OF COMMUNICATIONS, INFORMATION, ELECTRONIC AND ENERGY SYSTEMS (CIEES), 26-29 November 2020, Online ISSN: 1757-899X, Print ISSN: 1757-8981, https://doi.org/10.1088/1757-899X/1032/1/012015

This paper presents the physical deployment of 6LoWPAN network and the study of throughput and end-to-end delay indicators, which compared with the results obtained through the 6LoWPAN simulation product presented in previous author's research.
The tests for throughput and end-to-end delay from the simulator were obtained after building a 6LoWPAN network by one coordinator and 6 6LoWPAN sensor nodes connected in a star topology. The coordinator configured to work on channel 25. Up to 6 end 6LoWPAN sensor nodes can be connected to the coordinator. All end nodes are static, perform the same type of application and located at the same distance from the coordinator (from 1m to 5m). The tests for reporting the values for throughput and end-to-end delay were made with 2, 4 and 6 sensor nodes connected to the 6LoWPAN coordinator. Once the coordinator and end node information added, a simulation performed to send a certain number of packets. After adding the packets to the send queue, the calculated values for end-to-end delay and throughput displayed.
The results of the conducted experimental studies are in large numbers, so they are summarised and presented in a table. Since the simulation product considers tests in ideal conditions, at different distances the values obtained are identical. The difference in the experiments performed is manifested in relation to the different number of sent packets.
The physical building of the 6LoWPAN network is done with BeagleBone Black – BBB01-SC-505 board with Bone-Debian-9.9 operating system working as 6LoWPAN Gateway, TI transceiver - CC2531EMK and TI multi-standard sensor nodes – CC2650STK. The data transfer and the receipt number of bits from the end sensor nodes in the already built 6LoWPAN network can be tracked, when a second CC2531EMK transceiver configured to work as a 6LoWPAN sniffer. This can be done on a Linux machine using Sensniff program for 6LoWPAN.
The experiments are made with 2,4 and 6 sensors with simulator and with real network in the same conditions. For example, the deviation in the simulated results with 6 sensors from the real ones for end-to-end delay is average 99% for 5, 10, 15 and 20 sent packets, and for throughput is 98% for 5 packets, 94% for 10 packets, 86% for 15 packets and 79% at 20 packets.
The results of real network tests are variable because the communication between the sensors and the coordinator is influenced by environmental factors such as electromagnetic interference, radio interference, packet transmission errors, other sources operating on the same frequency, interference between sensors, etc.
The obtained trend in the simulation results and real conditions are approaching, which gives reason to allege that the simulation product is suitable for purposes of education.

В.4.4. **Haka, A.**, Aleksieva, V., Valchanov, H. Enhanced Simulation Framework for Visualisation of IEEE 802.15.4 Frame Structure on Beacon Enabled Mode of ZigBee Sensor Network. //2020 International Conference on Biomedical Innovations and Applications (BIA), 24-27 September, 2020, Varna, Bulgaria, Electronic ISBN:978-1-7281-7073-2, pp. 109-112, Print on Demand(PoD) ISBN:978-1-7281-7074-9, DOI: 10.1109/BIA50171.2020.9244507

This paper presents enhancements to the ZigBee network simulation product for IoT proposed by authors in previous research. The main improvements of the simulation software are: ability to calculate values for Received Signal Strength (RSS) and Received Signal Strength Indicator (RSSI); visualising the contents of the IEEE802.15.4 frame in beacon-enabled mode; study of classic algorithms for prioritising traffic in sensor networks; study of parameters affecting QoS such as Packet Delivery Ratio (PDR), Packet Loss Ratio (PLR), Delay and Throughput.

As an improvement to the simulation product for ZigBee network, one Knowledge Free and one Knowledge Based algorithm for prioritising network traffic implemented. Knowledge Free algorithms process requests in the order of their arrival. Such an algorithm for prioritising traffic is First Come First Served (FCFS). Knowledge Based algorithms use either application information, network information, or both to prioritise traffic. The implemented Least Number of Hops First (LNHF) algorithm bases on knowledge of the network information. According to this algorithm, requests from the devices closer to the coordinator are served with high priority.

The construction of a ZigBee network realizes using a graphical user interface, through which the coordinators are created and end sensor nodes added to them. Parameters such as: number of connected end nodes, channel bandwidth, region, frequency, beacon order and superframe order are set for each Personal Area Network (PAN) coordinator. To specify and link the created simulation with the restrictions for a certain region in the world, an option for selecting a certain channel and visualising the operating frequency added.

When the coordinator and end nodes correctly added with the appropriate configuration, the traffic generated by the end nodes in the network prioritised. When prioritising the traffic according to the selected algorithm, the contents of five IEEE 802.15.4 frames filled in.

The results for static nodes from the tests performed show that the LNHF algorithm improves QoS for end nodes, at a distance of up to 7m from the serving device. This will speed up the work, as the interference at these nodes is less, because the signal from the coordinator is better, respectively packet retransmissions will be less.

The results of the tests with mobile nodes for the considered prioritisation algorithms are similar. For the devices moving at medium speed, the allocated resources are few and the values considered deteriorate. This can worsen the QoS for these devices, as the handling of their requests will be delayed, and an additional delay will be caused by the initiation of a handover when the device is out of range of current coordinator.

B.4.5. **Haka, A.**, Aleksieva, V., Valchanov, H., Dinev, D. Analysis of ZigBee Network Using Simulations and Experiments //International Conference “Automatics and Informatics’2020” (ICAI'20), 01-03 October 2020, Varna, Bulgaria, pp. 1-4, Electronic ISBN:978-1-7281-9308-3, Print on Demand(PoD) ISBN:978-1-7281-9309-0, DOI: 10.1109/ICAI50593.2020.9311328.

This paper compares the results for the Received Signal Strength Indicator (RSSI) values from the end sensor nodes obtained by simulating a ZigBee network using the improvements to the simulation product presented in B.4.6. and through a real ZigBee sensor network.
Graphical user interface of simulator allows adding the coordinators and end sensor nodes for construction of a ZigBee network. Once the ZigBee PAN coordinators have been added, the end sensor nodes can be connected to them. The values for RSS and RSSI calculated immediately after setting the sensor distance from the coordinator. The changes for all inserted parameters reflect in the data tables and can check from the "Nodes Table" tab. The simulator calculates automatically the values for RSS and RSSI, based on distance between the added end sensors and PAN coordinator. The calculated values represented by graphs according to node’s distance to PAN or node’s ID.
The tests for RSS and RSSI from the simulator were obtained after building a ZigBee network by one coordinator (ZigBee router) and 6 ZigBee sensor nodes connected in a star topology.
The physical construction of the ZigBee network is done with BeagleBone Black – BBB01-SC-505 board with Bone-Debian-7.8 operating system working as ZigBee Gateway, Texas Instruments (TI) transceiver - CC2531EMK and TI multi-standard sensor nodes – CC2650STK. The ZigBee Gateway configured using TI Z-Stack Linux Gateway. The CC2531EMK board configured to operate as a ZigBee transceiver and sensor nodes to operate in ZigBee network using CC-DEVPACK-DEBUG of TI. The data transfer and the receipt of the RSSI values from the end sensor nodes in the already built ZigBee network can be tracked, when a second CC2531EMK transceiver configured to work as a ZigBee sniffer.
The results for the obtained RSSI values from the constructed ZigBee network are inconsistent in the tests for 2, 4 and 6 sensor nodes. The results of 2 sensors show that with increasing distance from the coordinator the obtained RSSI values deteriorate. This trend is not observed in the tests with 4 and 6 sensor devices. In them, with increasing distance from the coordinator, the obtained RSSI values are identical or better for some of the nodes and worse for others. This is due to the presence of external noise influences and interference between the sensor nodes, which can increase with the number of devices in the network.
The obtained results show that for 2 end devices in the network the values for RSSI obtained through the simulator are almost identical to those for the tests with a real network. The results with 4 and 6 end devices obtained through the simulator are close to those of the real network. The deviation in the RSSI values of the simulator is about 10dB compared to the actual results.

В.4.6. **Haka, A.**, Aleksieva, V., Valchanov, H. Software Tool for Evaluation of Traffic Prioritisation Algorithms in 6LOWPAN Network. //2020 21st International Symposium on Electrical Apparatus & Technologies (SIELA), Bourgas, Bulgaria, 2020, pp. 1-4, doi: 10.1109/SIELA49118.2020.9167147. Electronic ISBN: 978-1-7281-4346-0, USB ISBN: 978-1-7281-4345-3, Print on Demand(PoD) ISBN: 978-1-7281-4347-7, DOI: 10.1109/SIELA49118.2020.9167147

This paper introduces enhancements to the simulation product for 6LoWPAN networks proposed by authors, which enables service quality research. The influence of different algorithms for prioritising traffic on throughput, delay, packet delivery ratio and packet loss ratio considered. The included algorithms in the software tool are proposed by the authors algorithm and classic algorithms for prioritisation: First Come First Served (FCFS), Least Number of Sensors First (LNSF), Least Number of Hops First (LNHF), Least Number Distance Product First (LNDPF), Least Weighted Farthest Number Distance Product First (LWFNDPF). The software tool provides an interface for evaluation of proposed and classic algorithms on sensor networks.

In the proposed simulator the number of sensor nodes operating in a given region can vary up to 100, depending on the size of the area to be covered. Devices in this area may be fully functional or reduced functional. Fully functional devices can work both as coordinators and as end nodes, while those with reduced functionality only work as end devices.

A 6LoWPAN sensor network simulated with one fully functional device that serves the requests of the end devices. The purpose of the research is to determine the effectiveness of the algorithms embedded in the simulator for prioritising traffic and in which situations, for which nodes they improve the QoS.

The results of the proposed prioritisation algorithm show that the values for the studied parameters are better for the static devices closer to the coordinator. Prioritising requests from nodes that are closer to the coordinator in sensor networks is important, because they are networks of multiple devices that transmit data constantly. This causes interference in the communication environment and errors, which initiates the resending of packets. As a result, communication load and delay increases, and degrade the QoS. With fewer devices, requests with highest priority served with more resources - from the nodes located up to 6 meters from the coordinator. This speeds up serving for these nodes, while freeing up resources to use for low-priority devices and offsetting delays. In case of insufficient resources, the requests of the lowest priority devices postponed for service in the next time interval.

The results for the mobile nodes according to the proposed prioritisation algorithm show that the values for the studied parameters are better for the nodes moving at speeds above 3 m/s.

B.4.7. **Haka, A.**, Aleksieva, V., Valchanov, H. Deployment and Analysis of Bluetooth Low Energy Network. //IOP Conference Series: Materials Science and Engineering, Volume 1032, INTERNATIONAL SCIENTIFIC CONFERENCE OF COMMUNICATIONS, INFORMATION, ELECTRONIC AND ENERGY SYSTEMS (CIEES), 26-29 November 2020, Online ISSN: 1757-899X, Print ISSN: 1757-8981, https://doi.org/10.1088/1757-899X/1032/1/012016

This paper presents the deployment of a physical Bluetooth Low Energy (BLE) sensor network for IoT and a study of the RSSI values derived from the end sensor units in the network.

The physical building of the BLE network done with RaspberryPi 4 Model B board with Raspbian operating system working as BLE master device, with built-in BLE transceiver and Texas Instruments multi-standard sensor nodes – CC2650STK.

The star topology by connecting the end sensor nodes and the master one was realised to examination the alteration in RSSI values. Different experiments with 1, 2, 3, 4, 5 and 6 static nodes performed, where for every one the nodes are located at distances from 1m to 10m from the master device. The examination of alterations in the received RSSI values for static sensor nodes located at different distances from the master device and for mobile nodes moving at different speeds done.

For 1 node the results show that as the distance of the sensor from the master device increases, the received RSSI values deteriorate. However the value at 10 meters is significantly better than the previous ones. Although only one device is transmitting on the communication environment which is not loaded, the decline in the previous values may be due to external sources of interference. The trend that at closer distance to the service device the obtained RSSI values are better is confirmed from the other tests with 3, 4, 5 and 6 sensors. The measured values for RSSI decline more and more when the distance from the master device and the end nodes number in the network increase.

Similar experiments were performed with mobile nodes. For the second node it is seen that the RSSI values are considerably lower. This is bred by the load on the communication environment and the emerged interferences. The trend when the sensors moving at a lower speed, the received RSSI values are better is confirmed from the other tests with 3, 4, 5 and 6 sensors.

Experimental results for the RSSI with static sensor nodes show that with increasing distance between the end nodes and the master device, the received values aggravates with considerable changes. Experimental results for the RSSI with mobile sensor nodes show that with increasing the speed of end nodes, the received values aggravate, but the change in the results is smoother.

For both static and mobile nodes sustained the tendency of aggravation of RSSI values with enlarging number of end sensor nodes in the network.

B.4.8. **Haka, A.**, Aleksieva, V., Valchanov, H. ZigBee Simulation Framework for Studying the Formation of a Hierarchical Tree Topology. //2021 International Conference Automatics and Informatics (ICAI), 30 September-02 October 2021, Varna, Bulgaria, pp. 257-260, Electronic ISBN:978-1-6654-2661-9, Print on Demand(PoD) ISBN:978-1-6654-2662-6, DOI: 10.1109/ICAI52893.2021.9639563.

The gradual expansion of Internet of Things (IoT) technologies worldwide allows their implementation in diverse areas of modern life. One of the areas that allow the expansion of the IoT concept is the monitoring of environmental parameters in real time using sensor networks. Among modern sensor network technologies, ZigBee is one of the most common. This technology allows the construction of a Personal Area Network of a coordinator, routers and sensor nodes that consume low power. Extremely low power consumption allows ZigBee devices to be powered by batteries, which allows them to be portable and compact.

One problem with power consumption in the wireless network is the uneven consumption of the nodes. The structure of the network and the location of the nodes may be a prerequisite for some devices to be overused (e.g. a central node in the network is more likely to receive data and participate in a data transmission route). This can lead to potential segmentation and shorten the life of the entire network. To prevent a node from running out of power too quickly, solutions are needed to ensure the energy balance of the nodes in the network.

This paper presents a simulation product of ZigBee network that allows the study of hierarchical tree routing, using the implemented algorithm to construct the energy balanced hierarchical tree network based on priorities.

