Because of the reliability of deployment, cost efficiency, and flexibility of ad-hoc wireless local networks (WLAN). These wireless networks have grown to be the everywhere connection solution in residential and public access networking protocols. It is important to know which strategy performs better with the least amount of delay. The Multiple Access Control protocols (MAC) that are relied on ALOHA, and Carrier Sense Multiple Access with collision avoidance (CSMA/CA) as random access techniques, have substantially aided the rapid growth of such wireless access networks. This work provides a model-based design approach for modeling CSMA/CA and ALOHA random-access protocols for packetizing wireless networks. We analyze the TX and Back-off waveforms of the PHY/MAC transceiver of three radio nodes under CSMA/CA and ALOHA operation modes and compare the obtained results of the PHY/MAC Transceiver for the network nodes according to these modes. Every node is within a range such that the communication between each couple of nodes can be interfered with and received data from the third node. The MAC layer and the logical link control function composed the data link layer. Since the same radio band is used for TX and RX, the MAC function employed here is CSMA/CA and ALOHA, which had also called a random back-off. The MAC layer sends a control signal to the TX block to transmit either a data frame or an acknowledgment frame. The frame contents are loaded in the look-up tables. The contents can be changed in the workspace. The output of this block is a complex baseband IQ signal. The obtained results show the effectiveness of CSMA/CA over ALOHA modes when comparing the corresponding Back-off waveforms and when calculating the throughput values of the three network nodes

Keywords: ad-hoc networks, wireless LANs, Carrier Sense Multiple Access (CSMA), collision avoidance

IMPLEMENTATION OF CSMA/CA AND ALOHA RANDOM-ACCESS PROTOCOLS FOR PACKETIZING WIRELESS NETWORKS WITH MODEL-BASED DESIGN

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1. Introduction

Random access protocols have recently sparked renewed attention, not just among satellite communication experts, but also among researchers working in domains such as the Internet of Things and machine-to-machine communication. ALOHA as random access protocol is extremely appealing for such applications since they allow for minimal complexity transmitters and eliminate the need for time synchronization. ALOHA is a method that is frequently used to coordinate the operation of numerous intermittent transmitters on a single shared communication channel. Time diversity is used in ALOHA evolutions through proactive packet replication; however, time diversity is not completely used at the receiver.

In cognitive radio ad-hoc networking protocols, spectrum scarcity is a significant concern [1]. This issue stems from the reality that spectrum consumption should be competent in today's world. A random-access protocol called ALOHA is pioneering that went live in 1971 [2]. Nodes of ALOHA networking broadcast packets when they become accessible, regardless of the wireless carrier signal. Accordingly, if wireless packets are sent at the same time,

these data may collide at the receiver. As a result, a brief acknowledgment (ACK) packet is sent after successful packet reception [3]. Several studies discussed ALOHA random-access protocol with stochastic geometry-based modeling for investigating alternative medium access choices for LoRaWAN [4], for growing average system packets success probability (PSP) over un-slotted ALOHA [5], and in the enhanced contention resolution ALOHA scheme [6].

Transmissions are deferred if the medium is felt to be busy, for example, as per a binary exponential back-off. Collision avoidance can be achieved when:

1) waiting for the duration of inter-frame spacing (IFS) following the channel sensing (idle);

2) only transmitting data after a specific number of (avoidable consecutive) observed idle-time slots are selected at random from the conflict window when an adaptive variety of potential back-off durations is available;

3) exchanging Request-to-Send and Clear-to-Send frames (CTS and RTS).

Most wireless applications are interconnections to a network. According to the open systems interconnection model, the OSI model, a wireless network has seven layers in a vertical structure. In this work, let's focus on modeling

the first two OSI layers; the physical layer and the data link layer. The physical layer defines the baseband processing of the radio transceiver. The data link layer mainly provides the media access control function, which is also called the Mac layer with a logical link control function as shown in Fig. 1.
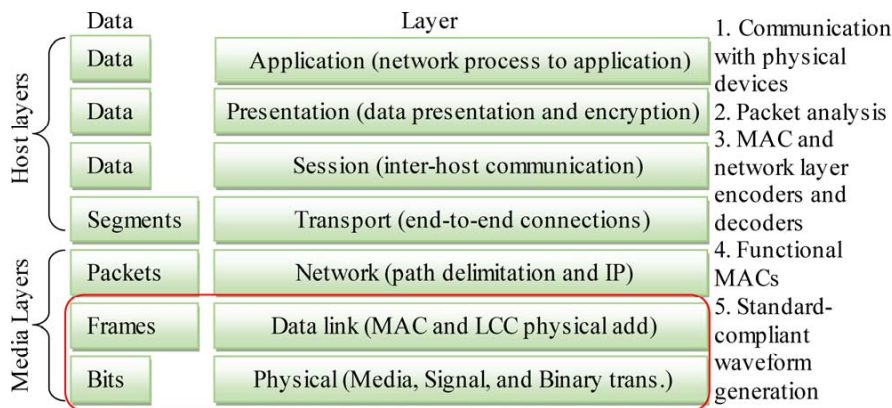

Fig. 1. Communication protocol layers

For the issue in which a timely response is not received, the packet data is retransmitted on afterward time defined by binary exponential back-off. Therefore, research on the development of "Carrier Sense Multiple Access with Collision Avoidance" (CSMA/CA) is a promoted random access method where network nodes sense the wireless region prior to delivering data packets [7]. A Packet Reservation Multiple Access Protocol employs a hybrid of slotted-ALOHA and CSMA/CA to contribute to spectrum with Primary Users (PU) and to deal with inefficient spectrum utilization and spectrum scarcity. Therefore, minor users can take advantage of PU's unused time slots.