In the simulation framework has been implemented the algorithm for the formation of tree energy-balanced ZigBee network based on priorities. The ZigBee topology consists of a single coordinator (the tree root), multiple routers (branches) and end devices (leaves). In this algorithm, the pricing method is used to achieve the goal. In the algorithm, it is assumed that the routers serve only to build the topology, and do not function as end devices. Each router and end device has a willingness to pay value - the priority for end devices and an energy level for routers. The coordinator and routers have a charging rate value - a price that must be paid by the end nodes to connect to them. Therefore, the higher the value for willingness to pay, the higher the priority has the end device. With routers, the case is similar, the higher the value of willingness to pay, the more energy there is. When an end device has a higher value for willingness to pay than the charging rate of its candidate parent, it is connected to it by changing its price. In this implementation, to construct the network first the routers connected and then the end devices to them. When the router connects to router or coordinator, the parent's charging rate does not change. In case there is a device with insufficient willingness to pay, it can be connected to the router with the smallest number of children.

The developed simulation framework has a modular architecture in which the system core manages the modules for building and modifying the topology, traffic prioritisation, IEEE 802.15.4 frame visualisation and graphical user interface management. Simulating a ZigBee network requires working through two main windows. One of them for adding parameters for the coordinator and the other for

routers and end nodes in the network. The algorithm implemented in the simulator for the formation of ZigBee tree connectivity and its visual presentation allows easy realisation and analysis of results. Experiments were performed with 2 routers and 8 end devices, 4 routers and 6 end devices, 6 routers and 4 end devices, as well as with 8 routers and 2 end devices.

The realised studies show that, as the number of routers in the ZigBee network increases, the depth in the hierarchy also increase. Conducted experiments show that the implemented algorithm ensures that the routers with more energy will arrange at a lower level in the hierarchical topology (closer to the coordinator). This provides that more devices will be connected to the routers with more energy. This in turn improves the energy efficiency of the network and prolongs its life.

B.4.9. **Haka, A.**, Yordanov, Y., Aleksieva, V., Valchanov, H. Simulation Environment for Bluetooth Low Energy Network. //2021 International Conference Automatics and Informatics (ICAI), 30 September-02 October 2021, Varna, Bulgaria, pp. 287-290, Electronic ISBN:978-1-6654-2661-9, Print on Demand(PoD) ISBN:978-1-6654-2662-6, DOI: 10.1109/ICAI52893.2021.9639521.

Modern technologies and especially connectivity, is supporting more and more areas of everyday life during the social isolation caused by the coronavirus in the last 18 months. One of these aspects is education, which has taken place entirely online. Thanks to the modern 4G and 5G communication infrastructures, it has become possible to conduct classes seamlessly in an online environment, regardless of the location of the teacher and the students. As mobile speeds improve, providers continue to tailor their services to customer needs. One of the newest services offered is broadband Internet of Things (IoT). These services cover different areas and allow the connection of a large number of devices with low complexity, low cost, long battery life and relatively low performance.

One of the most common technologies for IoT is Bluetooth Low Energy (BLE). As one of the most widespread IoT technologies, BLE is a goal for research and learning. The research of the technology can be done by constructing a real network, which will reflect the results reliably. However, simulation products can be used when constructing a real infrastructure is not cost effective. This also applies to learning, during which it is more useful to consider the actual configuration of a network, which will increase the professional experience of students. The actual configuration and construction of a BLE network can be complicated or impossible during online learning. To overcome these issues, a simulation product can be used, which, if open source, does not require financial investment. In addition, the software functionality of the simulation product can be extended, and during online learning it provides a comfortable environment for individual work.

This paper presents a simulation product for BLE network, which can be used both to study the basic functionalities of the technology and during onsite or online learning.

The developed simulator in the Department of Computer Science and Engineering at the Technical University - Varna has a modular architecture. When loading the application, the main functionality of the core is started, which is adding the Master device and realising its program logic for processing the incoming packets and their corresponding

protocol data unit type, as well as waiting for adding a Slave device and monitoring its status (Standby, Advertising or Connected). The core then turns to the Topology Modification and Maintenance module to determine the network topology. Visualisation of topology is performed by the module designed for this (Topology Visualisation). When a change in the state of the Slave device is detected from the Standby to Advertising, the core turns to the module for intercepting network traffic (Packet Sniffing), from which information is received about the exchanged messages between the devices in the network. To obtain statistical information about the time in which the end devices in the network were in a certain state, the core turns to the Statistics module. The processed information through the various modules is visualised through the built graphical user interface.

In order to compare the exchange of messages when establishing a connection, sending data and terminating the connection between Master and Slave devices in the BLE simulator and a real environment, a real BLE network is configured. To ensure comparability between the results of the real and simulated BLE network, an experimental topology of one Master and one Slave was realised. The BLE network is constructed by the Raspberri Pi 4 Model B development board with operating system Raspbian to work as a BLE master device. Communication with the end sensor nodes is carried out with a built-in, in RaspberryPi 4 board, BLE transceiver. The sensor nodes with which the experiments were performed are Texas Instruments multi-standard sensor nodes - CC2650STK, which can be configured to work with BLE technology. The visualisation of the message exchange when establishing a connection, sending data and terminating the connection between Master and Slave devices in a BLE network is performed using the intercepted packets via a Wireshark sniffer.

An identical experimental study was performed for the exchanged messages when establishing a connection, sending data and terminating the connection between Master and Slave in a real and simulated BLE network. The results show that the simulator can be used to present the highlights of the communication between Master and Slave.

B.4.10.**Haka, A.**, Aleksieva, V., Valchanov, H. Simulation Environment for Research of Algorithms for Traffic Prioritisation in ZigBee Network. //Proceedings, 2021 17-th Conference on Electrical Machines, Drives and Power Systems (ELMA), 1-4 July 2021, Sofia, Bulgaria, pp: 609-612, ISBN: 978-1-6654-3581-9, DOI: 10.1109/ELMA52514.2021.9503088

This paper presents a simulation environment that allows study the influence of the implemented algorithms for prioritising traffic on parameters related to Quality of Service (QoS) in ZigBee network.

Proposed traffic prioritisation algorithm for ZigBee is a modification of the previous proposed by authors algorithm and is intended to work in star topology. The product improvements are the ability to study the influence of different algorithms for prioritising traffic on parameters closely related to QoS, as well as visualisation of the built network topology. The simulation product has a modular architecture, and the operation of the individual modules is controlled by its core.

The algorithm checks several criteria for prioritising traffic in a ZigBee network. It is first checked for packages that are marked as urgent. In the presence of such packages,

they are served with the highest priority. When there are multiple emergency packets or they are missing, the traffic is prioritised according to whether it is required by a mobile or static device. Requests from mobile devices are served with higher priority. When there are packets from more than one mobile device, requests are prioritised according to the speed at which the devices move. Higher priority requests are served from devices that move faster. Another criteria for prioritisation with the same others is the distance of the sensor from the network coordinator. Requests from sensors closer to the coordinator are served with higher priority. When the sensors are at the same distance from the coordinator, their requests are prioritised according to the value of cost. The requests with higher cost value are served with higher priority. Finally, the requests are prioritised according to the sensor application.

The performed experiments aim to study the influence of the implemented algorithms for traffic prioritisation in ZigBee network on the parameters PDR, PLR, Delay and Throughput, which are important to ensure good QoS. The presented experimental results show that with increasing number of nodes the service of the proposed algorithm for prioritising traffic in ZegBee network becomes even. However, higher values are provided for the studied parameters for the nodes closest to the coordinator. This will improve QoS and speed up service for these devices. This will free up the occupied resource faster and allow the lowest priority requests from the most remote devices to be served faster.

In contrast, the service of the classical algorithms is significantly even, which loads the entire communication in the network and can lead to deterioration of QoS. In addition, providing more resources from the proposed algorithm for serving requests from higher priority nodes, unlike the classic ones, will extend their battery life, as power consumption is only in active periods, and their number can be minimised by speed up serving.

B.4.11.**Haka, A.**, Dinev, D., Aleksieva, V., Valchanov, H. Comparative analysis of ZigBee, 6LoWPAN and BLE technologies for the Internet of Things. //INTERNATIONAL SCIENTIFIC CONFERENCE OF COMMUNICATIONS, INFORMATION, ELECTRONIC AND ENERGY SYSTEMS (CIEES), 25-27 November, 2021, Ruse, Bulgaria, AIP Conference Proceedings, ISBN: 978-0-7354-4375-4, Volume number: 2570, Published: Aug 18, 2022, https://doi.org/10.1063/5.0099684

This paper presents the realisation of an IoT sensor network with Texas Instruments CC2650STK sensors, which can be configure and operate based on ZigBee, 6LoWPAN and BLE technologies. Experimental studies of the parameters End_to_End Delay, Throughput and PLR for the three technologies have been performed. Based on the results of the experiments, a comparison of the same between the considered technologies is presented. The aim is, as a result of the research, to formulate recommendations for the most appropriate technology for building a sensor network for IoT with the used sensor nodes.

The experimental studies for the considered technologies are realised with different number of simultaneously connected in the network static sensor nodes (2, 4 and 6). The experiments include calculating the values of the parameters End_to_End Delay, Throughput and PLR, which affect the QoS, at distances between the serving device and

the sensor nodes of 1m, 2m, 3m, 4m and 5m, when sending 5, 10, 15 and 20 packets. In order to ensure comparability between the obtained results for the studied technologies, a star topology was used in all experiments.

According to the obtained results, the values for End_to_End Delay increase with the number of end nodes in the considered technologies, as more time is required to serve the requests of all devices. As the number of packets sent increases, so do the values obtained for End_to_End Delay, as there are more requests for serving on the network. With ZigBee in most experiments, the minimum and maximum value for End_to_End Delay is better than 6LoWPAN and BLE. In addition, in most experiments, the values obtained for ZigBee are constant and do not change drastic with increasing distance between the end nodes and the serving device.

From the obtained results for PLR it can be seen that the values increase in direct proportion to the number of nodes in the network for the considered technologies.

The following recommendations can be formulated from the experiments and the results obtained:

- In applications where it is important that the values for End_to_End Delay are relatively low and constant; it is better for the CC2650STK sensor nodes to be configured to work with ZigBee technology;
- In applications where constant throughput values are required, it is better for the CC2650STK sensor nodes to be configured to work with ZigBee technology;
- When required to provide higher throughput with a larger number of nodes in the network, it is better for the CC2650STK sensor nodes to be configured to work with BLE technology;
- In applications where less packet loss is required, it is better for the CC2650STK sensor nodes to be configured to work with ZigBee or BLE technology, as the PLR values obtained are extremely close, with lower values obtained for ZigBee.

B.4.12.**Haka, A.**, Dinev, D., Aleksieva, V., Valchanov, H. A study of ZigBee Networks in Experimental Environment and Simulation. //2022 International Conference on Communications, Information, Electronic and Energy Systems (CIEES 2022) 24 – 26 November, 2022, Veliko Tarnovo, Bulgaria, pp. 1-6, ISBN 978-1-6654-9148-8, DOI: 10.1109/CIEES55704.2022.9990742

This paper presents an investigation of End_to_End Delay, Throughput and Packet Loss Ratio (PLR) parameters that affect QoS in one of the most commonly used IoT technologies – ZigBee. The conducted research presents results for the considered parameters based on simulation and a real ZigBee network with end nodes of the manufacturers Texas Instruments (TI) and Sonoff. Based on the calculated values, a comparison was made between the results, aimed at formulating recommendations for the selection of devices for building a ZegBee network, according to the specific QoS requirements in the network, as well as determining the application possibilities of the considered simulation product.

The experimental studies on the considered ZigBee devices were carried out with different numbers of static end nodes simultaneously connected to the network (2, 4 and 6). In each experiment, the end nodes are located at different distances from the master

device (1m, 2m, 3m, 4m, and 5m), and at each of the distances, 5, 10, 15, and 20 packets are sent from each node. The connection topology for the conducted experiments is star.
The ZigBee network with end nodes from the manufacturer TI is built with a BeagleBone Black (BBB) - BBB01-SC-505 board installed with Z-Stack Linux Gateway software to act as a ZigBee coordinator. Connected to the BBB board is a TI CC2531EMK transceiver configured to transmit and receive ZigBee signals. The end devices are TI CC2650STK configured to operate as ZigBee nodes.
The ZigBee network with end nodes of the manufacturer Sonoff is built with ZigBee2MQTT software installed on a Windows PC, which implements a ZigBee coordinator. A TI CC2531EMK ZigBee transceiver is connected to the Windows PC to communicate with the end nodes, Mosquitto server and Nodejs are also installed to read the data from end nodes. The final devices are the Sonoff Door Sensor and the Sonoff Temperature and Humidity Sensor.
The ZigBee network through the simulator is built entirely virtually with coordinator and end node parameters based on published standards.
Based on the conducted experiments and the summarized results, the following recommendations can be formulated:

- For ZigBee applications where significantly low and constant End_to_End Delay values are required, it is better to use TI devices in the network;
- For ZigBee applications where higher Throughput values are required, it is better to use TI devices in the network;
- For ZigBee applications where it is required to maintain low PLR values, both TI and Sonoff devices can be used in the network;

To study the direction and trend of change of the investigated QoS parameters in different situations, the considered simulation environment can be used, which is also suitable for use in training both in-person and in remote form.

B.4.13. **Haka, A.**, Dinev, D., Aleksieva, V., Valchanov, H. Internet of Things Sensor Data Storing Systems for Educational Purposes. //2022 International Conference on Communications, Information, Electronic and Energy Systems (CIEES 2022) 24 – 26 November, 2022, Veliko Tarnovo, Bulgaria, pp. 1-6, ISBN: 978-1-6654-9148-8, doi: 10.1109/CIEES55704.2022.9990805.

This paper presents two proposed and developed data storage systems of LoRa and ZigBee sensor networks that have wide application in the field of IoT. The systems were created in the Department of "Computer Science and Technology" of the Technical University - Varna for use in training. By developing a web interface, they provide remote monitoring of data stored in a non-relational database. The systems allow students to familiarize themselves with the configuration and operation of two of the most widely used IoT and home automation standards. They also allow students to study the workings of the MQTT protocol. In addition, they enable students to consolidate and acquire new knowledge and skills in the field of database management and programming.
For the purposes of training in the CST department, at the Technical University - Varna, a LoRa system for storing sensor data for IoT with a Web-based interface for work with the possibility of remote access has been developed. It is not necessary to generate

special identifiers to configure the system. The system consists of three main components Dragino LG01-S - Single Channel LoRa IoT Gateway for managing the network and receiving data from sensor nodes, an MQTT server for receiving and forwarding data from the LoRa Gateway and a MongoDB database for storing the received information. The LoRa Gateway needs to be configured to forward the received messages from the sensors to an MQTT server. The MQTT messages from the corresponding channel are then passed to the MongoDB database, where they are stored in the corresponding collection. Passing information from an MQTT server to MongoDB is provided with Python scripts. The developed Web interface provides appropriate visualization of the stored information and output of statistical samples based on the individual characteristics and time segments of work, as well as creation of a model of operation of the devices in the studied environment.
Advantages and disadvantages of existing ZigBee data storage solutions as well as the developed one are presented. According to the presented information, the developed solution includes some of the advantages of the existing ones and overcomes most of their noted disadvantages. The developed solution has shortcomings in the ability to provide a working environment for multiple users, limited storage for storing information and sharing information. The developed solution allows working with various IoT technologies, and the presented shortcomings can be overcome by improving the system. This shows that the developed system is suitable for learning purposes in a university environment.

B.4.14.**Haka, A.**, Yordanov, Y., Aleksieva, V., Valchanov, H. Study of Received Signal Strength Indicator values of Bluetooth Low Energy in Test Environment and Simulation. //International Conference AUTOMATICS AND INFORMATICS`2022, October 06 - 08, 2022, Varna, Bulgaria (ICAI'22), pp. 282-286, Electronic ISBN:978-1-6654-7625-6, Print on Demand(PoD) ISBN:978-1-6654-7626-3, doi: 10.1109/ICAI55857.2022.9960009

This paper presents a study of RSSI values under BLE technology in real network and simulation. The research aims to compare the results obtained in a real environment and simulation to formulate recommendations for the situations in which equipment from a specific manufacturer and the simulator can be used. The influence of the number of end nodes and the distance between them and the central one on the strength of the received signal in a real environment as well as in simulation is considered to determine the reliability of the simulated values and their applicability in research and training.
For experimental purposes, to study the RSSI values of BLE technology in a real environment, two BLE networks are connected with end nodes from two different manufacturers – TI and Arduino. The components of one BLE network are: Raspberry Pi 4 Model B with built-in BLE transceiver and sensor nodes CC2650STK from TI. The role of the master BLE device is performed by the Raspberry Pi 4 Model B board, on which the Raspbian operating system is preloaded. The CC2650STK end sensor nodes are pre-programmed to work with the BLE standard. The components of the other BLE network are: an Arduino nano 33 IoT main unit and Arduino nano 33 BLE sense sensor nodes from the Arduino company. The main BLE device is implemented with an Arduino nano 33 IoT board, which is configured to run the program described in

pseudocode Code 1. Several Arduino nano 33 BLE sense boards are used as end sensor nodes.
The experiments obtained on a BLE network with end devices from the manufacturer TI show that the reported RSSI values mainly vary in the range from -40dBm to -70dBm, with the exception of the experiments with 4 and 5 simultaneously connected end nodes. In these experiments, the reported RSSI values are increased for the nodes that are located farthest from the Master device. The reported values range from approximately -72dBm to -85dBm.
The RSSI values in the experiments in a BLE network with Arduino devices vary mainly in the range from -80dBm to -95dBm, with the exception of the experiments with 5 and 6 simultaneously connected end nodes. In these experiments, the reported RSSI values are increased for the nodes that are located after 3 meters from the Master device. The reported values range from approximately -80dBm to -105dBm.
A comparison was made between the experiments carried out under the same conditions. Based on the presented results, recommendations are formulated for the cases in which the considered end nodes and the simulator can be used.

B.4.15.Dinev, D. and **Haka, A.** RSSI study of wireless Internet of Things technologies. //Journal of Physics: Conference Series, Volume 2339, International Conference on Electronics, Engineering Physics and Earth Science 2022 (EEPES 2022) 21/06/2022 - 24/06/2022 Varna, Bulgaria, Online ISSN: 1742-6596, Print ISSN: 1742-6588, doi: 10.1088/1742-6596/2339/1/012014, https://iopscience.iop.org/article/10.1088/1742-6596/2339/1/012014

The different types of Internet of Things (IoT) technologies are growing and integrating more and more as the coverage and capabilities of new generation networks (4G, 5G) expand, which provide a high-speed environment for transmitting different types of data. IoT networks play variety of roles like to monitor parameters of the world around us like as temperature, pressure, humidity, illumination, and so on. In today's world, remote monitoring of many parameters is becoming more common, and the need for it is especially apparent during emergencies. Modern IoT sensor networks let for the periodically monitoring of metrics from static and moving sensor devices. These parameters can be used to monitor the state of the environment or the health of patients. On rare occasions, it might be essential to locate the network's sensor nodes. Tracking figures for Received Signal Strength Indicator (RSSI) is one method for accomplishing this with the help of a system of low-power sensor nodes.
The goal of this study is to compare the RSSI of several wireless technologies, including ZigBee, LoRa, and BLE. The wireless technologies under consideration chosen based on aspects like as popularity, public availability, and use in IoT.
Experiments with the devices carried out with various numbers of static end nodes linked in the networks (1, 2, 3, 4, 5 and 6). For the experiments, the physical star connection topologies are realised. The studies include calculating the values of the RSSI parameters, at distances of 1m, 2m, 3m, 4m, and 5m between the serving device and the sensor nodes when sending 20 packets.
The experimental results for RSSI values in the LoRa network with one node show that when the length between sensor and the gateway device grows, the RSSI indices

acquired got worse. According to the results for two sensor nodes, the received values for one of the devices are pretty close to the results in the testing with only one LoRa end node. The reported RSSI values drop as the range between the gateway and the number of end devices in the system is growing. The communication channel's load, as well as the concurrent transmission of the end nodes in it, produces a disturbance, lowering the quality and strength of the signal.

The experimental results with BLE for one node demonstrate that the obtained RSSI values worsen as the range between the sensors and the coordinator device grows. Although only one device is broadcasting in an unloaded communication environment, the prior values may have declined because of interference from outside sources. According to the results obtained from two sensor nodes, the measured RSSI values for one of the nodes are close to the results in a test with one node. The derived values for the second node may be seen to be much lower. The RSSI values worsen as the range from the main device rises. Other tests with up to 6 sensors support the pattern that the observed RSSI values are improved at closer distances to the service device.

The experimental results with ZigBee of one and two sensors show that as the length between the main unit increases, so do the obtained RSSI results. With three and more sensor devices, there is no evidence of this trend. With increasing distance from the coordinator, the obtained RSSI values for some of the nodes are identical or better, while for others they are worse. This is due to the presence of external noise impacts and sensor node interference, which can become more prevalent as the number of devices in the network grows.

The results demonstrate that LoRa has better RSSI values in the provided conditions but has a longer range, making it an ideal contender without exposing extra hardware, followed by ZigBee and BLE. The poorest of all was BLE, which had lower values than ZigBee and LoRa but could be the greatest answer in circumstances where systems must work on batteries due to its lower power consumption.

B.4.16.D. Dinev, **A. Haka**, V. Aleksieva and H. Valchanov, "Analysis of LoRa RSSI Data Using Simulations and Real Devices," 2023 18th Conference on Electrical Machines, Drives and Power Systems (ELMA), Varna, Bulgaria, 2023, pp. 1-4, doi: 10.1109/ELMA58392.2023.10202359.

Quality of service is a critical aspect of the Internet of Things (IoT) and is particularly important in LoRa networks. Long Range (LoRa) is a low-power wide-area network (LPWAN) technology that is commonly used for IoT applications because of its long-range capabilities, low power consumption, and low cost. In LoRa networks, QoS refers to the ability of the network to provide a reliable and predictable level of service to connected devices. This includes ensuring that data is delivered in a timely and efficient manner, with minimal packet loss and latency. It also includes providing sufficient bandwidth and ensuring that devices have adequate connectivity to the network.

This paper compares the Received Signal Strength Indicator (RSSI) values obtained from end sensor nodes in a simulated LoRa network with those from a real LoRa sensor network. The goal is to evaluate the accuracy of simulation results by comparing them with real-world measurements.

In LoRa networks, the Received Signal Strength (RSS) is the power of the received signal at the receiver's antenna, which is affected by various factors such as the transmission power, distance between the transmitter and receiver, and the radio environment. The RSS can be converted to the RSSI, which takes into account the gain of the transmitter and receiver antennas, the wavelength, and the distance between the antenna and the sensor node.
The simulator allows the creation of a LoRa network through the utilization of modules such as “Topology Modification”, “Creating Topology”, “Finding Best Path Between End Devices” block, and “Simulating Mobility”. These actions can be easily performed using the Graphical User Interface. The application's core oversees all processes during the simulation. The values for RSS and RSSI are calculated immediately after setting the sensor distance from the coordinator.
The LoRa sensor network comprises the Dragino LG01-S - Single Channel LoRa IoT Gateway, which handles network management and data reception from sensor nodes. Data transmission is facilitated by using the Dragino LoRa Shield with Arduino UNO. The LoRa Shield allows Arduino microcontroller boards to wirelessly transmit data over long distances with low power consumption. For the purposes of the experiments, a flame sensor and a DHT11 (temperature and humidity sensor) were employed.
The results show that for two end devices in the network, the RSSI values obtained using the simulator are nearly identical to those obtained using a real network. The simulator's results with 4 and 6 end devices are comparable to those of the real network. The variation in the RSSI readings of the simulator is roughly 5dB compared to the actual results.
The research results demonstrate that the RSSI study module developed and integrated into the simulator is an effective tool for studying RSSI values in simulated LoRa networks. The small difference in RSSI readings between the simulator and the actual results (approximately 5dB) shows that the simulation software is reliable and accurate.

B.4.17.**A. Haka**, Y. Yordanov, D. Dinev, V. Aleksieva and H. Valchanov, "Simulation Environment for Examining the Pairing Methods in BLE Technology," 2023 18th Conference on Electrical Machines, Drives and Power Systems (ELMA), Varna, Bulgaria, 2023, pp. 1-4, doi: 10.1109/ELMA58392.2023.10202261.

In recent years, an increasing growth of 5G technologies has been observed worldwide. Key to the development and deployment of 5G technologies, despite the higher cost of use, is layer support. One of the layers provided by 5G is Internet of Things (IoT) monitoring, which includes features of IoT systems that provide remote monitoring and analysis of data from sensors and other devices. One of the most common IoT technologies providing implementation of sensor networks is Bluetooth Low Energy (BLE). As one of the most widespread IoT technologies with a wide range of application, it is extremely important for BLE technology to ensure high quality of service (QoS). Providing high QoS can be done in various ways, one of which is to provide secure communication. Communication security research can be done by looking at a real BLE network as well as in simulation.
This report presents an improvement to the simulation product developed by the authors. The improvement is expressed in the possibility of researching the establishment of a

secure connection between a master and a slave device in a BLE network. The simulated process is based on the published BLE standards for establishing a secure communication link.

The Security Manager (SM) defines the methods and protocols for connecting and distributing keys, the relevant security tools, and a security management protocol. The SM uses the key distribution method to implement authentication and encryption functionalities in radio communications. Before transmitting data packets between the participating devices, a connection is established for the purpose of authentication. This process is made to set keys that can be used to encrypt a connection. Transport specific key distribution is done to share these keys. They can be used to encrypt a connection on future reconnections, verify data, or do random address resolution. The exchange of connectivity information between two devices is done through Pairing Request and Pairing Response packets. After the packets are exchanged, the two devices choose which key generation method will be used. Possible methods are: Just works; Numeric Comparison (Only for LE Secure Connections); PassKey; Out-of-band (OOB).

The encryption process implemented in the developed simulation product is pursuant with the Bluetooth Core standard. During the connection process are taken into account the set input-output capabilities of the device types possible to select in the simulator. Depending on the connection settings, it is selected whether to use the OOB, PassKey or JustWorks method for generating authentication keys.

The message exchange process from simulator when implementing secure communication shows the feature checking and the selection of the key generation method by standard. After that is realised the generation of the values necessary for the calculation of Mconfirm and Sconfirm and their transmission between devices. Next is the exchange of Mrand and Srand and the calculation by both devices by the confirm value generator function c1 whether this will validate the Mconfirm and Sconfirm values that were previously exchanged. If the values match, then follows STK generation. Then the exchange of data packets begins.

Detailed information about the I/O capabilities of the communicating devices through the simulation product, as well as the key generation method used, can be viewed by expanding the content of the messages exchanged for this purpose. Similarly can be monitored, the generated Mrand and Srand, Mconfirm and Sconfirm values, as well as the generated STK. The developed simulator allows studying various aspects related to the operation of the BLE standard without the need for the presence of physical devices.

The experiments conducted show that the simulator can be used to represent the highlights of communication between a master and a slave. The simulation product allows the investigation of various aspects of the BLE standard. This gives reason to claim that it is suitable for purposes of research of the technology. In addition, it does not require the presence of physical devices for operation, and this allows it to be used for educating in both a face-to-face and remote form.

B.4.18.Diyan Dinev, **Aydan Haka**, Veneta Aleksieva, Hristo Valchanov and Biliyana Ilieva, "An educational tool for Z-wave network simulations and finding optimal routes," International Conference on Electronics, Engineering Physics and Earth Science, June 21-23, 2023, Kavala, Greece (In Press)

The rapid advancement of technology has led to the emergence of the Internet of Things (IoT), a network of interconnected physical devices that collect and exchange data. IoT is transforming various industries, such as healthcare, manufacturing, and transportation, by enabling new applications and services that were not possible before. Z-Wave is a wireless communication protocol specifically designed for smart homes and IoT devices. It operates on a mesh network topology, meaning that devices can communicate with each other through a series of hops, allowing for greater range and reliability. One of the key advantages of Z-Wave technology is its low power consumption, making it ideal for battery-powered devices that require long battery life.

In order to gain a deeper understanding of a new technology in university education, pre-built simulators are used, specific simulators for training are developed, or remote access to a laboratory environment is provided. Simulation software has become a valuable tool in education, providing students with a platform to experiment and learn in a safe and controlled environment.

This paper presents a simulation tool that can build a Z-Wave networks and establish a method for identifying the optimal route between end devices for studying Z-Wave technology in an educational context.

The simulator uses a modified version of a method to find all routes between a specific Personal area network and another network. It searches for routes only to the designated end device. In a multi-hop network, there may be different routes with the same parameters. The simulator uses Dijkstra's algorithm to initially choose the shortest path route and prioritises routes based on their authentic value. The devices' routing tables contain this value as a negative, positive, or 0 number indicating the quality of the route. The route with the highest positive value is selected and its success is demonstrated by the number of successful broadcasts. The authentic value increases with successful transmissions and decreases with unsuccessful ones. Fragments are sent to the route with the highest authentic value in order of priority.