2. Literature review and problem statement

In multi-hop wireless networks, end-to-end delay analysis is an important evaluation parameter of network performance analysis. The research [8] proposes an analytical model for predicting the end-to-end delay performance of wireless networks using a random access strategy to manage node broadcasts on time-varying capacity shared channels. Although the end-to-end delay performance was discussed thoroughly, important parameters such as the throughput and energy consumption had not calculated efficiently. Therefore, a Discrete-Time Markov Chain (DTMC) model can be created to study the IEEE 802.15.6 Medium Access Control (MAC) protocol in the Wireless Body Area Network (WBAN) with energy harvesting devices under saturation conditions. This is done by the study [9], where a long-term performance, including throughput and energy consumption, was calculated using the statistical properties of the analytical model described. However, this study didn't offer effective solution for multi user network nodes. The study [10] argued this issue by proposing a beyond-5G scenario in which two sorts of users, defined as scheduled and uncoordinated nodes, share the same set of radio resources to transfer data to a base station. In spite of the authors also looked at two benchmark schemes: the Proportional

Fair (PF) method for resource scheduling and the discrete uniform distribution (DUD) strategy for packet length distribution, the investigation results were not sufficient. According to these limitations, the paper [11] examined the performance of ALOHA and CSMA in Spatially Distributed Wireless Networks, but this method for evaluating the performance of ALOHA and CSMA did not provide insight into the design of generic MAC protocols for ad hoc networks. However, the study proposed CSMA with receiver sensing to increase CSMA performance. The study [12] introduced a Modified-Packet Reservation Multiple Access Protocol for Cognitive Radio Networks, which uses the Opportunistic/Overlay Spectrum Access approach for sharing spectrum among primary users (PU) to address the problem of spectrum scarcity and inefficient spectrum utilization. Although the protocol described in this study is a hybrid of slotted-ALOHA and CSMA/CA, this filter obscures some features. In the study [13], the signal overlap ratio was modeled using several media access control protocols such as ALOHA, CSMA/CA, and CSMA/CA with booking based on the honeycomb network model. Inter-WBAN interference occurs when two or more WBANs overlap with each other. Inter-WBAN interference might result in transmission difficulties. The study [14] compared Carrier Sense Multiple Access, Frequency Division Multiple Access (FDMA), and Time Division Multiple Access (TDMA) with Slotted ALOHA (S-ALOHA), CSMA/CA, and Pure ALOHA with the main goal of determining which technique provides the highest throughput and lowest delay as load increases. According to the research, dealing with subtle difficulties like delays or optimizing ALOHA and CSMA in spatially distributed wireless networks is important in a variety of our daily demands. Therefore, this study didn't discussed the efficiency of WBAN energy to evaluate the considered networking strategy.

All this allows to argue that it is appropriate to conduct a study devoted on energy efficiency of WBAN to know which strategy achieves better in terms of energy preservation while simultaneously providing the least amount of delay. As a result, random access protocols to replicate CSMA/CA and ALOHA for wireless network packets must be developed.

3. The aim and objectives of the study

The main aim of the study is to simulate CSMA/CA and ALOHA random-access protocols for packetizing wireless networks with a model-based design.

The following objectives have been set to achieve the goal:
– to analyze TX and Back-off waveforms of PHY/MAC Transceiver for the network nodes under CSMA/CA and ALOHA modes;
– to compare the obtained results of PHY/MAC Transceiver for the network nodes under CSMA/CA and ALOHA modes.

4. Materials and methods

The MATLAB-based simulation platform is employed in this work. The top-level switch determines whether the MAC scheme is ALOHA or CSMA/CA. A Quadrature Phase Shift Keying QPSK-based physical (PHY) layer is used to encode or decode MAC frames to or from a PHY waveform. Because the back-off period is often significantly shorter than the period of a data-frame, the MAC layer functions over a timescale of 0.8 microseconds. This work presents a model for a 3-nodes PHY/MAC networking as depicted in Fig. 2.

Every node is within a range such that the communication between each couple of nodes can be interfered with and received data from the third node. From node 1 to node 3, from node 3 to node 2, and from node 2 to node 1, acknowledgment frames are sent. The PHY/MAC transceiver of Radio node 1, for example is shown in Fig. 3.

For simplicity, the modulation used in this network is QPSK at the rate of 20 megabits per second. "TX" is usually an abbreviation for "Transmit", and "RX" is for "Receive". The top level of the radio transceiver node, the transmitter, the TX/RX switch, and the receiver form the physical layer. The MAC layer and the logical link control function composed the data link layer. Since the same radio band is used for TX and RX, the MAC function employed here is CSMA/CA and ALOHA, which had also called a random back-off. The transmitter in the radio node is shown in Fig. 4.