Developed Z-Wave simulation software has few operational blocks: Core - crucial component of the system that is responsible for carrying out all the key operations related to creating and modifying the topology of a Z-Wave network; Graphical interface - provides a user-friendly interface; Creating and modification of topologies – divided by two sub-modules Hubs and End devices; Finding Optimal routes between end devices – determins the most efficient and reliable communication path between end devices in the network.

Suggested development of simulation software for educational purposes, which features easily upgradable with new modules and can provide significant benefits to student's learning experience. This type of software can facilitate adaptive learning and allow for the customisation of educational content to meet the specific needs of students. The software enables the creation and modification of Z-Wave network topologies, as well as the identification of the best path between end devices. The framework features "Breadth First Search" and "Dijkstra's algorithm" for all devices within the network.

B.4.19.**A. Haka**, D. Dinev, V. Aleksieva and H. Valchanov, "Integrated Environment for Monitoring Data from Wireless Sensor Technologies for IoT," 2023 International Conference Automatics and Informatics (ICAI), Varna, Bulgaria, 2023, pp. 71-76, ISBN:979-8-3503-1291-1, doi: 10.1109/ICAI58806.2023.10339040.

Modern information and communication technologies such as 4G, 5G, and 6G enable high-speed data transmission throughout the world. A large share of current information and communication technologies is occupied by the Internet of Things (IoT). IoT technologies are implemented using different standards with a variety of hardware because they have different types of applications. Some devices are powered by batteries, while others are powered by high-voltage networks. They are distinguished by the fact that they create a vast volume of data. The generated data is of different types because it is based on different standards and has a unique format. Monitoring parameters from different types of networks in a common environment requires combining data from different technologies and treating them in a common format. This unification can be achieved by converting the data read by an IoT technology and presenting it in a common format, then saving it to a shared database.

The present study proposes a solution for monitoring data from wireless sensor networks for IoT, implemented at the Technical University of Varna. The proposed solution uses Python programming to convert data received from different communication standards into one type and forward it to the database. MongoDB is used to store the received information since it has the ability to quickly save a lot of data from IoT sensors, using different technologies. For visual presentation of the data and tracking in a common environment, a web-based interface has been created. LoRa, ZigBee, and Bluetooth Low Energy (BLE) are the standards for real network realisation that are implemented in the deployed environment.

The system for storing data from LoRa and ZigBee wireless sensor networks is made up of two major components: a MQTT server (MQTT Broker) and a MongoDB database. In the BLE network, sensor data is stored in a text file and transmitted using the FTP protocol to the server machine to process the data. Text information is converted to JSON format with Python services and passed to MongoDB. The built web interface is used to visualise real-time data as well as data saved in the database, which is accessible through the included web server. Subscribing to MQTT topics, capturing data and storing it into the database is done via Python scripts. In addition, Python scripts convert textual BLE data to JSON and storing it in MongoDB.

The developed integrated environment for monitoring data from wireless sensor networks for IoT has a web interface. This interface allows for the display of data contained in the MongoDB database. For each sensor network considered, different web pages have been created with the possibility to view the data and visualise the graph according to a selected parameter. Graphs represent recorded data at a specific point in time. The interface allows each graph to define a time range for tracing recorded information. For each of the parameters considered in the sensor networks, it is possible to specify a threshold value. The web environment generates informational messages when threshold values are exceeded via e-mail notifications.

This report presents existing solutions for integrating data from various IoT technologies. Similar to these studies, a data integration environment from LoRa, ZigBee, and BLE standards for IoT wireless sensor networks has been proposed. The proposed environment allows the presentation of data from different technologies in a common format when devices operating on different standards are used. Monitoring the data, setting a sensitivity threshold and generating notification messages when a threshold is exceeded are available in the environment. The functionality of the developed environment has been proven with experiments in laboratory conditions at the Technical University-Varna. This claims that the environment thus realised allows expansion with other IoT technologies with minimal changes, and facilitates the tracking of the generated information.

Г. Публикации извън групата на монографичния труд
Г.7. Публикации в реферирани и индексирани в световноизвестни бази данни с научна информация

Г.7.1. **Haka, A.**, Aleksieva, V., Valchanov, H. Camparative Evaluation of Mechanisms for Traffic Prioritization in LTE Networks. //Proceedings, 2019 16-th Conference on Electrical Machines, Drives and Power Systems (ELMA), 6-8 June 2019, Varna, Bulgaria, pp: 406-410, ISBN: 978-1-7281-1412-5, IEEE Catalog number: CFP19L07-USB

With the completion of the first 5G standard in 2018, the wireless industry is taking an important step in determining how people interact with the world. The 4G LTE demonstrates how well wireless technology can support mobile and fixed broadband access and Internet of Things (IoT). 4G provides the foundation for 5G connectivity, allowing increase throughput speeds, decrease latency, and increase reliability.
LTE is one of the most widespread wireless access technologies, because of its high speeds in Downlink and Uplink directions. LTE also requires effective methods of prioritising traffic from the scheduler of eNodeB to improve Quality of Service (QoS) for end users. Maintaining high QoS can be achieved by prioritising client requests depending on a number of criteria such as: paid price for guaranteed service, subscriber mobility, type of service, time criticality, etc. Many authors, offer solutions for prioritising traffic. The main purpose of various prioritisation mechanisms is to improve the QoS for customers requiring critical service or for those who have paid a higher price for guaranteed high QoS. To meet the requirements of end-users, effective mechanisms for prioritisation and service must be offered. In addition, it is important to perform a comparative analysis of the considered traffic prioritisation mechanisms to determine their effectiveness.
In this paper is proposed several important criteria for implementing a comparative evaluation of prioritisation algorithms. Here is presented a complex comparative analysis of three mechanisms for prioritising traffic from the LTE Scheduler in eNodeB.
The complex comparison is based on the results of calculated average arithmetic mean and average geometric complex estimation. The calculation of these complex assessments is realised by assigning relative values to the individual criteria that are used. Numerical values of results obtained during simulating the operation of each prioritisation mechanism under the same conditions were used for some of the priorities. The choice of geometric and arithmetic mathematical dependence is defined as optimal in terms of cogency, normality and comparability. Errors in unit indicators estimates using geometric and arithmetic dependence provide compromise enforcement to the conditions for maximum sensitivity when deterioration of single indicators for quality and minimal sensitivity to errors in their determination.
Studies of the three algorithms have been performed and complex estimates are based on the data obtained. When examining the criteria separately, it can be seen that in the case of "Gives priority to non-GBR services when larger numbers are demanded" and "Provides priority to requests for which the maximum delay is high (HoL Delay)" the proposed mechanism does not provide good results. For "Gives priority to GBR services" and "Additional parameters for prioritization" there are equal results. However,

in the complex assessment, due to the wide range of criteria considered, the arithmetic and geometric complex estimation proves that the suggested by authors algorithm for the prioritization of traffic in LTE is better.

Г.7.2. **Haka, A.**, Aleksieva, V., Valchanov, H. Comparative Analysis of Traffic Prioritisation Algorithms by LTE Base Station Scheduler. //2020 21st International Symposium on Electrical Apparatus & Technologies (SIELA), Bourgas, Bulgaria, 2020, pp. 1-4, doi: 10.1109/SIELA49118.2020.9167040, Electronic ISBN: 978-1-7281-4346-0, USB ISBN: 978-1-7281-4345-3, Print on Demand(PoD) ISBN: 978-1-7281-4347-7, DOI: 10.1109/SIELA49118.2020.9167147

This paper examines the impact of the proposed by the authors traffic prioritisation algorithm in LTE network, Round Robin (RR), Maximum Rate (MAX-Rate), Proportional Fair (PF), Exponential/Proportional Fair (EXP-PF), and these proposed by Myo and Akyıldız on the QoS in 4G LTE wireless mobile network.
The comparison based on the results of throughput, delay, packet delivery ratio (PDR) and packet loss ratio (PLR). To study the impact of traffic prioritisation algorithms on QoS, the LTE simulation product proposed and further developed by the authors, used.
Experimental studies performed for static and mobile UEs for one LTE cell, for which transmit power is 40W (46.02dBm), 20 MHz bandwidth, noise power is -160.99dBm, 100 available PRBs, 6 sectors cell, and radius of 770m. Number of users used 20, 50, 70 and 100. Distance of static UEs to eNodeB (m) used – 10, 90, 170, 250, 330, 410, 490, 570, 650 and 730 (55m for all mobile UEs). Required type of service is GBR, required RBs from every UE are 5555 and pay price for guaranteed service with value 5. Movement Speed for Mobile UEs (km/h) used – 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100.
The presented results show that with a smaller number of subscribers, the proposed algorithm provides higher values for the studied parameters for static subscribers located within a range of up to 250 meters from the eNodeB and provides higher values for the studied parameters for mobile subscribers moving at more than 80 km/h. With the increase in the number of subscribers, the serving becomes equable, but better values provided for the highest priority subscribers, while for the other algorithms the results are almost uniform.
The advantage of the proposed algorithm over others is that it serves with high priority requests from subscribers at a closer distance to the eNodeB and requests from mobile subscribers. Serving requests from subscribers closer to eNodeB improves the QoS because the channel quality of these subscribers is better and communication errors are less, which leads to faster service. Priority service for queries from mobile users improves the QoS because this reduces the loss of handover. Allocating more resources to the higher priority users will speed up the service of their requests and the resources released by them will used to serve the low priority ones.

Г.7.3. **Haka, A.**, Aleksieva, V., Valchanov, H. A Comparison Study of Decisions for Computer Network Laboratory in Distant Learning Education. //Proceedings, 2021 17-th Conference on Electrical Machines, Drives and Power Systems (ELMA), 1-4 July 2021, Sofia, Bulgaria, pp: 468-471, ISBN: 978-1-6654-3581-9, DOI: 10.1109/ELMA52514.2021.9503088

This paper presents a comparative analysis of the investigated solutions for distance learning in computer network subjects.

Compulsory social isolation during a pandemic posed new challenges for the system of education. The indispensability quickly moves to a remote form of education necessitated the use of a different educational approach. During a full lockdown, three approaches for training in classes related to computer networks were used and studied - simulation products, real computer network with remote access and virtual computer network with remote access:

1) To use simulation products as Packet tracer, GNS3 etc.

2) In the Department of Computer Science and Engineering at the Technical University- Varna is developed from authors a real computer network laboratory with remote access. The remote access is implemented through web management system, developed by authors. Citrix XenServer has been chosen as a virtualization platform, which has high performance, easy maintenance and is free to use. The main idea of laboratory design is to create a snapshot of the virtual machine (for the respective operating system) for each of the computers, using Xen's snapshot capability.

3) To achieve high flexibility and to avoid some disadvantages of a previous solution, an experimental virtual infrastructure has been implemented. It is based on two Sun Fire Z20 server machines connected to a 1G Ethernet network and using VMware ESXi. The choice of VMware Infrastructure 3 is dictated by its capabilities for multiprocessor support, dynamic balancing and resource allocation between virtual machines, as well as migrating virtual machines between individual servers without interrupting their operation. Based on the virtual infrastructure, a number of virtual machines with respective operating systems have been launched. The virtual infrastructure can be accessed with the VMware vSphere Client software.

The goal of the study is to evaluate which solution is more appropriated for distance learning in the student courses related to computer networks. A system of criteria for evaluating the studied solutions is developed, according to the challenges in online learning.

The comparison is based on a proposed by the authors system of criteria, consistent with the challenges of distance learning. In order to ensure objectivity in the comparison, a complex assessment of the considered approaches is performed, based on complex arithmetic estimation. According to the results from an average arithmetic estimation, the most appropriated solution for distance learning is determined to be using a virtual network infrastructure.

Г.7.4. M. Yordanova and **A. Haka**, "Comparative Evaluation of Communication Protocols in the Automotive Industry," 2023 18th Conference on Electrical Machines, Drives and Power Systems (ELMA), Varna, Bulgaria, 2023, pp. 1-4, doi: 10.1109/ELMA58392.2023.10202531.

There is an increase in the use of communication and information technologies, such as Big Data, Blockchain, Internet of Things, and Automation in a wide range of fields, in modern daily life. The automotive industry is one of the areas where communication technologies are used. Modern vehicles contain multiple Electronic Control Units (ECUs) that communicate with each other to ensure vehicle normal operation. Communication protocols are used to exchange data between control units about the vehicle's state. The most commonly used protocols are Controller Area Network (CAN), Local Interconnect Network (LIN), FlexRay, Media Oriented Systems Transport (MOST), and Ethernet.

In this report, a comprehensive comparison is conducted among various protocols employed in the automotive industry. The primary objective of this study is to ascertain the most optimal intelligence transport protocol. To achieve this goal, multiple protocols are thoroughly evaluated and their respective merits and shortcomings are examined in detail.

In the realm of modern automobiles, communication protocols play a vital role in enabling diverse functionalities and facilitating seamless communication among various electronic components and systems. These protocols assume a crucial responsibility in ensuring reliable and efficient data transmission, which is pivotal for the overall performance, safety, and entertainment aspects of the vehicle. The automotive industry employs a range of communication protocols, each possessing distinct characteristics and serving specific applications. The report includes a comparison between CAN, LIN, FlexRay, MOST, and Ethernet communication protocols to determine the most suitable one for interconnecting the main ECUs.

Since there is no standardised system for comparing the protocols under consideration, the criteria system is proposed for its implementation. The main task of the proposed criteria system is to determine the most suitable automotive protocol for interconnection with the main ECUs. The system includes some of the criteria used in the evaluation of existing solutions. To achieve the comparison, the criteria - scalability, acceptance by the automotive industry and interoperability have been added. The criteria proposed for the complex assessment implementation are: Data Rate (Mbps), Cable Length (m), Interference immunity (dB), Error detection and correction, Maximum Power Consumption (mA), Implementation Cost ($), Scalability, Automotive Industry Adoption, Interoperability, Application.

The system used for comparison contains many different types of evaluation indicators. Therefore, it is impossible to derive a specific function for the quality of the investigated protocol. In such situations, it is possible to use the complex evaluation method. According to complex evaluation method in terms of consistency, normality, and comparability, the choice of average arithmetic and average geometric estimation is optimal. In addition, the complex evaluation method allows to avoid the subjectivity of the authors when evaluating the object of comparison.

The results of the conducted experimental studies in terms of the average arithmetic complex evaluation show that LIN is the most suitable automotive protocol. For its specific features, LIN is used as a sub-bus protocol, most often to CAN. This is the reason for the lower power consumption when using this protocol and this greatly affects the calculated assessment. From this point of view, the complex average arithmetic assessment shows that the CAN is most appropriate for interconnection with the main ECUs. The results obtained for the complex average geometric assessment confirm this statement.

Г.7.5. Aleksieva, Veneta, Hristo Valchanov, **Aydan Haka**, and Diyan Dinev. 2023. "Logistics Model Based on Smart Contracts on Blockchain and IoT" Engineering Proceedings 41, no. 1: 8. https://doi.org/10.3390/engproc2023041008

With the Internet of Things (IoT), the world is going through a technological revolution. One of the industries that IoT has impacted tremendously is logistics. Some goods that require special attention have individual storage spaces in which the temperature, humidity and arrangement are strictly specific. Such are dangerous goods, medicinals or goods with a limited shelf life. Warehouse layout is important to be able to establish the flow of their transportation from the manufacturer's warehouse to their destination at the end user. In this context, IoT-based logistics focuses on warehousing, receiving and loading goods, tracking their location and condition, and inventorying their availability. That is why the main applications of IoT in the logistics process are related to shipment/cargo tracking, monitoring of shipments in cross-docking warehouses, inventory control, theft protection and product tracking. This ensures transparency of the entire process and minimizes the risks of theft, loss and damage to the tracked objects.
From the perspective of reducing the risks of loss, theft and damage for which the company insures its cargo, the application of IoT with blockchain solutions implemented with smart contracts improves the transparency and security of the entire process, increases the trust between the logistics company and the insurance company, ignores the possibility of fraud.
In this paper, an abstract model for the integration of blockchain technologies and IoT is proposed. Applying it, the authors' proposed logistics business model based on IoT and smart-contracts on blockchain, suitable for managing cross-docking warehouses and transportation, is developed.
The proposed abstract model integrates a smart contract with Blockchain and IoT to perform secure transactions in any business and register heterogeneous data. In the abstract model proposed by the authors, the integration of the two technologies is considered in 7 layers - the upper 5 layers represent the operation of the blockchain technology, and the lower 2 layers form the IoT blockchain layer, which provides the communication channels between the IoT sensors, the physical wireless network and the blockchain network. At this layer, the data is collected and transmitted for recording on the blockchain network. In this way, the proposed abstract model represents the process of integrating the two technologies regardless of the chosen blockchain implementation on the one hand. On the other hand, it makes blockchain management independent of the selected sensors, the implemented physical network, the selected wireless

communication technology, etc. What's more - sensors can be of different types - GPS sensors, RFID sensors and IoT sensors for BLE, ZigBee, 6LoWPAN, etc.
The proposed logistics model, based on Blockchain and IoT modifies the traditional cloud-based model. Real-time data collected from IoT sensors is recorded in the blockchain and processed by a smart contract. IoT sensor data is sent at fixed time periods that can be set by the management platform, with IoT sensor data for temperature, humidity, tilt when out of tolerances (which are pre-set in the local system) are sent overtime. When transporting from the vehicle, data from IoT sensors for weight change and door opening are also sent overtime. Data is logged in the cloud/web based system and stored for subsequent analysis and proof of an event occurring. In this way, the circumstances of the occurrence of an unwanted event, which may lead to damage to the goods, their destruction or their theft, are registered. Thus, both the employees directly involved in this process can be held accountable, and compensation can be claimed against an insurer who was given access to the critical data through the smart contract running on the blockchain.
The implementation is done on the HyperLedger Fabric private blockchain. The model does not reflect the relationship with a specific insurance policy, claim for the occurrence of an event and claim processing. Only the option through the smart contract for the insurer's automated access to information to reliably prove the moment of occurrence of an insured event and the circumstances that led to it is reflected.
In this paper, a logistics process management model is proposed, consistent with the presented abstract layered model. A smart contract implementation on HyperLedger Fabric is presented, which proves both the applicability of the proposed layered model and the effectiveness of the application of smart contracts on blockchain for logistics business.

Г.7.6. Veneta Aleksieva, Hristo Valchanov, **Aydan Haka** and Diyan Dinev, "Model of controlled environment based on Blockchain and IoT," 2023 4th International Conference on Communications, Information, Electronic and Energy Systems (CIEES), 23 – 25 November, 2023, Plovdiv, Bulgaria, pp: 1-4, Electronic ISBN:979-8-3503-3691-7, DOI: 10.1109/CIEES58940.2023.10378795

The advent of Industry 4.0 and the development of 5G/6G communications has made it possible to enter a number of innovations in business, but many of them have not yet fully developed their capabilities. The businesses expect all wireless connectivity providers as members of a common ecosystem to work together and avoid fragmentation of the network infrastructure. This means to have a workflow with reliable data, end-to-end real-time observability and workflow automation. Blockchain-based solutions offer this, but they have limitations. Data are generated at high speed, especially in IoT networks. Since many IoT devices have limited memory resources, they cannot store the captured data indefinitely, but rely on a stream-based processing concept, i.e., they process the data on the fly. This means that when designing centralized and resource-intensive solutions with intensive generation of heterogeneous data, a balance must be sought between which data to process with BigData technologies, and which to store and manage on the blockchain. In a hacker attack, data can be manipulated imperceptibly and purposefully. Attackers can falsify data to their advantage or harm data users, mix fake data with real data, or withhold data. This can happen both when transferring data

from the IoT sensors and when storing the data. But blockchain gives assurance that the data will not be manipulated and will only be used by authorized users. The synergy of blockchain and BigData can solve countless data-centric problems – securely storing data without being able to modify it, but also establishing trust and full transparency of transactions.

There are many developments for application of the blockchain in various aspects of the IoT network. Small delays in responses to requests and adequate management of IoT devices with low network latency requires decentralized management of the IoT network and orientation towards cloud-edge solutions based on IoT and blockchain. Due to the great heterogeneity of managed objects with IoT sensors, which necessitates the use of heterogeneous networks to connect with them, a unified architecture of these cloud-edge IoT based solutions has not been established.

This paper proposes an abstract cloud-edge model for monitoring and managing an IoT-based sensor network using blockchains to store unexpected events.

The proposed model consists of five components - IoT sensors in the managed and monitored objects; Network from IoT sensors through standard connectors/interfaces connected to the Edge gateway via cable (Ethernet) and/or various wireless technologies; Network Management – consists of separate sub-components: Planning, Flexibility and Investment; Edge Environment – consists of two parts: Data Collection and Edge Management System; Storing BigData from Cloud Orchestrator – all Edge Environments connect to it. It consists of two parts: Cloud Data Space and Cloud Management System.

The model is not oriented towards a specific business, because standard IoT connectors and unified interfaces enable the seamless collection of large volumes of disparate information from various IoT sensors. Even after data have been fully analyzed and a value-added data product has been generated (information or knowledge), the raw data are still available. They do not lose their meaning in the process, since they can be processed again, in another way, in order to derive new information or knowledge from it. Therefore, the volume of the data to be administered increases constantly, since processed data are neither consumed nor become worthless. But blockchain gives the confidence that data will not be manipulated and will only be used by authorized users. Storing specific information on the blockchain provides time-stamped, secured, immutable, valued, veracity data.

Based on this model, the authors developed a prototype solution for the edge part of the model. The proposed solution has been tested indoors with six types of sensors (temperature, humidity, smoke, open window, open door, motion). The sensors used connect to the Edge Gateway via three different wireless technologies (BLE, LoRa, ZigBee). The information is stored in a MongoDB database, and the blockchain is implemented with Hyper Ledger Fabric. The tests performed prove the workability of the prototype and the applicability of the proposed model.

Г.8. Публикации в нереферирани списания с научно рецензиране

Г.8.1. **Хъкъ А.**, Алексиева, В. Моделиране на разпределяне на честотната лента в пасивни оптични мрежи //Компютърни науки и технологии, ТУ-Варна, 2016, бр.1, с. 45-51, ISSN 1312-3335

In this paper is proposed a software simulation for analysis of the efficiency of allocating bandwidth in passive optical networks. An algorithm is presented for resource allocation in two stages for maximum utilization of bandwidth using orthogonal frequency multiplexing in the passive optical networks (OFDM-PON) - first it is allocated time interval (timeslot) for each subscriber unit (Optical Network Unit - ONU) and second sub-channels are arranged, where each of them consist of a group of subcarriers. Implementing the proposed approach based on dynamic allocation of subcarriers channels provides efficient allocation of bandwidth and reduces delays in transmission of requests of individual users.

The PON network consists of a centralized Optical Line Termination (OLT) on the ISP side and multiple Optical Network Unit (ONU) devices on the user side. ONUs share resources in a common optical stream that connects them to OLTs. The PON system must implement an appropriate MAC mechanism to ensure efficient transmission, efficient use of network resources, arbitrage access to the shared environment and avoid data collisions.

In the present development, an algorithm for resource allocation in two stages for maximum utilization of the connection capacity by using OFDM-PON is presented. OFDM-PON uses a synchronous frame structure to provide differential service to requests. When allocating resources, the proposed algorithm first allocates the time slot for each ONU and then arranges the subchannels (subcarrier group). This algorithm must meet two constraints:

• calculations for the allocation of resources are made for a single frame;

• One ONU uses only one subchannel to send to OLT data for multiple services within the frame duration.

The proposed algorithm is applied only in the upstream direction and is implemented in two phases:

1) Time slot allocation - assigns a temporary subchannel for each ONU

2) Redistribution of subchannels - the temporary subchannel j for ONU [i, j] will be replaced by a confirmed subchannel in which there is enough resource to deploy ONU [i + 1, j], thus minimizing the number of delayed for next frame resource blocks, and the bandwidth is compressed, i.e. no free trays remain.

To analyze the bandwidth allocation algorithm proposed in the present study, a traffic model for several OLTs is created, but visualization of the transmission matrix is performed only for an optional OLT.

A database has been created for storing the data from the individual experiments for the individual OLTs and for the users connected to them.

Г.8.2. Aleksieva V., **A. Haka**, Simulation framework for realization of priority-based LTE Scheduler, Techsys 2017, Technical University of Sofia, brunch Plovdiv, ISSN Online: 2535-0048, pp. II-181-185

In this paper is proposed a simulation framework for LTE technology, which realized a priority-based algorithm for LTE Scheduler, which reorders packets, based on classification mechanism.

The aim of the proposed algorithm is to achieve keeping the network throughput as high as possible at a small price of only a bit more handovers. The functions for management of QoS in access networks are responsible for the efficient allocation of resources in a wireless interface. They are generally defined as the control algorithms of radio resources and incorporate power management, control of the transfer connection, access control, load control and the management packet, but directly related to QoS level cell are the last three. They are used to ensure a maximum throughput for individual services.

The present paper offers an algorithm for UEs service in the distribution of resources in the uplink of LTE network as composed of two modules - by a control mechanism for admission (admission control) and Scheduler. According to the network load, the admission control for the reception of orders manages the number of UEs, which can enter into the Scheduler, in order to avoid overloading the system with too many UEs.

The Scheduler allocates RBs among UEs according to UEs needs based on the priority.

A simulation environment was established for implementation and exploration of the proposed algorithm. Used software tool is Visual Basic 2010. On this stage of simulator, the data from different experiments are send in .xls format to the next estimation.

The results give reason to conclude that the presented algorithm for admission control in the Scheduler for LTE network can be applied successfully in the number of UEs under 100, because regardless of the intensity of the requests of the active UEs the average connection time is under 25ms-time, fully satisfying the requirements of 3GPP standard.

Simulation's results show that the proposed mechanism improves QoS, but the observed parameters degrade when the use of more subscribers is related to the priority implemented Scheduler, in which less priority queues may not be served in the case of network overload or congestion. There are presented drop ratio with prioritization and without prioritization. This algorithm always assures a minimum transmission for all the service classes, although with different performances due to prioritization.

Г.8.3. Aleksieva V., **A. Haka**, Simulation framework for realization of priority-based LTE Scheduler, Journal Of The Technical University - Sofia, Plovdiv Branch, Bulgaria Fundamental Sciences and Application, 2017, Volume 23, ISSN 1310-8271, pp. 101-105

This article is an expanded and supplemented version of the paper Г8.10. In this paper is proposed a simulation framework for LTE technology, which realized a priority based algorithm for LTE Scheduler, which reorders packets, based on classification mechanism.

LTE uses multiple access technology (OFDMA), where the total bandwidth is divided into Resource Blocks (RBs) in the frequency domain. The Data is transmitted in the Transport Blocks (TB) in one transmission time interval (TTI) for 1ms. Each RB consists from 12 subcarriers (each of them is 15kHz). The frame is 10ms and divides into 10 equal subframes. Each subframe contains 2 slots*0.5ms. Each RB is related to one slot in time. One TB is related to 1 subframe and it is the minimum unit to schedule. The serve rule is to find first space that can fit the TB. If there are not enough RBs in the current TTI, the scheduler tries to find resources in the next TTI. This strategy minimizes the response latency, which is the best practice for delay sensitive traffic. But this procedure is not applicable for beacon transmissions (it is sent among devices each 100ms), because of emergency information it conveys, therefore the reserved resource blocks exist to accommodate the temporary overload.

The present paper offers an algorithm for UEs service in the distribution of resources in the uplink of LTE network as composed of two modules - by a control mechanism for admission (admission control) and Scheduler. According to the network load, the admission control for the reception of orders manages the number of UEs, which can enter into the Scheduler, in order to avoid overloading the system with too many UEs.

The Scheduler allocates RBs among UEs according to UEs needs. Resource allocation in the Scheduler is based on the priority of the traffic (highest is the first):

1. Video, voice, interactive gaming – default bearer, non-GBR
2. E-mail, chat, ftp, www, p2p, file sharing – default bearer, non-GBR
3. Video streaming- GBR
4. Video call- GBR
5. Online gaming- GBR
6. VoIP call- GBR
7. IMS Streaming– default bearer, non-GBR
8. Speed of UE
9. Distance to eNodeB
10. Payed priority

A simulation environment was established for implementation and exploration of the proposed algorithm. It has modular architecture. The input of data for each device starts from initial parameters for the eNodeB.