Based on the channel status, the MAC layer sends a control signal to the TX block to transmit either a data frame or an acknowledgment frame. The frame contents are loaded in the look-up tables. The contents can be changed in the workspace. The output of this block is a complex baseband IQ signal. The receiver modeling is shown in Fig. 5.
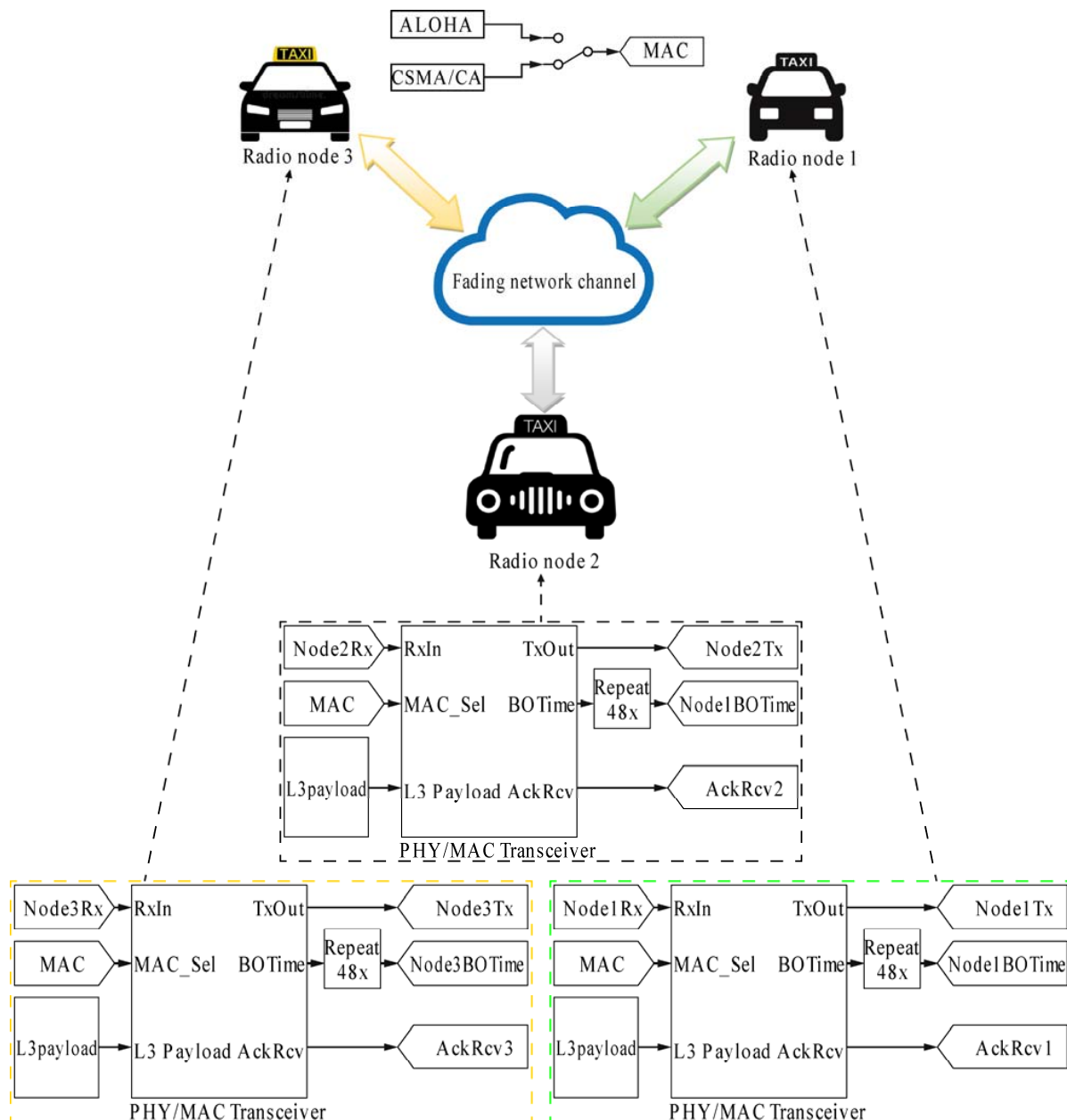