Г.8.4. **Haka A.**, Modified Simulation Framework for Realization of Horizontal Handover in LTE Cellular Networks. //53rd International Scientific Conference on Information, Communication and Energy Systems and Technologies (ICEST 2018) Proceedings of Papers, Sozopol, Bulgaria, June 28-30, 2018, Issue: 1, ISSN 2603-3259, pp. 158-161, ISSN Online: 2603-3267

LTE is a widely used 4G technology defined by 3GPP, capable of realizing Broadband Wireless Access services. LTE supports high spectrum efficiency low latency scalable bandwidth from 1.4 MHz to 20 MHz, using MIMO technology, OFDM technique for downlink and SC-FDMA for uplink, and allows the user to access the service in a state of moving both in one cell or between cells (Handover) without any termination of communication. There are two basic Handover technologies: Hard Handover – also called break-before-make; Soft Handover – also called make-before-break.
Furthermore Handover procedure is divided into two categories:

- Horizontal handover – automatic switching between access points in one technology;
- Vertical handover - automatic switching from one technology to another at the point where the service is delivered.

The realization of Handover procedure depends on eNodeB's Reference Signal Receive Power (RSRP) values measured from UE. To keep mobile users satisfy, carrying out a Handover requires providing good QoS. This can be achieved by studying the delay value during Handover and prioritizing the different types of network streams.
The research was performed with the developed simulation environment, allowing the performance of horizontal handover in LTE with the help of the implemented modification. Improvements consist in the fact that for mobile UEs a direction of movement can be selected in the range of the eNodeB, which allows implementation of mechanism for realization of Handover. Before the Handover is realized, it is checked at what speed and what direction the subscriber moves. After that, is calculated the distance that the UE will travel within five minutes in meters. The calculated value is added to distance to eNodeB given to the UE. After that, if the distance to eNodeB is greater than the radius of the serving eNodeB, the Handover to the target eNodeB is realized in to the movement direction. For the mobile UEs for which the value of distance to eNodeB is not greater than radius of cell, the Handover is not occurs, and they stay at the range of the serving eNodeB. The Handover is realized by the standard, and the context of the UE is transmitted to the next eNodeB. After the Handover is completed, the scheduler of eNodeB then prioritizes users by proposed mechanism, and redistributes resources according to priority.
According to the experiments, the number of realized handovers increases with increasing the number of high speed UEs unlike the number of unrealized, which depends on number of low speed UEs. Furthermore it can be seen that the applied prioritization improves the QoS for high speed users, because unlike the other UEs, the high speed UEs has lower delay value. Although the delay values increase with increasing the number of UEs, they stay lowest for high speed UEs.
In this paper is proposed simulation framework for realization of horizontal Handover in LTE network. The framework performs an algorithm for realization of UE mobility between neighboring cells, according to the prioritization mechanism. Simulation's results show that the proposed prioritization mechanism improves QoS for high speed

UEs. There are presented number of realized and unrealized Handovers and delay value for resource allocation by users. It was always assured a minimum delay value for allocated resources for high speed users realized Handover.

Г.8.5. **Хъкъ, А.**, Василев, Р. Система за симулиране на механизма на изграждане на най-предпочитания път при 6LoWPAN технология. //Компютърни науки и технологии, ТУ-Варна, 2018, Брой 1, стр. 17 - 23, ISSN 1312-3335

This article presents a developed environment for simulating the construction of a 6LoWPAN network, in which prioritisation of the transmitted traffic is implemented according to the network requirements. The simulator provides an opportunity to build and choose the end-to-end best route and constantly monitor the status of the constructed routes.

The proposed simulator includes an Emergent Direct Mode connection mode consisting of a Hassle Free Route routing mechanism and an Adaptive Retry mechanism to improve resending. This routing mechanism allows the prioritisation of packets carrying important or vital information according to the 6LoWPAN network being built. After the Emergent Direct Mode is identified, the preferred route is constructed by the Hassle Free Route mechanism, and the retransmission control mechanism is updated with the Adaptive Retry Mechanism.

According to the Hassle Free Route mechanism in 6LoWPAN multihop networks, the best route is selected according to whether it is the shortest, and an authentic value is added to each route, which determines its priority. The authentic value is stored in the routing table of the nodes and it can be:

- negative number – informs that there are too many failed transmissions on the route;
- value "0" - indicates that the route has not yet been evaluated;
- positive number – marks that the route is problem-free. A larger value means that the route is more successful than others, thus indicating the number of successfully transmitted fragments along a particular route.

On each successful transmission, the authentic value is incremented by "1" and in case of failed transmission, it is decremented by "1". When a fragment with an Emergent dispatch header arrives, it is forwarded along the route with the highest authenticity value. These fragments have a higher priority and are transmitted via the most preferred route. The Emergent Direct Mode scheme also uses an Adaptive Retry Mechanism to provide retransmission, ensuring that urgent fragments are not dropped along the route.

The software used to create the simulation product is Microsoft Visual Studio 2012 and the C# programming language because it allows the use of an event-oriented development environment. A database was built to store the data from the individual experiments for each 6LoWPAN coordinator and the end devices connected to them. The creation of the 6LoWPAN network is done through the created user interface. Connections are established between PAN coordinators and their networks, over which the transmission of packets is simulated until they reach the desired destination. For each end device or coordinator, there is an option to update the data. After the information about the coordinators, the connections between them and the end devices to each coordinator is entered, the simulation of the implemented Emergent Direct Mode is realised. The simulator prioritises urgent traffic, if any, and forwards it along

the best route chosen according to the Hassle Free mechanism, tracking its authentic value for each route and assessing how reliable it is. Before the transmission is implemented, all packets are added to a sending queue where they are prioritised and transmitted along the selected route. The application provides a visualisation of the results of the implemented mechanisms for selecting the most preferred route in 6LoWPAN technology.

Г.8.6. **Haka, A.** Software tool for comparing LTE traffic prioritisation algorithms. //Monthly scientific and technical journal ELECTROTECHNICA & ELECTRONICA E+E, Bulgaria, 2019, Vol. 54. No 9-10/2019, pp: 146-152, ISSN: 0861-4717

This article discusses traffic prioritisation algorithms as a means of improving quality of service. Round Robin, MAX Rate, Proportional Fair and EXP Proportional Fair algorithms are considered. In addition, an interface is presented, with the results of which a complex comparative analysis of the considered algorithms was performed. The complex comparative analysis is carried out between the algorithm proposed by the author and standard algorithms for traffic prioritisation in LTE technology.
The interface used to study traffic prioritisation algorithms in an LTE network consists of two main forms – a form for adding base stations and information about them and a form for entering subscribers and information about them. The interface provides results for transmission matrix, Throughput, Delay, Packet Delivery Ratio, SNR, Channel Gain against the traffic prioritisation algorithm used.
Since the complex comparative analysis is evaluated under equal criteria, and the influence of handover is not considered, for the current study all tests are performed within one LTE cell. The cell works in 20MHz bandwidth and supports 100 UE's, which are static, and mobile, requiring different types of service and each subscriber requires 10 000 Resource Blocks (RB).
In order to avoid the subjectivity of the author when evaluating the algorithms under consideration, the method of complex evaluation is used. To compute the complex quality indicator, one of the following mathematical dependencies is chosen: quadratic, geometric, arithmetic or harmonic. The comparison according to the criteria under consideration is based on average arithmetic and average geometric estimation. The choice of geometric and arithmetic mathematical dependence is defined as optimal in terms of cogency, normality and comparability. Errors in unit indicators estimates using geometric and arithmetic dependence provide compromise enforcement to the conditions for maximum sensitivity when deterioration of single indicators for quality and minimal sensitivity to errors in their determination.
According to the results obtained for the complex evaluation, the prioritisation algorithm proposed by the author is better than standard algorithms. The main advantage of the proposed algorithm is that it fully complies with the 3GPP standard, serves with high priority guaranteed bitrate (GBR) services, allows the internet service provider to implement priority serving for requests from UEs that have paid a higher price for a guaranteed service, as well as requests from mobile UEs, which will reduce losses caused by a handover. This in turn will improve the quality of service for end users.

When examining the criteria separately, it can be seen that the proposed algorithm does not provide good results, or they are equal with all others. However, in the complex assessment, due to the wide range of criteria considered, the arithmetic and geometric complex estimation proves that the suggested by author algorithm for the prioritisation of traffic in LTE is better than RR, MAX Rate, PF and EXP-PF algorithms.

Г.8.7. **Айдън М. Хъкъ**, ИЗСЛЕДВАНЕ НА БЕЗЖИЧНИ ТЕХНОЛОГИИ ЗА INTERNET OF THINGS (IOT) МРЕЖИ. //Компютърни науки и технологии, Година XVIII, Брой 1, 2020, pp:51-58, ISSN 1312-3335

Modern communication technologies (4G, 5G) occupy an increasingly large part of everyday life and help to overcome crisis situations such as the one with COVID-19. Thanks to high-speed communication infrastructures, it becomes possible to conduct electronic health examinations, training, meetings, assemblies, conferences, etc. In addition, to improve and maintain electronic healthcare, as well as technologies based on which sensor networks are implemented, Internet of Things (IoT) technologies are increasingly being introduced, the communication of which relies on high-speed networks such as 4G and 5G.

This article examines the development of IoT technologies in the most actively developing markets in the world and in Bulgaria. In particular, the state of the world market of some of the widespread IoT technologies - Bluetooth Low Energy (BLE), ZigBee and 6LoWPAN - is considered.

Currently, IoT networks rely on 4G and 5G infrastructures for fast and reliable transmission of small amounts of data related to remote monitoring of environmental parameters, patient status, etc. Over the years, IoT technologies have become more popular and more widespread. For the actively developing regions of the world, IoT connectivity from millions in 2013 are growing at breakneck speed and reaching billions in 2019 and 2020.

One of the widely used protocols for wireless sensor networks is BLE. The growth and spread of Bluetooth technology as one of the main ones for IoT is confirmed by the increasing number of working groups, active specification development projects, new members of working groups and committees, as well as the number of purchased Bluetooth devices. Forecasts show that after 2020 classic Bluetooth devices in the market will gradually decrease and more and more classic devices compatible with the BLE standard and fully BLE-based will enter.

Other widely deployed IoT protocols are ZigBee, standardised and supported by the ZigBee Alliance, and 6LoWPAN. The protocols are based on the IEEE 802.15.4 radio communication medium and allow building a fully connected network. The statistics for 2018 show that worldwide sales of IEEE 802.15.4 chips for smart homes and buildings, measuring, smart cities and industrial automation reach half a billion. According to the forecasts from 2019 sales of IEEE 802.15.4 chips by 2020 will reach 1 billion, with sales of new chips by 2024 expected to reach the same size.

In Bulgaria, the more widespread high-speed communication technology is 4G, with 5G and IoT technologies gradually entering. In Bulgaria, the telecommunication operators that mainly accept and implement IoT solutions are A1 and Vivacom.

Launched in 2018 A1's IoT network is based on the Narrowband-IoT (NB-IoT) standard. The operator offers NB-IoT solutions for air control, waste management, smart lighting and smart parking.
The platform presented in 2018 Viva Smart of the telecom operator Vivacom unites all its IoT projects. Through it, the telecom offers smart services in three areas: smart city (VIVA Smart City), cloud solutions and equipment colocation (Smart Data Hub) and digital education. Operator Vivacom provides IoT solutions for the communication connectivity of bicycle rental systems, intelligent video surveillance of the urban environment and integrated urban transport. In 2018, a pilot solution for smart city parking based on LoRaWAN technology was launched. In addition, a pilot project for smart waste collection has also been launched.
Telecom operator Telenor has experience in early IoT solutions known as M2M communication in Norway and Sweden, and in 2018 launched NB-IoT technology for IoT.
In Bulgaria, the 6LoWPAN protocol is used in a pilot network for IoT launched in 2016 in Sofia. BLE technology is mainly used in sports and entertainment, and in 2019 a meeting is held in Sofia to promote the BLE standard as an IoT solution.
Modern communication technologies worldwide are moving towards high-speed technologies known as 5G, along with the introduction and use of IoT technologies. The wide spread of IoT technologies in the world in recent years is a prerequisite for expecting their ever greater growth and expansion. Bulgaria follows the direction and trend of communication development worldwide, but at a significantly slower pace. In recent years, operators have continued to test, expand and migrate to 5G technologies while maintaining and improving existing 4G. Along with this, attention is paid to the importance and benefits of IoT, and more and more solutions are implemented and tested that meet the requirements and existing problems in the country.

Г.8.8. **Айдън Хъкъ**, ИЗСЛЕДВАНЕ НА UPLOAD И DOWNLOAD ТРАФИКА ПРИ БЕЗЖИЧНА 6LOWPAN СЕНЗОРНА МРЕЖА ЗА INTERNET OF THINGS (IOT). //СБОРНИК ДОКЛАДИ МЕЖДУНАРОДНА НАУЧНА КОНФЕРЕНЦИЯ, УНИТЕХ’20, 20 – 21 НОЕМВРИ 2020, ГАБРОВО, pp: 308-312, ISSN: 2603-378X

In recent years, modern everyday life has become more and more unthinkable without the new communication technologies (4G, 5G) that connect users all over the world. In parallel with these technologies, Internet of Things (IoT) technologies are also developing. The construction of various wired and wireless IoT solutions can be realised based on various protocols such as Bluetooth Low Energy (BLE), ZigBee, Z-Wave, 6LoWPAN, Thread, WiFi-ah (HaLow), etc. These technologies are widely used in the fields of monitoring, control, protection, automation, etc. One of the IoT technologies that is expected to become widespread is 6LoWPAN, as it is a sensor network on the one hand and an IPv6 network on the other. This report investigates the Upload and Download traffic of a real built 6LoWPAN network of IoT sensor nodes.
The physical construction of 6LoWPAN network is done with BeagleBone Black – BBB01-SC-505 board configured with Bone-Debian-9.9 operating system which works as 6LoWPAN Gateway, Texas Instruments (TI) Transceiver – CC2531EMK and TI

Sensor Nodes – CC2650STK . The study of Uplink and Downlink traffic is realised by building a physical "star" topology.
After the start of the 6LoWPAN network, the sensor nodes connect to the coordinator, the information about which can be seen on the application to monitor the operation of the coordinator. The values for the Upload and Download traffic are taken by the application for monitoring the work of the coordinator after there is an initiated communication between it and the sensor nodes. The volume of Upload and Download traffic depends on the Bandwidth of the connection, which in turn depends on factors such as used peripherals, network connection, type of transmission medium, network organisation, etc. Upload and Download traffic analysis is used to detect network problems and improve connection quality.
The results show that with a smaller number of nodes in the network, the values for Upload traffic are identical to those for Download. As the number of sensors in the network increases, the values obtained for Download traffic are slightly lower than those for Upload, and this depends on the state of the communication environment and the disturbances that occurred in it during the reading of the values.
When transmitting a larger amount of packets, the values for Upload and Download traffic increase, regardless of the distance of the sensor nodes from the coordinator. Because there is not an abundance of requests in the communication environment and there are enough service resources available, the reported values change minimally.