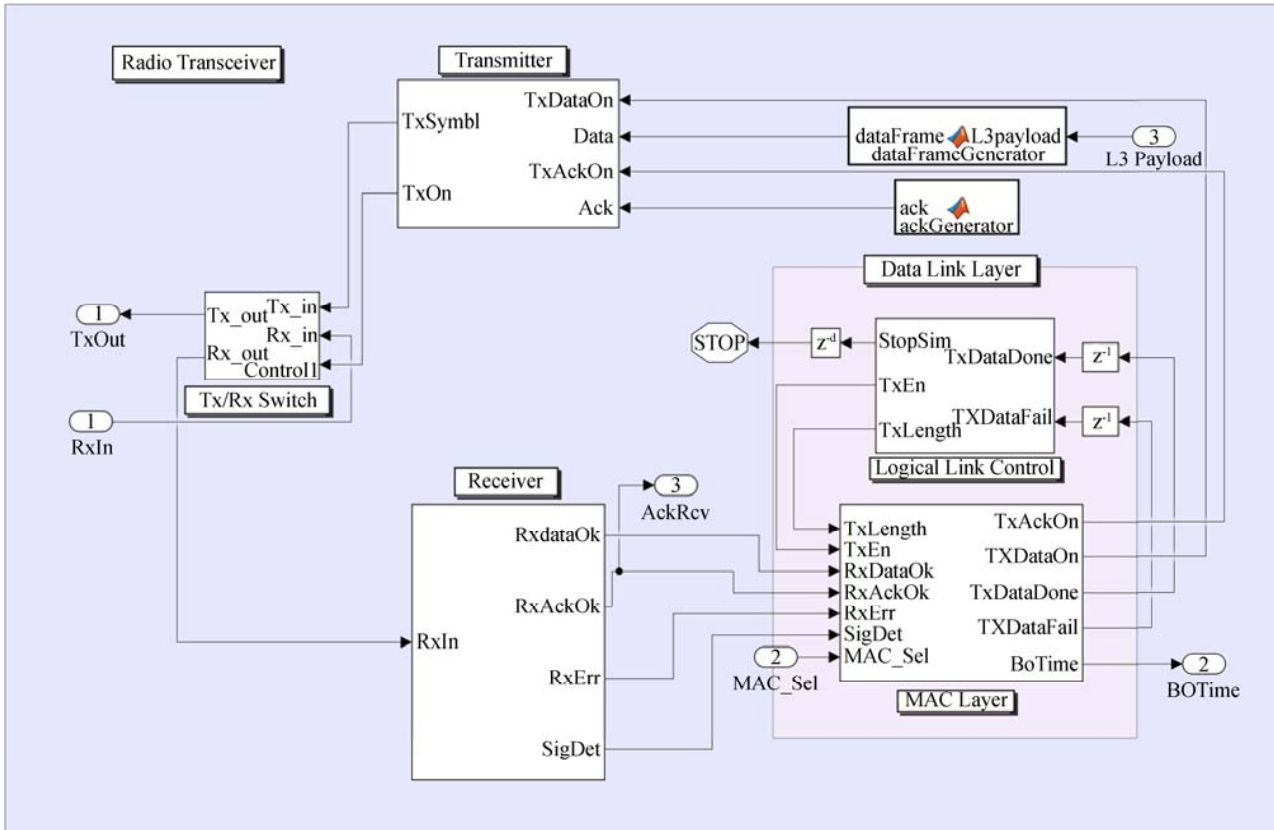Fig. 2. Wireless network model of three radio nodes

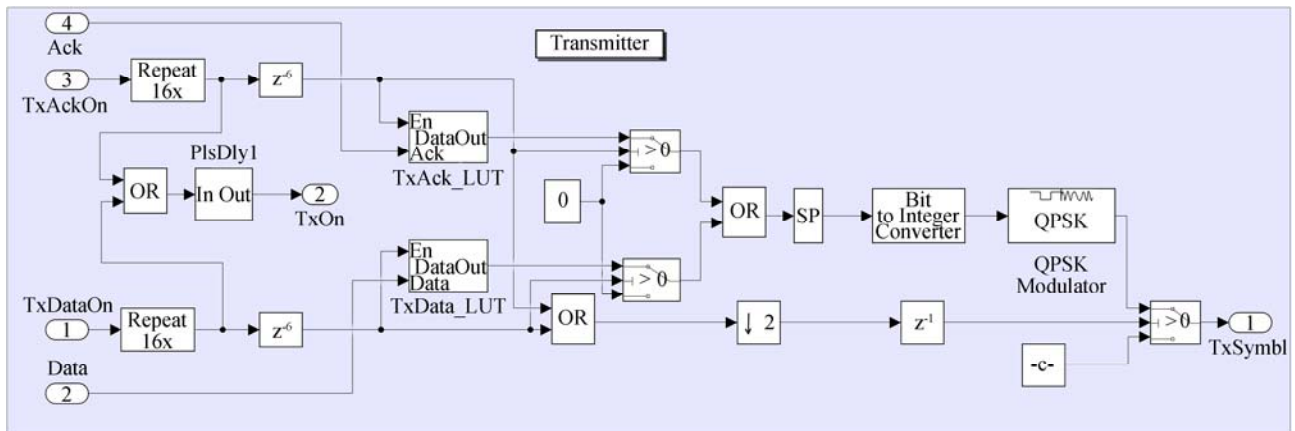Fig. 3. PHY/MAC transceiver of Radio node 1

Fig. 4. Transmitter model of PHY/MAC transceiver of Radio node 1

It consists of the signal detector, the decision feedback equalizer, and the demodulator with cyclic redundancy checks. This receiver provides a function of signal detection, channel equalization, single synchronization, and the hider payload CRC's. Also, this receiver can compensate for a certain carry frequency offset. This block sends out the status of the received frame to the MAC layer and the bit stream of the received data. The Logical link control of data link layer of Radio node 1 is shown in Fig. 6, while the MAC layer of data link layer of Radio node 1 is shown in Fig. 7.

The three transceivers are interconnected by a radio feeding channel. Each radio node can transmit and receive signals to and from other nodes. This topology of the net-

work can be extended to a network with a larger number of radio. The single format has a common structure for wireless networks. It has three essential parts; the Physical header, the MAC header, and the Payload. The signal frame can be a data frame for content delivery, and an acknowledgment frame for access control as shown in Fig. 8.