Г.8.9. **Айдън Хъкъ**, КОМПЛЕКСНА ОЦЕНКА НА СИМУЛАТОРИ ЗА ZIGBEE БЕЗЖИЧНИ СЕНЗОРНИ МРЕЖИ ЗА ЦЕЛИТЕ НА ОБУЧЕНИЕТО. //СБОРНИК ДОКЛАДИ МЕЖДУНАРОДНА НАУЧНА КОНФЕРЕНЦИЯ, УНИТЕХ’20, 20 – 21 НОЕМВРИ 2020, ГАБРОВО, pp: 313-318, ISSN: 2603-378X

The state of emergency declared worldwide in 2020 requires taking measures for remote work in all spheres of life. This can be achieved with the means of modern technologies such as 4G, 5G and Internet of Things (IoT). There are numerous IoT protocols to cover both small and large areas. One of the most well-known protocols for implementing a short-range, low-power IoT network is ZigBee, developed by the ZigBee Alliance.
The expanding use of IoT technologies in modern life requires their more active research in order to improve efficiency and service. This can be realised by building a real infrastructure for the researched technology or by simulating its operation.
In the field of education, the two approaches can be combined in order to examine the results of real infrastructure and simulation, as well as to analyse inconsistent results. In case of impossibility to invest funds in purchasing equipment for the observed technology, simulation products are used, which may have a free license for use.
Comprehensive evaluation of simulation environments for ZigBee sensor networks can be performed based on a set of evaluation criteria. The resulting complex assessment for each simulation product allows comparing them and determining the most suitable of them for educating purposes. This approach is also suitable for avoiding the author's subjectivity in evaluating the considered simulation environments. The comparison according to the considered criteria is based on average arithmetic and average

geometric evaluation, which are defined as optimal in terms of consistency, normality and comparability.

Numerous simulation products have been created to enable simulation and research of ZigBee technology. Some of the most famous ones are considered in the present study: ZBOSS, OPNET, QualNet, OMNeT++, NS-2, NS-3 and MATLAB. The considered environments are compared with the simulation software developed by the co-author team, and the average arithmetic and average geometric estimation of each is presented.

According to the complex comparative analysis, the QualNet simulator is the most suitable for studying ZigBee sensor networks. Comprehensive evaluations of the developed simulation product give reason to claim that it approaches the best in terms of quality.

Regarding the criteria "Easy installation", "Learning time", "CPU usage", "Memory usage", "License to use" which are important in terms of learning, developed in the Department of Computer Science and Technology at Technical University of Varna simulation product provides better or comparable results compared to others.

Г.8.10. **Haka, A.** Improved simulation environment for visualisation the content of IEEE 802.15.4 frame on 6LoWPAN network. //Monthly scientific and technical journal ELECTROTECHNICA & ELECTRONICA E+E, Bulgaria, 2020, Vol. 55, No 5-8/2020, pp: 86-93, ISSN: 0861-4717

Modern high-speed communication technologies provide an environment for the wider use and development of the Internet of Things (IoT). Among the means to achieve the IoT concept are sensor networks that enable real-time tracking of various parameters. The growing use of sensor networks requires their more active research. This can be done by studying the real network infrastructure and simulation.

This article presents an improvement of the simulation product developed by the author for the 6LoWPAN sensor network. The improvement allows visualisation of the content of an IEEE 802.15.4 frame. This allows the study of various parameters affecting the Quality of Service (QoS). Here, the influence of already implemented traffic prioritisation algorithms on the parameters Packet Delivery Ratio (PDR), Throughput, Delay and Packet Loss Ratio (PLR) that affect QoS is investigated.

In 6LoWPAN, there are various classical traffic prioritisation algorithms, and the introduction of virtualisation of sensor networks allows the implementation of more flexible solutions. The article presents the traffic prioritisation algorithm proposed by the author and classic ones such as First Come First Serve (FCFS), Least Number of Sensors First (LNSF), Least Number of Hops First (LNHF), Least Number Distance Product First (LNDPF) and Least Weighted Farthest Number Distance Product First (LWFNDPF). The impact of the presented traffic prioritisation algorithms on QoS is investigated using the developed simulation environment for a 6LoWPAN network. The simulator visualises an IEEE 802.15.4 frame in beacon-enabled mode. The simulation environment allows visualisation of graphs for the considered QoS parameters, taking into account the influence of the implemented algorithms for prioritising the traffic. In order to determine the change trend of parameters affecting QoS in different traffic prioritisation algorithms, experiments were conducted with 5 and 10 simultaneously connected end sensor nodes.

With the proposed traffic prioritisation algorithm, as the number of nodes in the network increases, the service becomes even, but still with more resources for the most prioritised nodes. The proposed algorithm accelerates the service for the highest priority nodes, thereby freeing up the resource occupied by them faster, which can be used to service the lower priority nodes. This speeds up the entire network.
In classical traffic prioritisation algorithms, service is uniform regardless of the number of nodes in the network and their distance from the coordinator. Evenly serving requests results in additional serving delay as more service requests accumulate for the next time slot. In addition, the service satisfaction does not change for either the highest priority or the lowest priority node. This leads to an overall slowdown in network performance as well as QoS degradation.

Г.8.11. **Хъкъ, А.**, Йорданов, Й. СИМУЛАЦИОННА СРЕДА ЗА ВИЗУАЛИЗИРАНЕ НА BLUETOOTH LOW ENERGY ПАКЕТИ. //Компютърни науки и технологии, година XIX, брой 1, 2021, pp:6-14, ISSN 1312-3335

The use of wireless devices in our daily lives is rapidly growing every day. One of the stated goals of various companies and researchers, since the dawn of radio technology, has been to create the most efficient, successful and cheap to manufacture modules to be released on the market. When it comes to energy-efficient radio modules that can send the right amount of data at low power consumption, one of the technologies that stands out is Bluetooth Low Energy (BLE). The active entry of BLE into modern life, as one of the most widely used technologies for the Internet of Things, is a prerequisite for researching the technology and considering it in education. A convenient tool for achieving this is the use of a simulation product that provides the opportunity for independent work in both face-to-face and distance learning. This article presents an environment for simulating the basic functionalities of a BLE network based on published standards.
BLE technology was introduced into the Bluetooth standard in version 4.0 and is more popular in applications where power consumption is critical and data to be transferred is small. The physical layer (PHY) refers to the radio hardware used for communication and data modulation/demodulation. BLE operates in the ISM band (2.4 GHz spectrum), which is segmented into 40 radio frequency channels, each spaced 2 MHz apart. Three of these channels are called primary advertising channels, while the remaining 37 are used as secondary advertising channels and for data transfer during a connection. The BLE standard describes a number of PDUs, some of the most common ones are ADV_IND, ADV_NONCONN_IND, CONNECT_IND or AUX_CONNECT_REQ, ADV_EXT_IND, AUX_ADV_IND, AUX_CONNECT_RSP, LL Data PDU, LL Control PDU.
The simulation environment developed in the Department of Computer Sciences and Technologies at the Technical University - Varna has a modular architecture. The environment allows simulating the main processes of BLE technology operation, which are based on published standards. Starting the application initiates the execution of the main functionality of the core – adding a Master device and implementing its program logic for processing incoming packets and their corresponding Packet Data Unit type, as well as waiting for the addition of a Slave device and tracking its status. When

reporting a simulation of packet exchange between devices in the BLE network, the core turns to a module to trace the generated traffic.
The simulation environment provides the ability to visualise PDUs for different BLE packets, as well as analyse additional information to them. Packet visualisation is based on published BLE standards. The simulator provides the possibility to view PDUs of ADV_IND/ ADV_NONCONN_IND, CONNECT_IND, LL Data and LL_TERMINATE_IND packets.
This article presents the possibility to visualise several different PDUs under Bluetooth Low Energy technology of the developed simulation product. It allows obtaining information from transmitted packets between devices in a BLE network without having to purchase hardware to build the network and monitor the transmitted traffic. The available functionality allows simulating the main aspects related to the operation of BLE technology. This, in turn, gives reason to claim that the product is suitable for use during educating in a present and remote form.

Г.8.12. **Хъкъ, А.** СРАВНЕНИЕ НА СИМУЛАТОРИ ЗА 4G ТЕХНОЛОГИИТЕ - WIMAX И LTE. //Компютърни науки и технологии, година XIX, брой 1, 2021, pp:15-22, ISSN 1312-3335

Globally, the telecommunications technology market is mainly oriented towards 4G and 5G because of the high speed and low latency they can provide. In recent years, 5G technologies have been increasingly researched, tested and commercialised mainly in the USA, Russia, Australia, European and Asian countries. This process is happening relatively slowly because of the smaller number of consumer devices supporting 5G, as well as because of the occupied frequencies for these technologies by the military. Thus, 4G technologies still occupy a leading place in the world market.
The main 4G technologies are LTE, WiMAX and HSPA+, with LTE mainly being used. The implementation and use of such technologies requires their preliminary research, which can be realized with simulation products.
This article presents a comparison between simulation products developed by the author for WiMAX and LTE technologies for 4G networks. The developed simulation products allow studying the impact of traffic prioritisation algorithms on the parameters Throughput, Delay, PDR and PLR, on which QoS depends.
Researching algorithms for prioritising traffic in a real network is not cost-effective because it requires investing funds to purchase, install, configure, and maintain the equipment. An alternative approach to researching traffic prioritisation algorithms is simulation products. They provide an opportunity for the user to simulate different scenarios in the cellular network, for which the influence of the implemented algorithms and mechanisms on QoS can be studied. In addition, when simulators are open source, the investment of financial resources for their use is eliminated, and the possibility of modifying the code to explore other aspects of the relevant technology is also provided. Another important feature of simulators is that they provide an environment for independent work, which is applicable in training, especially in an online environment. On the other hand, simulators only provide results that reflect the tendency of a specific algorithm or mechanism to work, as well as predictive results for their impact on QoS.

The presented simulators for WiMAX and LTE cellular networks are compared based on criteria for the implementation of a comparative analysis of simulators of LTE cellular networks proposed in a previous study. Since WiMAX, like LTE, is a cellular network technology, these criteria can be successfully applied to the comparison of simulators in this area, as well as to the comparison between simulators of the two technologies. The proposed criteria are specified for LTE technology and for the purposes of the current study some of them have been modified. Since the criteria used are of different types, in order to realise the comparison between the simulators and to overcome the subjectivity of the author when evaluating the object of comparison, the method with the calculation of complex evaluations is applied.
Comprehensive evaluations of both simulators show that they provide approximately the same means of researching 4G networks. From the results regarding the considered benchmarks, it is clear that the simulators are suitable for edicating, as they are open source, provide an easy user interface, allow simulating the basic functionality of the standards, and allow to study the impact of the implemented prioritisation algorithms of traffic on the parameters Throughput, Delay, PDR and PLR affecting QoS.

Г.8.13. **Хъкъ, А.**, Йорданов, Й. СИМУЛАЦИОННА СРЕДА ЗА ИЗУЧАВАНЕ НА BLUETOOTH LOW ENERGY ТЕХНОЛОГИЯ. //Сборник доклади международна научна конференция УНИТЕХ 2021, Габрово, 19-20 ноември 2021, pp:213-218, ISSN: 2603-378X

The social isolation caused by the coronavirus crisis over the last 18 months has led to the emergence of various challenges to activities that are normally carried out in person. Special difficulties arose during the educational process, related to the transition from a present to a remote form, such as communication problems, inability to work with physical devices and perform individual tasks, etc. Simulators provide an opportunity to install in separate machine, as well as individual work, when studying standards, algorithms or mechanisms of a specific technology. This report presents a simulation environment for studying Bluetooth Low Energy (BLE) technology for educational purposes.
BLE technology was introduced into the Bluetooth standard in version 4.0 and is more popular in applications where power consumption is critical and data to be transferred is small. It is mainly used in fitness devices for health monitoring, "smart" lighting system, real-time localisation system, sensor networks and home navigation applications. The technology provides the attributes: simplicity, low power, strong communication signal, real-time operation, compatibility, etc.
The main processes in the operation of the BLE technology, as well as in sending advertising messages, establishing connections and terminating them, which are based on the standard, are implemented in the developed simulation environment in the Department of Computer Sciences and Technologies at the Technical University - Varna. The simulator is developed with Java, Apache Maven, JavaFX & Scene Builder and Lauch4j technologies. It has a modular architecture and when the application starts, it starts executing the main functionality of the core, which is to add the Master device and implement its programming logic to process the incoming packets and their corresponding Packet Data Unit type, and wait for the Slave device to be added and

tracking its status (Standby, Advertising or Connected). The processed information through the various modules is visualised through the built-in graphic interface. The main window of the program is visualised when it is started. It has a menu bar and a tab bar, each tab representing a different functionality of the program.
This report presents a simulation product for BLE technology. The developed simulator allows studying various aspects related to the operation of the BLE standard without the need for the presence of physical devices. The provided functionality shows that the simulator can be used to represent the highlights of the communication between a master and a slave device, gives the possibility to display statistical information about the time that the end devices were in a certain state, as well as to examine the content of the frames transmitted between communicating devices. The possibilities provided by the developed simulation product give reason to claim that it is suitable for use in edicating both in-person and online.

Г.8.14. Yordanov, Y. and **Haka A.** Bluetooth Low Energy Technology Simulators. //The Journal of CIEES - Communications, Informacion, Electronic & Energy Systems, Year 2022, Volume 2, Issue 1, July 2022, pp: 7-11, Print ISSN: 2738-7283, Online ISSN: 2738-7291, DOI: 10.48149/jciees.2022.2.1

The Internet of Things (IoT) technologies are becoming more and more widespread in modern everyday life, which is leading to their growing worldwide distribution. Among the most common IoT technologies is Bluetooth Low Energy (BLE). The widespread use of BLE technology demands offering and researching solutions to improve its performance. Simulators are a suitable tool for researching theoretical improvements to the standard. Implementations of applications to simulate the operation of devices with BLE technology are limited, and most are developed as emulators.
Simulation products provide an environment for research and study of the main functionalities of the technology in consideration, and the capabilities provided are usually based on existing standards. This allows the simulators to be actively used in the study of new theoretical solutions to improve the technology under consideration. The simplified ability to work with the provided interface, as well as the ability to make modifications to open source solutions makes the simulators an attractive tool with wide application in education. The ability of the simulators to be used on personal machines by the trainees allows for both Onsite and Online work. In addition, the issues addressed during the lesson can exercise at any time.
This article presents several simulation products which examines the basic functionality of BLE technology, as well as their advantages and disadvantages.
Based on the review the most common and used simulators are MATLAB, BLE Peripheral Simulator and BLE Simulator of Mikhaylov. The main advantages and disadvantages of the considered solutions presented.
In order to overcome some of the disadvantages of the existing solutions for simulating BLE technology to the simulation product developed by the authors, functionality extensions have been implemented. The product was developed in the Computer Science and Engineering Department at Technical University - Varna, Bulgaria. Extensions are expressed in providing the opportunity to study the measured RSS and RSSI values of the received signal.