The first block of the data link layer is a logic control function. This function randomly generates arriving times of data frames and the number of segments of each frame. It also controls the retransmission of a segment that failed in delivery. A retry can be stopped once the retry limit is reached. The MAC layer implemented in this work has two selectable MAC functions. We only discuss the CSMA/CA as shown in Fig. 9.
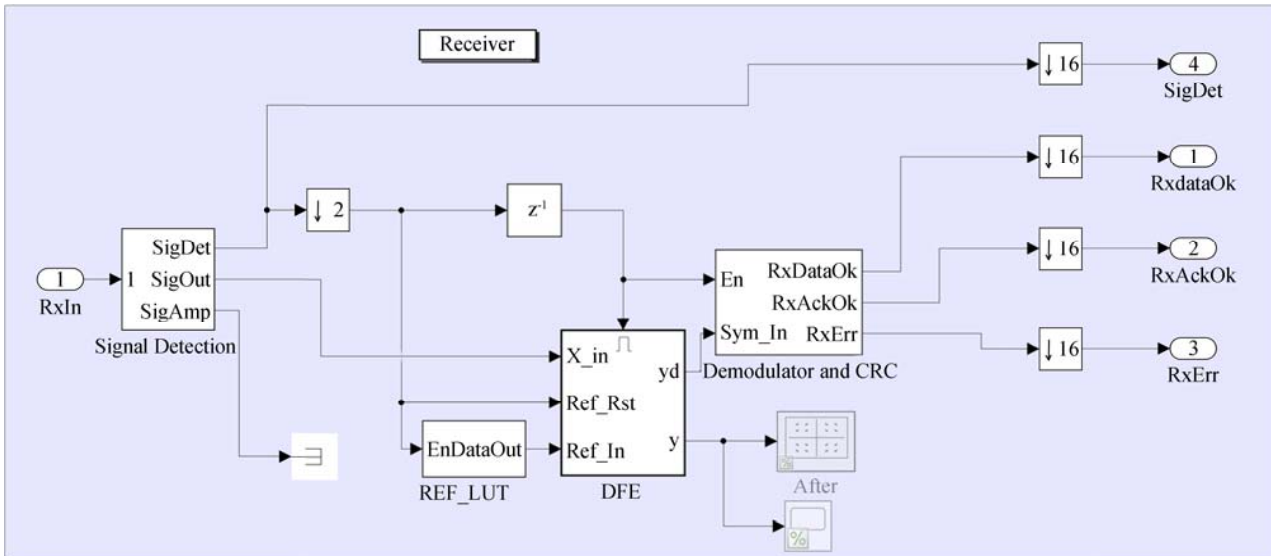
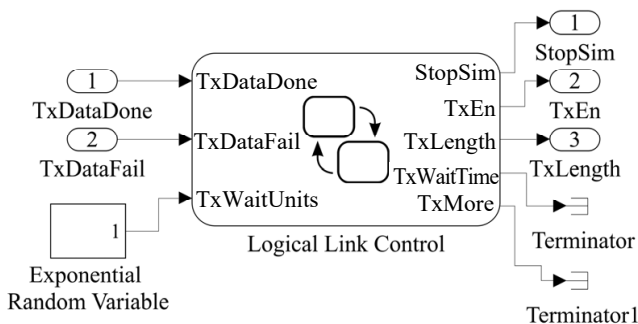Fig. 5. The receiver model of PHY /MAC transceiver of Radio node 1

Fig. 6. Logical link control of data link layer of Radio node 1

As shown in Fig. 9, any node before transmitting, it must make sure the RF media has been quiet for a period of (DIFS) time. Then, the node interests the random back off.

Once this back-off counter goes to zero, the node starts transmitting. Once the receiving node received the data frame correctly, it sends the ACK frame back within the (SIFS) time.

This mechanism continues until all the data frames in the transmitting node are sent out. Then, all now go back to the silent period of DIFS to start a new contention window. This is also the mechanism used in (802.11) MAC. The MAC output signal can show the transmitter for sending data or ACK frames in a regulated order.

In order to compare the network nodes under CSMA/CA and ALOHA modes, let's evaluate the wireless network by calculating the throughput parameter from the ACK frames for the three nodes under CSMA/CA and ALOHA modes of operation. One of three simulation blocks for calculating the node throughput is shown in Fig. 10.
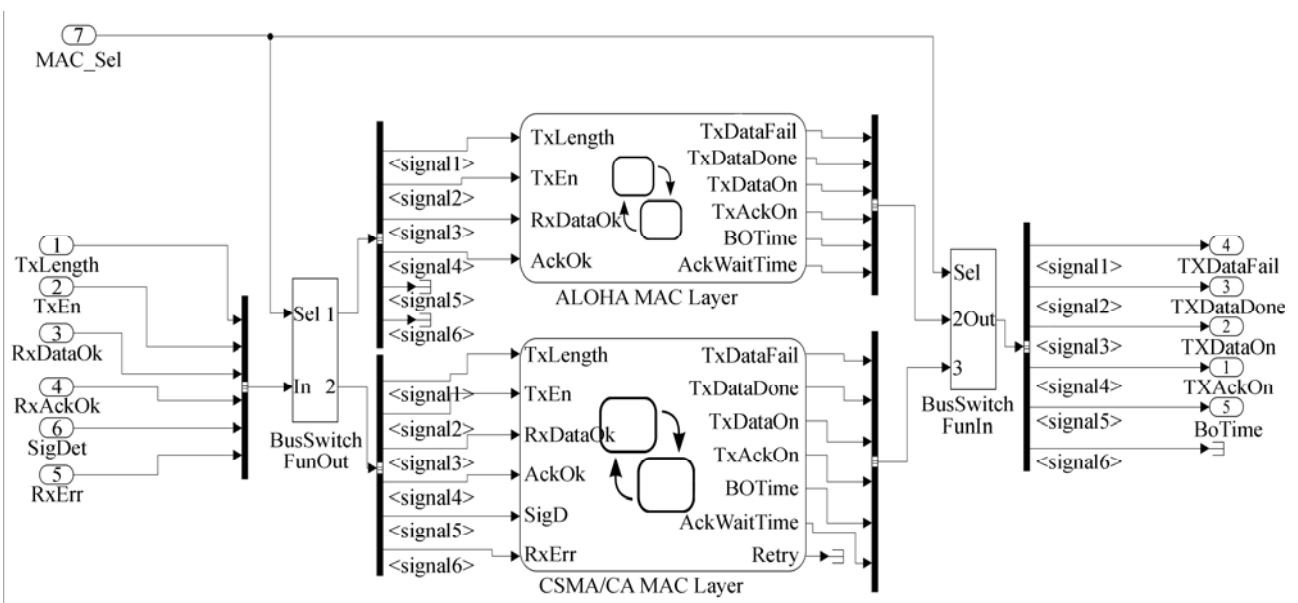

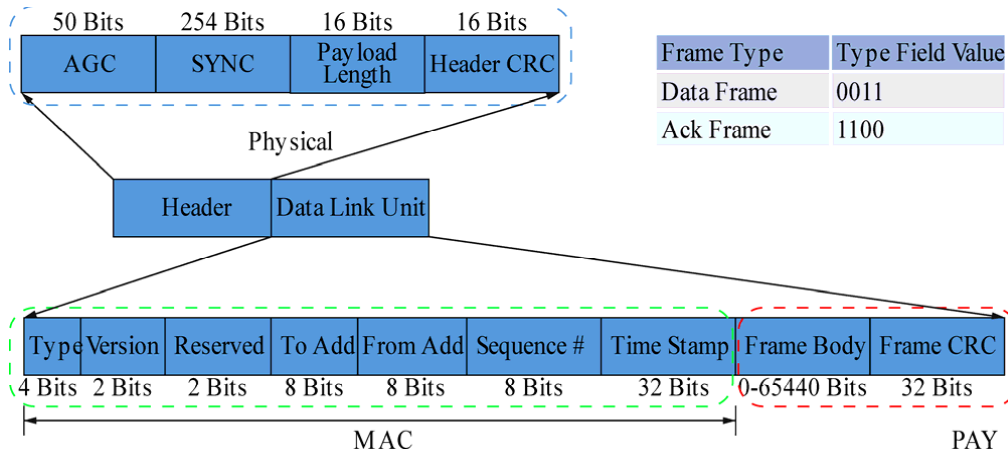Fig. 7. MAC layer of data link layer of Radio node 1

Frame Type	Type Field Value
Data Frame	0011
Ack Frame	1100

Fig. 8. Single format of the considered wireless network

ACK: ACK packet to Node
Data n: Data packet n
SIFS: Short Interframe Space
DIFS: Distributed Interframe Space
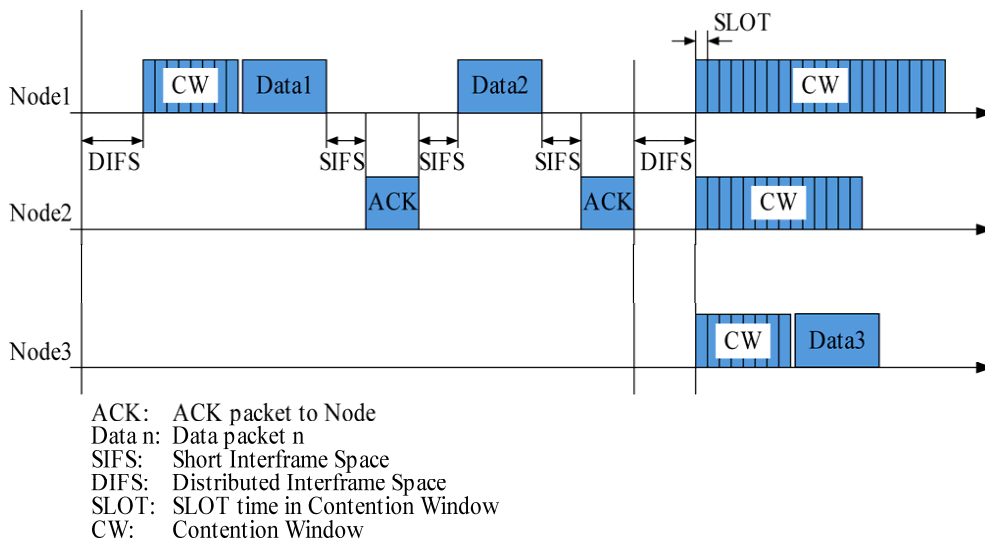SLOT: SLOT time in Contention Window
CW: Contention Window