The product for simulation of BLE technology developed by the authors, provides an easy-to-use user interface for studying the main functionalities of the standard. Java, Apache Maven, JavaFX & Scene Builder and Lauch4j technologies were used to develop the environment. It has a modular architecture and the operation of all processes is controlled by the application core. The application is open source, free to use and does not require installation.

The functionalities of the environment include: adding a Master and Slave device, with the ability to select and modify the parameters of Slave; visualisation of the connection topology in the network, as well as its modification; research of the used communication channels; tracking of the conducted communication and the transmitted information between the devices; presentation of statistical information on terminal devices; visual presentation of the messages exchanged between Master and Slave when establishing a data transmission connection and its termination. The product provides an opportunity to study the measured RSS and RSSI values of the received signal.

The presented simulators are compared on the example of other researchers, using a compilation of criteria for comparing simulators for wireless networks for IoT. The obtained results show that the developed simulation product is not inferior in quality and capabilities provided to the existing ones.

Г.8.15. **Хъкъ, А.**, Съвременни изчислителни модели за технологии за Интернет на обектите. //Компютърни науки и технологии, 2022, pp: 14-24, година XX, брой 2, ISSN: 1312-3335

Modern information and communication technologies are developing at an extremely fast pace. One of the actively developing areas of these technologies is communication infrastructures based on 4G and 5G, as well as those of the new generation 6G. Along with them, the use of Internet of Things (IoT) technologies is also growing. These technologies occupy many areas of modern life, and their goal is to improve the functions and services in these areas. To improve the performance, fault tolerance, security and speed of technologies in this area, various computational models are used, aiming to improve the quality of service and the user experience. There are three main computing models that are used in working with IoT technologies - Cloud Computing, Edge Computing and Fog Computing.

This article examines the three main computing models used in working with IoT technologies. Their features, architectures and benefits are presented. The differences between the three models are presented in order to determine the most suitable one for working with IoT technologies.

The Cloud computing model is a technology that allows users to access or receive different services from different parts of the world through the Internet. Cloud computing is not just a specific technology, but a large form of several specialised technologies known as cloud business models. Cloud computing is the process of providing any kind of online service to the user through the Internet. Cloud computing is a space where data can be stored and used, and it is also the space from which data is less likely to be lost, deleted or corrupted. There are 4 types of cloud computing

deployment models: public, private, hybrid, and community. Cloud computing architecture consists of two main components – Frontend and Backend.

The Edge computing model moves computing resources from data centers and cloud structures closer to end devices. The goal of this model is to maintain lower latency requirements, with the ability to process data more efficiently, to save network costs. The IoT is a specific example where this model can be applied, due to the enormous traffic generated by the billions of devices deployed every year. When data is processed in an area closer to the end devices instead of in a cloud structure, the cost of transmission is reduced. Potential gains from the Edge computing model include revenue from anyone benefiting from higher data speeds and computing power delivered closer to the end user. The difference between Edge and Fog computing is that Fog computing describes the decentralisation of computing infrastructure or bringing the cloud structure closer to the end user. There are different types of Edge computing technologies such as Fog computing, Edge computing, Micro data centers, Small cloud structures, Emergency response units. The architecture of Edge computing is presented abstractly at several levels - level of Cloud, level of Edge datacenters, level of Neighborhood edge nodes, level of Roadside edge nodes, level of Edge gateways, level of Edge devices.

The term "Fog computing" was coined by Cisco Systems as a new model to facilitate the wireless transfer of data to distributed devices in the IoT network. The devices on these networks generate a huge amount of data that needs to be processed and analysed. Such processing requires a lot of resources (processing power, memory, power supply, etc.), and these are often limited in end devices. This requires the transfer of computing tasks from the end devices to other, more powerful devices. In order to overcome the weaknesses of cloud structures, an intermediate layer is introduced between end devices and cloud structures, known as Fog computing. In this intermediate layer, devices with greater computing power known as Fog Nodes are deployed. These nodes represent computing resources located in a geographically distributed manner, close to the end devices. End devices, in turn, offload computing tasks to the nodes in the "fog" instead of the cloud fabric. However, the use of decentralised nodes in the offloading fog leads to a significant delay, but also mitigates the problem of bottlenecks when communicating with a cloud structure. Fog Nodes can be thought of as small data centers close to the user network. The architecture of Fog computing is presented abstractly at several levels - level of Cloud, level of Fog Nodes and level of End Nodes.

The features, architectures, benefits and differences between the three models are presented. Based on the differences described, it can be seen that the most suitable model for working with IoT technologies is Fog computing. It provides high computing capacity, large storage space size, low latency, easy mobility and does not burden end devices with additional calculations.

Г.8.16. Динев, Д., Илиева, Б., **Хъкъ, А.**, Z-WAVE - РЕШЕНИЕ ЗА ПРЕДИЗВИКАТЕЛСТВАТА НА ДОМАШНАТА АВТОМАТИЗАЦИЯ. //Компютърни науки и технологии, 2022, pp: 43-48, година XX, брой 2, ISSN: 1312-3335

Z-Wave is an international standard for wireless home automation. Home automation allows connecting all electricity-related functions such as light, heating, cooking, cooling, security, etc., and applying automation to these functions. Home automation also helps conserve energy and other resources. Interconnection of all these functions can be done using cables or wireless technology. Cable solutions are very reliable, but require proper planning of cables and devices during the construction of the home and the installation of all utilities. For retrofits or partial solutions, the wired home automation system is not applicable. This is where wireless solutions come into play.

To determine a good wireless technology for home automation, a list of requirements such as reliability and security of communication, radio emission attenuation, ease of use, investment protection, interoperability must be considered. Z-Wave technology is the key to total control for home security systems with low power consumption and minimal noise. This article presents Z-WAVE wireless technology as a solution to home automation challenges.

Z-Wave technology works by remote control and uses low-power radio waves. Its network covers all areas of the home, with radio waves easily passing through walls, floors and furniture. There are two main types of devices defined in the Z-Wave protocol: controllers and slaves. Controllers can initiate transmission as well as keep all smart devices connected to network routes. Slaves, on the other hand, are just end devices with general-purpose input-output functionality that "blindly" execute the controller's requests. This is also the case for message forwarding: in the received packet, the controller instructs a specific device whether the message should be forwarded or not. Controllers are further differentiated based on their network functionality. The main types are portable and static controllers.

Portable controllers can freely change their location on the network. They have the ability to discover and rediscover their position in the network by sending pings to surrounding nodes. Typically, portable controllers are battery-operated devices that are used by the user to send commands to the network.

Static controllers take a fixed position in the network and are powered by the main line. They are always in listening mode, therefore other devices can communicate with them at any time. In a more complex network, a static controller can extend its functionality and become a storage device for the latest network configuration, called a Static Update Controller (SUC). A static controller can even become the main controller in the network and use portable controllers as proxies to switch other nodes on and off.

Slaves have much simpler functionality than controllers. They cannot initiate transmission unless they respond to the controller's request. Therefore, in order to receive information from a regular slave device, the controller must check the status of the device at periodic intervals.

Z-Wave are smart home devices. Thanks to the wide variety of supported smart home products, Z-Wave offers many options for homeowners. In this way, the smart home can be customised to meet the exact needs of the user. There are applications such as

"smart" lighting, "smart" plugs, sensors and locks. The advantages of this wireless communication protocol are easy deployment, immune to interference, greater network coverage, energy efficiency, interoperability. Disadvantages of this wireless communication protocol are: not suitable for streaming and transmitting a large amount of data, limited number of nodes (up to 232), increase in implementation costs when expanding network coverage, security issues, no open source resources.
This article presents Z-Wave technology, its specifics, devices used, advantages and disadvantages. From the research done and the presented advantages of the technology in consideration, it can be argued that Z-Wave is a good solution to the challenges of home automation.

Г.8.17. Динев, Д., **Хъкъ, А.** LORA И ZIGBEE СЕНЗОРНА МРЕЖОВА СИСТЕМА ЗА СЪХРАНЕНИЕ НА ДАННИ. //Сборник доклади международна научна конференция УНИТЕХ 2022, Габрово, 18-19 ноември 2022, pp: I-312 - I-317 , ISSN: 1313-230X

The growing use and development of modern information and communication technologies increases the share of networks used for home automation, environmental monitoring, smart city, etc. These modern applications in everyday life ensure the spread of Internet of Things (IoT) technologies. A wide share in the field of the IoT is occupied by the use of various technologies for wireless sensor networks. These technologies allow quick and easy network construction without the need for wiring between end components. In order to provide effective control and management of the sensor network, a monitoring and data storage system is required, which allows the examination of captured data in real time and the analysis of such data from previous events, as well as the generation of signals and warning messages when a certain event occurs.
This report presents proposals for data storage systems and the capabilities of web interfaces developed for them for LoRa and ZigBee technologies for wireless sensor networks, which were implemented in the Computer Science and Technology Department at the Technical university - Varna.
The part of the system implementing the storage of data from LoRa and ZigBee wireless sensor networks consists of an MQTT server (MQTT Broker) and a MongoDB database. The visualisation of the data in real time and those stored in the database is implemented through the developed web interface, which is accessible through the included web server. Subscribing to topics, capturing data and storing it in the database is done via Python scripts.
The LoRa sensor network consists of a Dragino LG01-S LoRa IoT Gateway and a Dragino LoRa Shield with an Arduino UNO. The ZigBee sensor network consists of a ZigBee coordinator implemented with ZigBee2MQTT software on a Windows machine, a TI CC2531EMK transceiver and end sensor nodes from Sonoff.
The web interface for data visualisation is developed using PHP, JavaScript HTML. The database management server system is implemented on MongoDB. The developed LoRa web interface provides appropriate visualisation of the stored information and output of statistical samples based on the individual characteristics and time segments of operation, as well as creation of a model for the operation of the devices in the

studied environment. The interface allows visualisation of the selected value for an environmental parameter according to a user-defined time interval. It also provides an option to set a threshold value. A mail server is also set up, sending messages to the user's e-mail when certain threshold values are exceeded.
The developed ZigBee web interface allows displaying statistics and graphs for the various environmental parameters monitored by the sensor, as well as creating a model of the operation of the devices in the studied environment. The interface allows the user to select the type of environmental parameter for which the value change graph is presented. After selecting a graph generation parameter, it is possible to select a sensor from a drop-down menu whose measurements should be presented. In addition, the user of the system has the possibility to enter a threshold value for the considered parameter. When working with the temperature, humidity and battery level parameters, exceeding the set threshold leads to the generation of a notification message about the event.
The proposed systems provide a good opportunity to explore the operation and configuration options of LoRa and ZigBee wireless sensor networks. They are connected to subjects related to studying databases, programming and using the MQTT protocol. This gives students the opportunity to consolidate their knowledge of relevant subjects and get additional.

Г.8.18. **Айдън М. Хъкъ**, Мариета М. Йорданова, МЕТОДИ ЗА ЗАЩИТА НА ИНТЕЛИГЕНТНИ ТРАНСПОРТНИ СРЕДСТВА С ИЗПОЛЗВАНЕ НА ИЗКУСТВЕН ИНТЕЛЕКТ. //Компютърни науки и технологии, 2023 (Под печат)

Various communication and information technologies related to Big Data, Blockchain, Internet of Things, automation in various fields, are increasingly entering modern everyday life. The goal of communication and information technology is to provide a high-speed, reliable and fault-free environment for data transmission between connected devices over long distances.
The automotive industry is one of the areas where modern communication technologies are used for fast, secure and reliable transmission of data ensuring safe transportation. They are most widely used in electric vehicles such as cars and trucks, railway vehicles, etc. The development of artificial intelligence enables the entry and improvement of capabilities of movement with limited human intervention of modern vehicles.
Autonomous driving is a high-risk application where malfunctions and cyber-attacks can cause safety issues. Autonomous vehicles are cyber-physical systems operating in particularly challenging environments. They are equipped with advanced perception and planning systems capable of recognising road markings, road users, objects and taking the necessary actions. These capabilities rely on sophisticated digital systems and software powered by artificial intelligence technologies such as machine learning and deep learning play a major role.
Machine Learning is the core of artificial intelligence, which encapsulates Supervised Learning, Unsupervised Learning and Reinforcement Learning. Deep Learning, on the other hand, is a complex of all learning technologies.
Autonomous vehicles provide new opportunities for hackers and malicious actors to implement a variety of successful cyberattacks that can lead to catastrophic accidents and cause major safety issues. The main motives of these attacks are to gain remote

control of the autonomous vehicle, to steal important and confidential information that can be used to launch additional attacks or to disrupt its operation by damaging important components and make the mode of autonomous driving unavailable. Attacks targeting autonomous vehicles are diverse, with some of the most common being: attacks based on data manipulation; identity compromise attacks; service-based attacks; software-based attacks.

Artificial intelligence plays an important role in providing protection in autonomous vehicles. It is believed that artificial intelligence is still far from being "inherently" safe. Therefore, research focuses on practical solutions for machine learning with different safety strategies such as: Safe Fail and Safety Margins.

With the increasing incursion of artificial intelligence algorithms in modern vehicles, the need for regulations for the development of artificial intelligence systems also increases. In April 2021 The European Commission is introducing the first ever AI regulation to reduce the dangers of "high-risk" AI applications.

This article presents an application of artificial intelligence in the field of autonomous vehicles. Levels of autonomy, training methods, vulnerabilities and threats, and protection of autonomous vehicles with artificial intelligence are discussed. The introduction of artificial intelligence into the modern world is causing difficulties related to security and data privacy. However, numerous studies present different approaches and methods for realising protection against cyberattacks that are based on the capabilities of artificial intelligence. Published standards and regulations related to artificial intelligence and its security bring regulations on its work and are a prerequisite that these technologies have been actively implemented in recent years and this trend will continue in the future.