Fig. 9. MAC Layer: CSMA/CA (802.11) MAC protocol (Carrier Sense Multiple Access and Collision Avoidance)
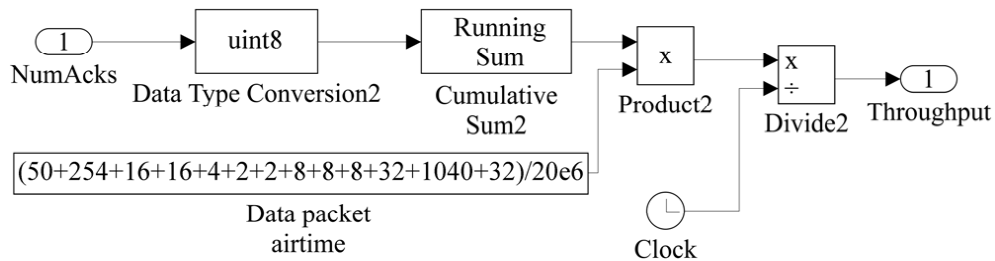
Fig. 10. Throughput calculator block

The input of each throughput calculator block receives its ACK frame from the corresponding radio node PHY/MAC Transceiver.

5. Results of the developed wireless network

5. 1. Results of analyzing TX and Back-off waveforms of the network nodes under CSMA/CA and ALOHA modes

The channels of the wireless network, shown in Fig. 2, are modeled by fading with Doppler frequency spreading of 50 Hertz and a signal-to-noise ratio of 25 DB. The TX waveforms and the Back-off for the three nodes under CSMA/CA CAM networking are shown in Fig. 11, *a*-c, respectively.

The green plots of the bottom of each one in Fig. 10, *c* are the transceiver signal back-off of the three nodes, while that at the top axes depicts the transmitted signal.

The TX waveforms and the Backoff for the three nodes under ALOHA CAM networking are shown in Fig. 12, *a*–c, respectively.

This shows the efficiency of the MAC layer and the dynamic behavior of a multi-node wireless network.
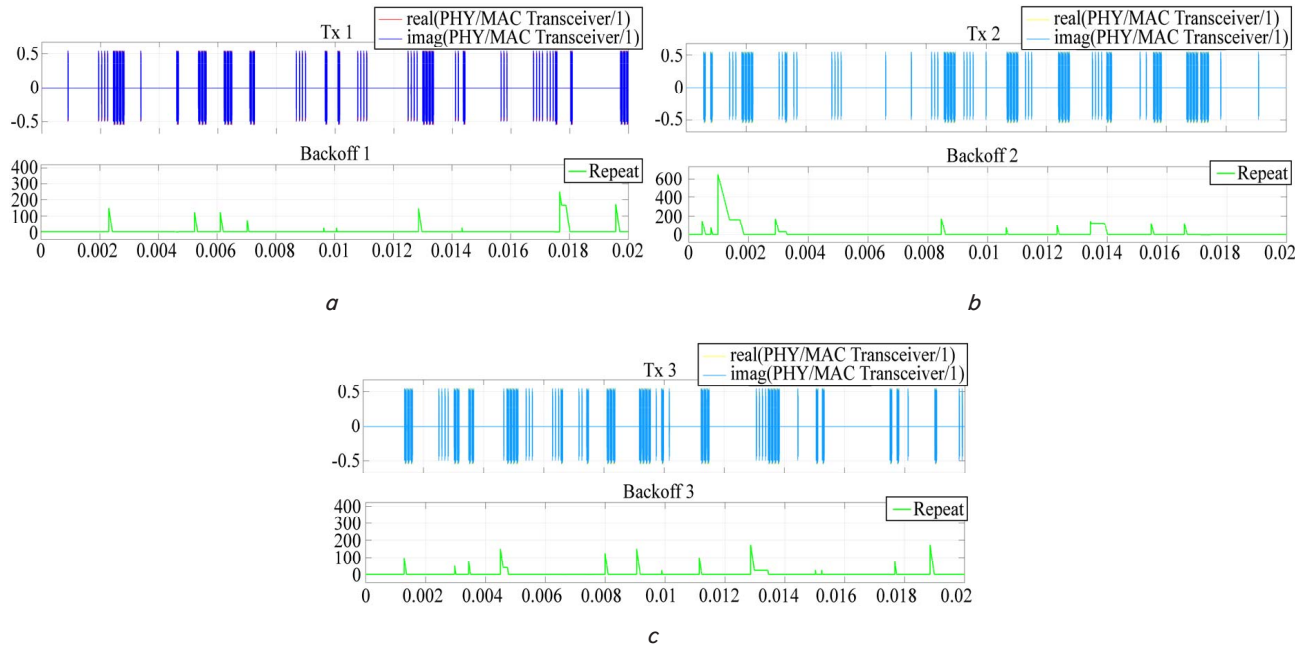
Fig. 11. Tx and Backoff waveforms of PHY/MAC Transceiver for: *a* — node 1; *b* — node 2; *c* — node 3 under CSMA/CA mode
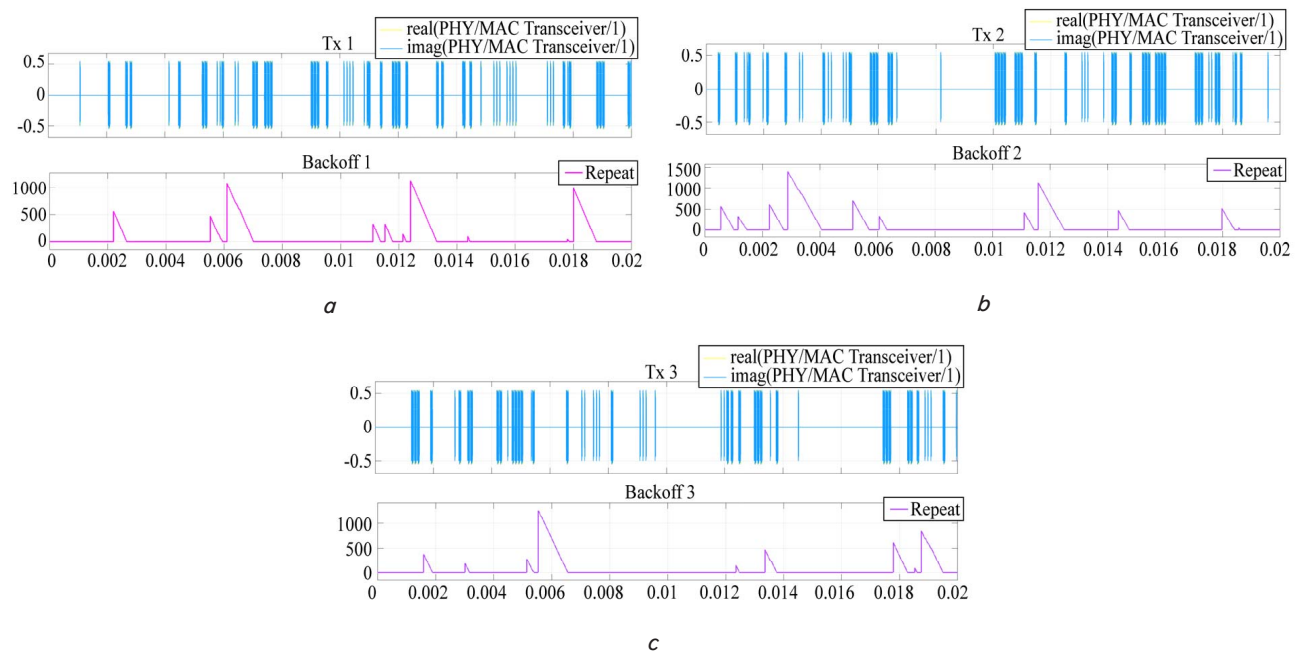

Fig. 12. Tx and Backoff waveforms of PHY/MAC Transceiver for: *a* — node 1; *b* — node 2; *c* — node 3 under ALOHA mode

5. 2. Results of the comparison obtained for the network nodes under CSMA/CA and ALOHA modes

Table 1 demonstrates the comparison to evaluate the wireless network by calculating the throughput parameter for the three nodes under CSMA/CA and ALOHA modes of operation.

Table 1

Comparison of the wireless network by throughput parameters

_	Throughput value		
	Radio Node 1	Radio Node 2	Radio Node 3
CSMA/CA	0.08464	0.1067	0.1178
ALOHA	0.06992	0.08832	0.06992

The results demonstrate that the created protocols' performance is assessed based on the throughput values for the three nodes, with a substantial variation of the CSMA/CA over that for the ALOHA protocol.

6. Discussion the results of simulating CSMA/CA and ALOHA random-access protocols

CSMA/CA and ALOHA are the two MAC schemes that can be employed for the default packet arrival rates. Varying the MAC strategy to ALOHA results in decreased throughput of a node since the nodes do not detect the

wireless carrier, and ALOHA packets clash more frequently as can be seen when comparing the back-off signals of three node CSMA/CA-based transceivers depicted in Fig. 11 with that of ALOHA-based transceivers shown in Fig. 12. In the same context, the throughput comparison table (Table 1) of the wireless network demonstrates a significant increase for the CSMA/CA over that for the ALOHA protocol.

Each node's dialog mask can be used to tailor packet arrival rates. The saturation point of the network can be determined repeatedly and empirically, for example, by gradually raising each node's packet arrival rate. Boosting low-arrival rates is able to boost node performance; however, rising high-arrival rates, further than the saturation point, might reduce throughput by causing packets to clash and nodes to back-off further repeatedly. When the arrival-rates of every node are disproportional, wrongness scenarios are able to be generated. For instance, a single node might capture the medium regularly and keep a low disagreement window, whereas new nodes may take an extended duration to capture the medium and only use it infrequently.

As a limitation, this work didn't cover end-to-end delay performance for different random-access scenarios in the wireless network, which is considered as a disadvantage of this study.

In future work, to enable different random-access scenarios, it is possible to adjust the nodes' random seed within the block mask of the network. The random seed, for instance, controls how quickly the initial transmission occurs for a particular packet arrival rate.

7. Conclusions

1. The analysis of Tx and Backoff waveforms of PHY/MAC Transceiver for the network nodes under CSMA/CA and ALOHA modes show the effectiveness of CSMA/CA over ALOHA when comparing the corresponding Back-off waveforms. Moreover, CSMA/CA performs better than ALOHA model in terms of Back-off quality.

2. The performance evaluation of the developed protocols is completed according to throughput values of the three nodes; where there is a significant difference as indicated for the throughput of 0.1178 for CSMA/CA and 0.06992 for ALOHA protocol.

Acknowledgments

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